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Importance of Rice Research and Development in Rice Seed Policies

Insights from Nigeria

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Notices

Contents

Tables

Figures

ABSTRACT

Seed is an important input in agriculture. Appropriate seed policy enables the supply of good varieties to farmers at a low cost. Thus, improved seed-sector functions, including seed subsidies, effective regulations, certifications, and efficient private-sector participation, receive significant attention. Relatively less attention, however, has been given to the suitability of varieties that various seed-sector policies try to disseminate. For countries like Nigeria, where agricultural research and development (R&D) has long been incapacitated, seed-sector policies may often have insufficient outcomes, not so much because of the efficiency of those policies but mostly because varieties being promoted are outdated (even though they are called *improved varieties*) or suitable only in certain environments but not in most of the other areas with diverse agroecological conditions.

This paper addresses these issues using rice in Nigeria as an example. First, this paper shows that rice varietal development in Nigeria has been lagging behind that of other developing countries in Asia and Latin America, due partly to insufficient investment in domestic rice R&D. The paper then illustrates using a household model simulation that impacts of certain policies, such as the seed subsidy, may be greater (smaller) if they are applied to good (poor) varieties. The paper concludes by discussing key policy implications and future research needs.

Keywords: rice R&D, rice seed policies, seed sector, household model, Nigeria

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ABBREVIATIONS AND ACRONYMS

ADP	agricultural development projects
ASTI	Agricultural Science and Technology Indicators
ATA	Agricultural Transformation Agenda
CRET	coordinated rice evaluation trials
ECOWAS	Economic Community of West African States
FAO	Food and Agriculture Organization of the United Nations
IAR&T	Institute for Agricultural Research and Training
IITA	International Institute of Tropical Agriculture
INGER	International Network for Genetic Evaluation of Rice
IRRI	International Rice Research Institute
NAERLS	National Agricultural Extension and Research Liaison Services
NARP	National Agricultural Research Project
NARS	National Agricultural Research Systems
NASC	National Agricultural Seeds Council
NCRI	National Cereal Research Institute
NERICA	New Rice for Africa
NGO	nongovernmental organization
OP	open-pollinated
PPP	purchasing power parity
PVS	participatory variety selection
R&D	research and development
SSA	Africa south of the Sahara
UNDP	United Nations Development Programme
WARDA	African Rice Center (formerly West Africa Rice Development Association)
WDI	World Development Indicators
WTP	willingness to pay

1. INTRODUCTION

Seed is one of the key inputs in agriculture. Improved seeds of suitable varieties have often been a source of agricultural growth around the world (Traxler and Byerlee 1993). High-yielding rice varieties in Japan were a key driver of agriculture in the 19th century (Jirström 2005). Hybrid rice in China has significantly contributed to the transformation of Chinese agriculture since the 1980s (Lin 1994).

Impacts of seed policies are likely to be heterogeneous, not only because of diversity in production environments but also because of the diverse traits within seeds themselves, which vary depending on the crops as well as varieties. Seeds for vegetative crops like potatoes are often costly because diseases tend to accumulate in vegetative material and yields tend to decline fast if old seeds are not replaced with new seeds (Fuglie et al. 2006). For certain crops like rice, on the other hand, seeds of existing varieties tend to account for a relatively small share of production costs. Rice seeds can be recyclable unless they are hybrids and have high seed multiplication rates. Once a particular variety is available, its supply may increase quickly within a short period of time. Because the price elasticity of seeds can be very high, rice seeds tend to account for a relatively small share of production costs. Thus the private sector has relatively little incentive to develop new rice varieties, and historically the public sector has led rice research and development (R&D) around the world. R&D on varietal development, therefore, is an important part of rice seed policy.

Nigeria has seen rapidly growing rice consumption in the past few decades, much faster than the domestic production increase (Table 1.1). The government of Nigeria has recently shifted its focus to the growing domestic rice production sector to reduce reliance on rice imports (Johnson, Takeshima, and Gyimah-Brempong 2013). Currently, the Nigerian government has been implementing the Growth Enhancement Support under its Agricultural Transformation Agenda (ATA), whereby seeds of maize and rice are provided to farmers at discounted prices. This strong commitment by the government is an encouraging trend toward transforming agriculture in Nigeria. A recent study assessing the donor-led seed voucher program indicates that the rice seed subsidy can have a positive impact on farmer welfare in Nigeria (Awotide et al. 2013). Questions, however, still remain about how the rice seed subsidy can contribute to agricultural transformation through increased rice production in order to reduce reliance on rice importation, which is one of the goals under ATA. One of the concerns, as described in this report, is the pattern of rice R&D in Nigeria, its implication on varietal development, and how the impact of seed policies including the seed subsidy are affected by this pattern.

Table 1.1 Trends in rice production and consumption in Nigeria (million metric tons, milled equivalent, five-year averages)

Period	1961–1965	1966–1970	1971–1975	1976–1980	1981–1985	1986–1990	1991–1995	1996–2000	2001–2005	2006–2009
Production	0.14	0.21	0.31	0.40	0.87	1.48	1.99	2.17	2.09	2.49
Consumption	0.14	0.22	0.30	0.82	1.36	1.77	2.32	2.82	3.25	3.66

Source: Author’s calculations based on FAO (2013).
Note: Consumption is the total quantity supplied, including food and nonfood uses (including uses as feed and seeds).

With this background, this report provides some illustrations of the importance of R&D, and how rice seed policies have different impacts depending on the suitability of varieties promoted. The report first summarizes the general operations of the rice seed sector in Nigeria. It then provides key international and historical perspectives on rice R&D and sheds light on key patterns of varietal development in certain rice ecologies in Nigeria. Using a household simulation model for the lowland rice ecology in North Central Nigeria, it illustrates how certain seed policies like the seed subsidy can have greater impacts if combined with strong R&D that provides higher-yielding varieties.

2. GENERAL FUNCTIONS OF RICE BREEDING, VARIETY SELECTION, AND SEED PRODUCTION IN NIGERIA

The rice research system in Nigeria has changed over time. Historically, the National Cereal Research Institute (NCRI) has been in charge of rice research. Based on research by Agricultural Science and Technology Indicators (ASTI 2013), approximately 40 percent of NCRI's resources are allocated for rice, and approximately 30 percent of its activities are on crop genetic improvement.

Research has been rather centralized since the 1970s. The Agricultural Research Institutes Decree in 1973, which was considered a watershed in state-federal funding of agricultural research, vested power in the federal commissioner for agriculture to establish agricultural research and training institutes as well as to take over any existing state research stations (Roseboom et al. 1994). This system might have reduced initiatives for states to fund agricultural research (Roseboom et al. 1994). NCRI and other national research institutes were established under the 1975 Research Institutes (Establishment) Order. Federal control over regional universities and their agricultural research institutes has been strengthened since then (Roseboom et al. 1994).

Collaborative rice development started in the 1990s under the National Agricultural Research Project (NARP) by the World Bank (Maji and Fagade 2002, 108; Alene et al. 2007). Under NARP, state agricultural development projects (ADPs) and universities were brought into the mainstream of rice varietal evaluation nationwide. In terms of breeding, however, state-level institutions like ADPs and universities of agriculture do not seem to be involved with much rice research—there has been only one variety of non-NCRI origin (FARO 42 originates from the Institute for Agricultural Research and Training, or IAR&T).

Recently, participatory variety selection (PVS) has been used, albeit on a small scale. Positive results have been found outside Nigeria for PVS, such as faster variety development (Walker 2007) and a 40 percent higher yield in a poor rice-growing area in South Asia (Joshi et al. 1996). Some early success for beans, rice, and maize has also been observed in other parts of Africa (Sperling, Loevinsohn, and Ntabomvura 1993). PVS, however, faces challenges. Importantly, it has been difficult to aggregate across farmer preferences and elicit information on strategic longer-term research priorities through exclusively relying on participatory methods such as PVS (Pingali 2010). In Nigeria, PVS has been applied to New Rice for Africa (NERICA), a group of interspecific crosses between Asian and African rice developed by the African Rice Center (formerly West Africa Rice Development Association, or WARDA). While NERICA is promising, only farmers in certain areas have been reached with it (Maji and Fagade 2002).

Rice Variety Release Mechanism[1]

Before 1984, research institutes released rice seeds to farmers through various channels and programs with rice components (Maji and Fagade 2002, 105). At the national research level, two or more advanced-yield trials were conducted, the most outstanding entries were tested for a further two years in zonal trials, and then outstanding varieties were released to replace existing ones (Maji and Fagade 2002, 105).

The system was changed in 1984. Under the new system, outstanding entries from all the research institutions involved in rice research in the country were nominated into a network of coordinated rice evaluation trials (CRETs) coordinated by NCRI (Maji and Fagade 2002, 106). The network included national institutes (NCRI and IAR&T) and international centers and programs such as the International Institute of Tropical Agriculture (IITA), International Rice Research Institute (IRRI), International Network for Genetic Evaluation of Rice (INGER), and WARDA. After two years, the best entries from the CRET in each ecology were recommended for release to the national varietal release committee. Varieties released under this program include IRAT 133 and IRAT 144 (upland short duration); ART 12 (ITA 116), FAROX 299, and ITA 128 (upland short medium); FAROX 228-2-1-1, FAROX 228-3-1-1, and FAROX 228-4-1-1 (lowland short maturity); and ITA 212, ITA 222, and ITA 306 (lowland medium

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[1] This section relies heavily on Maji and Fagade (2002).

CRET). Many of these varieties were recommended by the Third National Coordinating Research Project on Rice and released by NCRI in 1986 (Maji and Fagade 2002, 106).

After 1986, the release process was modified again slightly. During this period, approximately two to five of the most promising materials from any CRET nursery were nominated into farmers' field trials. Among varieties released between 1985 and 1995, 95 percent appeared in the CRET trials, 67 percent originated directly from IRRI, and 86 percent passed through INGER-Africa trials for one year before release.

Varieties released after 1992 have mostly been upland varieties, earlier developed by IITA. IITA's rice breeding during this period has focused on reducing the height of FARO 11 and increasing tillering ability. This effort led to the development of the ITA 300 series, of which ITA 301 and 315 were released as FARO 48 and 49.

Seed Quality Control and Certification

The Seed Certification Department of the National Agricultural Seeds Council (NASC) conducts seed certification as established by the 1992 Seed Decree. NASC assigns about one to three seed certification officers to assist each ADP as well as each seed company or group of small companies (Bentley et al. 2011); they visit fields with the ADP's seed officers to inspect (the ADP pays the council some amount per hectare (ha) per year for inspections). A production field is rejected if the plots are too weedy, diseased, inadequately rogued, or mixed with other varieties (Bentley et al. 2011). Seed certification officers inspect each outgrower four to five times per year; at the last visit, they collect samples of harvested seed for lab tests. Certifications were not required prior to 2009. However, with the agreement by the Economic Community of West African States (ECOWAS) in 2009, certifications have become mandatory in Nigeria (Bentley et al. 2011). Although under the agreement any varieties that have been released elsewhere in ECOWAS countries can be sold in Nigeria, it is unclear how mandatory certification will affect the speed of variety release.

Certified Seed Production

Since the seed project funded by the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Development Programme (UNDP) in 1975–1980, ADPs have been producing subsidized seeds. By 1992, the ADPs were producing enough seeds to plant 8–15 percent of Nigeria's crops (Bentley et al. 2011). In the period 2005–2009, ADPs were major suppliers of certified seeds for rice and open-pollinated (OP) maize, supplying 2,458 tons[2] of rice and 1,326 tons of OP maize seeds out of 3,835 and 2,382 tons, respectively, supplied in Nigeria (Table 2.1). In contrast to rice and OP maize, certified seeds for hybrid maize and sorghum in Nigeria are mostly supplied by private companies. Sizes of ADPs and their seed production capacity vary across states. For example, the Ekiti state ADP has the biggest seed plant in Nigeria and can process 3 tons of seed per hour (Bentley et al. 2011). In the Kaduna state ADP, about 40 outgrowers produced 236 tons of rice seeds in 2008, which the state ADP bought at approximately US$1[3] per kilogram (/kg) (Bentley et al. 2011). NASC holds annual meetings in December or January in the north (Zaria) and the south (Ibadan) with the ADPs, seed companies, research institutes, and outgrowers. The ADPs and the companies submit *indents* (estimates of foundation seed needed) at these meetings. Based on the indents and the amount of seed used the year before, the Seed Council determines how much foundation seed to distribute. The ADP buys foundation seed from NASC, distributes it to outgrowers, and buys back the harvest (Bentley et al. 2011). Once the certified seeds are available, Kaduna state ADP starts selling them to farmers, announcing the sales on the radio and posting the price on bulletin boards (Bentley et al. 2011).

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[2] Tons are metric tons throughout the text.

[3] All dollar amounts are in US dollars.

Table 2.1 Certified seed production of rice and other major crops in Nigeria (metric tons), 2005–2009

Crop		2005	2006	2007	2008	2009	Average (2005–2009)
Rice	ADPs	1,005	1,647	2,909	6,501	227	2,458
	Companies	415	1,108	2,591	1,806	936	1,371
	NGOs	0	0	0	0	21	4
	Total	1,421	2,756	5,501	8,314	1,184	3,835
Maize hybrid	ADPs	0	0	0	0	0	0
	Companies	1,386	2,948	1,137	2,641	3,150	2,252
	NGOs	0	0	0	0	0	0
	Total	1,386	2,948	1,137	2,641	3,150	2,252
Maize OPV	ADPs	680	1,006	1,244	3,437	264	1,326
	Companies	372	1,319	942	1,130	1,429	1,038
	NGOs	0	0	0	0	89	18
	Total	1,052	2,325	2,186	4,567	1,782	2,382
Sorghum	ADPs	55	77	82	180	17	82
	Companies	241	642	117	2,186	492	736
	NGOs						
	Total	296	718	199	2,366	509	818

Source: Bentley et al. (2011).
Note: ADP = agricultural development project; NGO = nongovernmental organization; OPV = open-pollinated variety.

In Nigeria, private companies are also gradually becoming involved in information dissemination. The National Agricultural Extension and Research Liaison Services (NAERLS) at Ahmadu Bello University has two radio stations and allows the company to air spots at a low cost. One of the seed companies in Nigeria, Nagari Seed, has some slots on the radio through the ADP and NAERLS to advertise and disseminate information about its seeds (Bentley et al. 2011).

3. KEY RICE POLICY ISSUES IN NIGERIA: RICE RESEARCH AND DEVELOPMENT

International Perspective of Public Rice R&D

Seed is one of the key inputs in agriculture. One of the goals of the seed sector has been to establish a system to supply appropriate varieties to farmers. Seeds consist of various attributes, and each attribute has different values for farmers and consumers with different tastes, as well as for different production environments with particular agroecological constraints. Traditionally, the seed demand has been met by the private sector. In Africa South of the Sahara (SSA), the seed sector for maize and vegetables has been growing. In eastern and southern Africa, hybrid maize has been widely adopted since as early as the 1970s in Kenya (Gerhart 1975; Kostandini et al. 2011; Suri 2011) and Zimbabwe (Eicher 1995). Nigeria has also experienced widespread adoption of improved OP maize varieties, including improved drought-tolerant maize called TZB (Goldman and Smith 1995; Smith et al. 1994; Alene et al. 2009). Private companies have started handling maize and vegetable seeds in Nigeria. Several private companies like Premier Seed and Nagari Seed have been developing their own hybrid maize varieties through research, and up to 2009 they obtained release of close to 10 varieties (Bentley et al. 2011). Between 2005 and 2008, Premier Seed produced about 1,000 tons of hybrid maize seed annually.

On the other hand, the private sector has found it more difficult to engage in the rice seed sector. Only recently has the private seed sector grown, with the increased use of hybrid varieties of rice (Morris, Singh, and Pal 1998; Gerpacio 2003; Kolady, Spielman, and Cavalieri 2012). This is often because rice seeds can be recycled over many years, and farmers replace them with new seeds from the market only every once in a while, slowing down the growth of commercial seed markets for rice. Developing hybrid rice is also often costlier than developing hybrid maize (Byerlee 1996, 708). As a result, private investment in rice R&D has also been negligible. In Asia and Latin America, historically, governments' major seed policy focus has been on public R&D for varietal development.

Public rice R&D is expected to be an important component of rice seed policy in SSA including Nigeria as well. Recent research has brought important attention to other seed-sector issues, including capacity building for seed certification, quality regulations, information dissemination, development of a private sector–led formal seed supply system, and use of seed distribution as a social safety net (Takeshima et al. 2010; Minot et al. 2007; Cromwell 1996; Tripp 2000; Sperling, Cooper, and Remington 2008). Effective implementation and outcomes of these policies may, however, critically depend on how good the varieties are, and this is often highly determined by public R&D in case of rice.

Regarding rice R&D, Nigeria is still behind many other countries in Asia and Latin America. While only a few countries, such as Japan, have reached the advanced science–based stage, many Asian countries, like India, China, Thailand, and Indonesia, have also reached the intermediate hierarchical stage, wherein substantial, if not cutting-edge, development activities for new varieties exist (Table 3.1). This situation is in contrast to countries like Nigeria where domestic rice research is still primarily on selection and transfer of imported varieties. Table 3.2 indicates important consequences of the weak domestic R&D capacity. Up to 1999, South and Southeast Asia released 18 improved varieties developed by their National Agricultural Research Systems (NARS) per 1 million ha of rice area. The figure for Nigeria is only about half that (10 per 1 million ha). In addition, while Asian countries increased their reliance on NARS toward the 1990s, Nigeria has had virtually no new NARS varieties released since the 1990s.[4]

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[4] The slow release of NARS varieties is unlikely to be because of the national seed system. The Crop Variety Registration and Release Committee is part of NASC. Although the committee can take up to two to four years of trials (on-station and at several locations on-farm) before releasing a variety in Nigeria (Bentley et al. 2011), these restrictions should apply to IITA and WARDA varieties that have been released since the 1990s. More generally, by the same reasoning, the 1992 Seed Decree cannot explain the slow outcomes of NARS varieties in Nigeria.

Table 3.1 Typology of rice research and development

Low-skilled stage	Intermediate hierarchical stage	Advanced science–based stage
Dependent primarily on technical and engineering skills and characterized by widely diffused commodity-oriented experiment stations	… with appreciable scientific skills and substantial economies of scale to be gained by the concentration of these skills in leading institutions	… with a large supply of conceptual scientific skills and emphasis by the most highly regarded centers on research that does not have a direct technological objective
Depends on the transfer and simple adaptation of technology	Adds capacity to develop new technology (given the state of scientific knowledge)	Appends skills that permit basic scientific breakthroughs
Japan—before mid-1920s	Japan—after mid-1920s India, China, Thailand, Indonesia—1980	Japan—1980s

Source: Barker et al. (1985).

Table 3.2 Number of released varieties in Nigeria and Asia, by NARS and other sources

Area	Source	Pre-1970s	1971–1980	1981–1990	1991–1999	2000–2012	Total	Number per million ha in 1999
Nigeria	Total	12	13	18	8	10	61	30
	IRRI, IITA, WARDA	1	5	4	6	10	26	
	Foreign	10	3	3	2	0	18	
	NARS	1	5	11	0	0	17	10
S + SE Asia	Total	533	409	663	435		2,040	20
	IRRI	62	71	75	14			2 (11%)
	NARS	471	338	588	421		1,822	18

Source: South and Southeast Asia: Author’s modification based on Hossain et al., Tables 5.3 and 5.5 (2003). Nigeria: Author’s modifications based on Table 3.8.

Note: IRRI = International Rice Research Institute; IITA = International Institute of Tropical Agriculture; NARS = National Agricultural Research Systems; WARDA = African Rice Center (formerly West Africa Rice Development Association).

Although varieties developed by international agricultural research centers such as IRRI spread widely, NARS-bred varieties had been popularly adopted as well in Asia. Table 3.3 summarizes the major rice varieties grown in 1998 in selected Asian countries. While IRRI varieties like IR 8, IR 36, and IR 64 were being widely adopted across countries, NARS-developed varieties were covering a substantial share of the rice area in many Asian countries. In countries like Bangladesh, India, Pakistan, Sri Lanka, and Thailand, NARS-bred varieties dominated in 1998. These patterns indicate that rice production ecology and preferences vary across countries, and NARS has played an important role in successfully developing and releasing varieties suitable for local conditions. In some countries like Sri Lanka, there were even some sentiments against internationally developed varieties like IR 8 among the domestic rice breeders, who were able to develop better varieties than IR 8, such as BG 11, in the 1970s (Wickremasinghe 2006). By the mid-1970s, the domestically developed BG series was successful. In contrast, most major rice varieties in Nigeria are of foreign origin, except the old FARO 15, which was developed way back in 1974.

Table 3.3 Major rice varieties adopted in selected Asian countries, 1998

Country	Variety	Year released	Rice area covered (%)	Origin	Country	Variety	Year released	Rice area covered (%)	Origin
Bangladesh	BR 11 (Mukta)	1980	17	NARS	Pakistan	Super Basmati	1996	60	NARS
	BR 14 (Gazi)	1983	8	NARS		Basmati 385	1985	25	NARS
	BR 3 (Biplab)	1973	7	NARS		KS 282	1982	7	NARS
	IR 8	1966	5	IRRI		IR 6	1971	7	IRRI
	BR 11	1980	3	NARS		Basmati 198	1972	1	NARS
India (eastern Madhya Pradesh)	Swarma	1982	30	NARS	Philippines	IR 64	1985	30	IRRI
	Safru 17		20	NARS		PSBRC 14	1992	12	NARS
	Mahomaya	1994	10	NARS		PSBRC 28	1995	2	IRRI
	Ramikajr		10	NARS		PSBRC 18	1994	3	IRRI
	IR 36	1976	5	IRRI		PSBRC 34	1995		NARS
India (Kapurthala)	PR 111	1993	27	NARS	Sri Lanka	BG 300	1987	22	NARS
	PUSA 44	1993	25	NARS		BG 352	1992	12	NARS
	PR 106	1978	20	IRRI		BG 94	1978	12	NARS
	PR 113	1998	10	NARS		BG 350	1986	7	NARS
	IR 8	1966	7	IRRI		BG 450	1985	6	NARS
India (Tamil Nadu)	CO 37		14	NARS	Thailand	RD 6	1977	28	NARS
	CO 43	1982	14	NARS		KDML 105	1959	23	NARS
	CO 45	1991	5	NARS		SPR 60	1987	1	NARS
	CO 46	1997	2	NARS		RD 23	1981	1	NARS
	CO 47		1	NARS		RD 10	1981		NARS
Indonesia	IR 64	1985	30	IRRI	Vietnam	IR 64	1985	20	IRRI
	Cisadane	1980	2	NARS		DT 10	1990	14	NARS
	Memberamo	1995	3	NARS		OM 997	1994	9	NARS
	PB 42	1980	1	IRRI		IR 56279		6	IRRI
	IR 36	1976	1	IRRI		IR 50404	1992	3	IRRI
Malaysia	MR 84	1986	77	NARS	Nigeria	FARO 44	1993	11	Taiwan
	MR 77		7	NARS		FARO 15	1974	7	NARS
	MR 167		6	NARS		FARO 46	1992	6	IITA
	IR 42	1977	3	IRRI		Ex China	1988	5	China
	Semerak		2	NARS		FARO 52	2001	4	IITA

Source: Hossain et al. (2003); ASTI (2013) and various literature for Nigeria.
Note: IRRI = International Rice Research Institute; IITA = International Institute of Tropical Agriculture; NARS = National Agricultural Research Systems.

Such success of NARS R&D in Asian countries can be attributed to the size of funding, human capital, and decentralized nature of breeding. While it is challenging to determine the exact amount of funding spent on rice research due to limited information, available evidence indicates that several Asian countries allocated more funding for rice research per rice-cultivated area from the 1960s through the 1990s than Nigeria did in the late 1990s (Tables 3.4 and 3.5). Clearly East Asian countries such as Japan and South Korea had invested substantially from the early 20th century. But even countries in South Asia, Southeast Asia, and Latin America had already been investing more substantially in rice R&D in the 1960s than Nigeria did in the 1990s. While Nigeria spent only about $0.20–$0.35 per ha of rice area in 1997 and 1998 (constant 2010 US dollars, purchasing power parity adjusted), South Asia and Southeast Asia had already spent approximately $0.70–$0.90 per ha in the 1960s. By 1974, Indonesia, Thailand, or Vietnam were already spending at a level similar to that of Nigeria in the late 1990s by rice area, and a much higher level per capita. Bangladesh, India, and the Philippines spent substantially more in 1998 than did Nigeria, in terms of both area and population. In Nigeria, agricultural R&D was likely to have been higher in the 1970s and early 1980s than in the 1990s, as rice R&D per rice gross domestic product in Africa in general had been relatively higher around that time compared with other regions (Judd et al. 1986; Lipton 1988). This period coincided with steady rice yield increases in Nigeria up until the mid-1980s, when its yield was similar to that of Bangladesh, India, or Thailand, and even higher than that of Brazil (FAO 2013). These facts also indicate that domestic investment in R&D might be critical for rice productivity growth.

Table 3.4 Annual investment in rice research prior to 1975

Period	Million US dollars, 2010 constant				2010 US dollars/hectare, PPP[b]		
	East Asia[a]	Southeast Asia	South Asia	IRRI	East Asia	Southeast Asia	South Asia
1900–1920	5		1				
1921–1940	15	1	2				
1951–1955	56	12	10				
1956–1960	98	11	10	6			
1961–1965	180	15	17	10	5.9	0.8	0.7
1966–1970	253	18	22	16	6.2	0.9	0.7
1971–1975	271	17	25	22	7.4	0.9	0.8

Source: Author's modifications based on Evenson and Flores (1978). Figures are converted into 2010 US dollars by accounting for the 5.62 times increase in consumer price index in the United States between 1970 and 2010. Regional rice areas from FAOSTAT (FAO 2013).

Note: IRRI = International Rice Research Institute; PPP = purchasing power parity. [a] Excludes China. Evenson and Flores (1978) did not provide the definitions of each region. We therefore used the FAO definitions. [b] Due to the lack of information, we obtained conversion rates for 1980 from World Development Indicators and calculated the averages across all countries in each region: East Asia = Japan, South Korea; Southeast Asia = Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Vietnam; South Asia = Afghanistan, Bangladesh, Bhutan, India, Iran, Nepal, Pakistan, Sri Lanka.

Table 3.5 Rice research expenditure in selected countries,[a] 1974 and 1998

Country	Amount (thousand US dollars, 2010)		PPP adjusted		Amount per rice area (2010 US dollars/ha, PPP)		Amount per 1,000 people (2010 US dollars, PPP)	
	1974	1998	1974	1998	1974	1998	1974	1998
Bangladesh[b]	646	4,548	922	9,097	0.1	0.9	13	73
Indonesia	2,959		3,699		0.4		28	
India	20,982	16,455	34,970	54,848	0.9	1.2	58	54
Japan	247,480		224,982		82.6		2,055	
Nepal	538		1,076		0.9		83	
Philippines[b]	2,690	4,682	5.380	11,705	1.5	3.2	135	158
Pakistan	1,130		2,260		1.4		34	
South Korea	1,345		1,921		1.6		56	
Thailand	1,614		2,690		0.4		65	
Thailand[c]	6,690	14,000	11,149	26,923	1.5	2.9	270	449
Taiwan	9,146		11,433		14.7			
Vietnam	861		1,722		0.3		35	
Latin America (Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela)[d]	22,200		33,783		4.5		123	
Nigeria		197		538–985		0.3–0.5		approx. 5–8
IRRI	12,912	45,484						
WARDA		2,200		3,300				

Source: Author's modifications based on Hossain et al. (2003, 77ff.) for Asian countries and IRRI; Jaroensathapornkul (2007) for Thailand; de Janvry et al. (1987, Table 13) for Latin America; Ojehomon et al. (1999, cited in Dalton and Guei [2003]) for Nigeria; and WARDA (1999) for WARDA. All 1974 figures (except as explained in note c, below) are from Evenson and Flores (1978) and Barker et al. (1985, Table 14.9).

Note: IRRI = International Rice Research Institute; PPP = purchasing power parity; WARDA = African Rice Center (formerly West Africa Rice Development Association). [a] Figures are converted into 2010 US dollars. PPPs for Asian countries are estimated by author using PPP conversion factor (gross domestic product) to market exchange rate by the World Bank, World Development Indicators (WDI). For Latin America, we took the average across 7 countries. For Nigeria, PPP-adjusted figures have some ranges due to conflict between the Dalton and Guei (2003) figure and the WDI-based figure. For figures in 1974, we applied PPP conversion rates for 1980 (except Vietnam, for which we used 1985) due to the lack of information. [b] Figures for 1998 represent the total funding for the Bangladesh Rice Research Institute and the Philippines Rice Research Institute. [c] Figures represent the averages of 1970–1979 and 1990–2000, respectively, with author's recalculation into 2010 US dollars, based on Jaroensathapornkul (2007). [d]Figures are for 1980.

In addition to the concurrent spending, more human capital had been made available for rice research in many Asian countries compared with Nigeria (Table 3.6). While there were only 6 rice scientists for 1 million ha of rice land in Nigeria in 1999, many Asian countries had approximately 10–20 rice scientists in 1983 and 1999. Nigeria also has only 2 rice breeders, compared with 50 in Egypt (Diagne et al. 2011).

Table 3.6 Number of rice research scientists per million hectares of rice area in selected countries, 1983 and 1999

Country	Year	
	1983	1999[a]
Bangladesh	13	16
Cambodia		18
India	13	15
Indonesia	7	
Laos		43
Nepal	11	
Pakistan	12	
Philippines	34	53
Sri Lanka	18	25
Thailand	14	14
Vietnam	4	11
Nigeria		6
Republic of Guinea		36
Côte d'Ivoire		19

Source: Hossain et al., , Table 5.1 (2003) for Asian countries. Author's modification based on Dalton and Guei, Table 6.2 (2003) for Nigeria, Guinea, and Côte d'Ivoire.

Note: [a] Year is 1998 for Nigeria, Republic of Guinea, and Côte d'Ivoire. Dalton and Guei (2003) reported that out of 106 scientists in selected West African countries, 45.6 scientist years are allocated for variety improvement, among which 5.3, 9.4, and 3.1 are in Nigeria, Guinea, and Côte d'Ivoire, respectively. Dalton and Guei (2003), however, did not report the number of scientists in each country. We therefore calculated the number of scientists for each country, assuming that the breakdown of the number of scientists is the same as the breakdown of the time allocated for variety improvement in each country. For example, since 5.3 out of 45.6 scientist years are in Nigeria, we assume 12 (= 106 * 5.3/45.6) scientists are in Nigeria. With 2 million ha of rice area in 1998, the number of scientists per million ha in Nigeria becomes 6.

Rice R&D Issues in Nigeria

In Nigeria, rice is produced in three major systems: irrigated, rainfed lowland, and upland. Although no official government statistics exist, various estimates indicate that rainfed lowland is the major production system, accounting for about two-thirds of area and production, but upland also accounts for a significant share (Table 3.7). Currently, irrigated rice area accounts for a very small share. Rice R&D needs differ for each of these systems, given the transferability of foreign technologies and the level of research investments made so far.

Table 3.7 Dominant rice production systems in Nigeria

Production system	Average share of national area (%)	Average share of national production (%)	Average yield range per year (metric tons/ha)	% of area under improved varieties
Irrigated	4	7	> 2.0	80
Lowland (rainfed)	64	65	2.0–3.0	37
Upland (rainfed)	30	27	1.0–2.0	67
Mangrove (deep water)	2	1	-	

Source: Author's estimates modified from Ezedinma (2005, Table 1), Erenstein et al. (2004, Table 1), and Living Standards Measurement Study 2010–2011 and 2012–2013 data (World Bank 2013). Percentage of area under modern varieties is from Dalton and Guei (2003).

Note: We adjusted the irrigated area downward to be more consistent with the estimates from Living Standards Measurement Study 2010–2011 and 2012–2013 (World Bank 2013), and included the difference in the rainfed lowland category. We then adjusted the share of national production proportionately.

The adoption rate of modern varieties is high, at 80 percent, in irrigated rice production in Nigeria (Table 3.7). Varieties that can work in an irrigated environment are relatively more available from IRRI, WARDA, and IITA. Varieties like FARO 44, which was brought from Taiwan, have overcome yellow mottle virus and are realizing reasonable yield in some irrigation schemes like the Bakolori Irrigation Project in northern Nigeria.

The prospect of improving performance of the existing rice irrigation scheme in Nigeria is, however, limited due to the small share of irrigated rice compared with total consumption in Nigeria. In addition, it is not likely that the currently successful varieties like FARO 44 in northern Nigeria can be easily multiplied into newly opened irrigated areas or into the North Central and South zones. Even in an irrigated environment, it is still difficult to multiply the success of certain varieties in one location to other locations. For example, in Ghana the government conducted seed selection in the first decade of this century and identified Jasmine 85 as one of the successful varieties to be multiplied to various irrigation schemes. The fertilizer response of Jasmine 85 varieties, however, appears to be high only in Kpong, and lower (around 2–3 tons) in other major irrigation projects (Takeshima, Jimah et al. 2013). Identifying good varieties for a particular location thus may require long-term investment into R&D and breeding at the local level.

Rice Research Needs for Rainfed Lowland Ecology

Adoption of modern varieties[5] is still relatively low in the rainfed lowland ecology in Nigeria (Table 3.7).[6] An important question is whether this is due to insufficient R&D for rainfed lowland rice, and whether strengthening domestic R&D funding can substantially increase the development of appropriate varieties for this ecology. Though it is an empirical question, there are some indications.

Pubic spending on domestic rice research is important, particularly when productivity increase is needed for rainfed lowland (*fadama*), where only minimal or partial water control is possible. This is because the adaptability of varieties developed by international institutes such as IRRI, and probably WARDA and IITA, usually requires a viable irrigated system (Evenson and Gollin 1997), which may not hold in Nigeria, unlike Asian countries during the Green Revolution era. In a country that relies on rainfed production, domestic research is likely to be critical. Thailand, where the rice sector grew mostly in rainfed conditions, made significant public investment in domestic rice research (Table 3.5). Because the discovery of new varieties is a stochastic process (Evenson and Kislev 1976), naturally more public investment is needed to raise the likelihood of developing improved varieties that have better attributes.

As examples, Table 3.8 lists the major problems of these varieties introduced into rainfed lowlands—they include (1) susceptibility to blast, which is a problem more commonly observed in Nigeria but rare in Sahelian countries (Singh et al. 2000); (2) iron toxicity; and (3) weed competition (Rodenburg et al. 2009). These problems are often location specific, and developing suitable varieties for the rainfed conditions has been difficult due to insufficient domestic rice research.

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[5] Dalton and Guei (2003) defined *modern varieties* as the semidwarf varieties developed after hybridization of Dee-geo-woo-gee.

[6] This prevalence of traditional varieties cannot be evaluated solely as the failure of rice seed breeding because it may simply mean that, outside the area where modern varieties can be grown, additional substantial area can be planted with traditional rice varieties. However, when thinking about substantially raising the productivity of rice in this ecology, it seems important to achieve increased adoption of modern varieties in areas where traditional varieties are currently grown.

Table 3.8 Origins of key rice varieties in Nigeria

Variety (FARO)	Year released	Origin[a]	Ecology[b]	Characteristics	Pedigree/parentage
1	1955	Guyana	SS	• Weak nitrogen response (MF)	BG 79
2	1958	Guyana	SS		BG 90-2
3	1958	Nigeria	U	• Weak nitrogen response (MF)	Agbede
4	1959	India	DW		Kavunginpoohala 12
5	1960	Madagascar	SS		Makalioka 825
6	1961	Fr. Guinea	L, DW		Indochinablank
7	1962	Thailand	L, DW		Maliong
8	1963	Indonesia	SS	• Popular in rainfed lowland in 1963–1965 (S)	MAS 2401
9	1963	Malaya	SS	• Long grain • Popular in south Guinea savannah (Niger and Benue states)	Siam 29
10	1963	Kenya	SS		Sindano
11	1966	Congo/Zaire	U	• Resistant to blast (MF)	OS 6
12	1969	Suriname	SS	• Tall, long-duration variety to suit the long growing seasons in SE Nigeria (MF) • Resistant to blast (MF) • Photoperiod sensitive	SML 140/10
13	1970	Philippines	SS	• Start of the introduction of IRRI semidwarf varieties	IR- 8
14	1974	Nigeria	SS		Chanyza 123 × ICB
15	1974	Nigeria	SS	• High elongation ability to suit medium- to deepwater ecology (MF) • Stiff strawed, early maturing, high yielding (MF) from IR8 • Lodges heavily with too much nitrogen (MF)	FARO 1 × IR-8
16	1974	Nigeria	SS		Mas 2401 × SML 140/10
17	1974	Nigeria	SS		Mas 2401 × Tjina
18	1974	Indonesia	SS	• High resistance to blast (MF)	Tjina
19	1974	Philippines	SS		IR 20
20	1974	Philippines	SS		BRI-76
21	1974	Philippines	SS	• Early-maturing variety (only one before 1976) (MF)	Taichung Native 1
22	1974	Philippines	SS		IR 627-1-31-3-27
23	1974	Philippines	I / SS	• Resistant to blast (MF)	IR 5-47-2
24	1974	Vietnam	I / SS		Degaule
25	1976	Nigeria	U		Jete × Tjina (FAROX 56/30)
26	1982	Nigeria	SS		TOS 78 = IR 269-26-3
27	1982	Nigeria	SS		(TOS 103) IR 400-15-12-10-2 × IR 662
28	1982	Nigeria	SS		Tjina × IR 8 (FAROX 118)
29	1984	Nigeria	SS	• Susceptible to blast by 1990 (S)	Pesa / TN 1 Remadja (BG 90-2)

Table 3.8 Continued

Variety (FARO)	Year released	Origin[a]	Ecology[b]	Characteristics	Pedigree/parentage
30	1986	Nigeria	I / SS	• Highest yield (6.5 metric tons/ha) in the experiment in 1980s, good cooking quality (F)	FARO 15 / IR 28 (FAROX 228-2-1-1)
31	1986	Nigeria	I / SS		FARO 15 / IR 28
32	1986	Nigeria	I / SS		FARO 15 / IR 28
33	1986	Nigeria	I / SS	• Susceptible to iron toxicity (F)	FARO 12 / IR 28
34	1986	Nigeria	I / SS		FARO 12 / IR 28
35	1986	IITA	SS	• Susceptible to iron toxicity (F)	BG 90-2(FARO 2), TETEP
36	1986	IITA	IS		ITA 222 Maushuri / IET 1444
37	1986	IITA	IS		ITA 306 (TOX 494-3696/TOX 711/BG 6812)
38	1986	Côte d’Ivoire	IS		IRAT 133 (IRAT 13 / IRAT 10)
39	1986	Côte d’Ivoire			IRAT 144 (IRAT 13 / IRAT 10)
40	1986	Nigeria	IS		FAROX 299
41	1986	Côte d’Ivoire	U		IRAT 170 (IRAT 13 / Palawan)
42	1986	IAR&T (1981)	U		ART 12 (ITA 116)
43 (ITA 128)	1986	IITA (1986)	U		ITA 128 (63-83 / Iguape Cateto, IET 144, IR 1416-131, Lite 506)
44	1992	Taiwan (1993)	I	• Early maturity • Popular in the northern dry zones • Resistant to rice yellow mottle virus • Susceptible to iron toxicity	SIPI 661044, SIPI 651020
45	1992	IITA (1991)	U		ITA 257 (IRAT 13/Dourado Precose 689/TOX 490-1)
46	1992	IITA (1991)	U	• Yield potential = 2 metric tons/ha • Good grain quality—easy to thresh	ITA 150 (63-83/Multiline)
47	1992	IITA (1991)	U	• Taller	ITA 117 (13A-18-3-1/TOX 7)
48	1992	IITA (1991)	U	• Reduced height of FARO 11 • High yielding under high nitrogen fertilization • Susceptible to drought, also leaf scald / bacterial blight in humid forest (MF)	ITA 301 (IRAT 13/Dourado Precose 689 / Padipapayak)
49	1992	IITA (1991)	U	• Reduced height of FARO 11 • High yielding under high nitrogen fertilization • Susceptible to drought, also leaf scald / bacterial blight in humid forest (MF)	ITA 315 (IR 43 / Iguape Cateto)
50	1992	IITA	IS		ITA 230 (BG 90-2*/Tetep)
51	1997	Indonesia	I / L	• African rice gall midge tolerant • Popular in the South East (MF)—adopted widely before release	PELITAI 1, IR 789-98-2-3, IR 2157-3

Table 3.8 Continued

Variety (FARO)	Year released	Origin[a]	Ecology[b]	Characteristics	Pedigree/parentage
52	2001	IITA / WARDA	I / SS	• Iron toxicity tolerance • High yield, stability under low input conditions • Susceptible to African rice gall midge (MF)	WITA 4 (TOX 3100—44-1-2-3-3)
53	2003	IITA	U	• Resistant to blast	ITA 321
54	2003	WARDA	U		WAB 189-B-B-B-HB
55 NERICA 1	2003	WARDA	U		CG-14 * WAB 56-104
56 NERICA 2	2006	WARDA	U		CG-14 * WAB 56-104
57	2006	WARDA	L		TOX 4004-43-1-2-1
58 NERICA 7	2011	WARDA (2011–2012)	U		CG-14 * WAB 56-104
59 NERICA 8	2011	WARDA (2011–2012)	U		CG-14 * WAB 56-104
60 NERICA L19 (W)	2012	WARDA	L	• Resistant to pests and diseases, also tolerant to drought	IR64 and TOG5681(*Oryza glaberrima*) (K)
61 NERICA L34 (W)	2012	WARDA	L	• Resistant to pests and diseases, also tolerant to drought	IR64 and TOG5681(*Oryza glaberrima*) (K)
Other varieties released outside FARO					
UPIA 1	2013	IRRI	L	• Early maturing and high yielding, resistant to iron toxicity, African rice gall midge	IR 68
UPIA 2	2013	IRRI	L		IR 69513-21-SRN 2-UBN 1-B-7-2
UPIA 3	2013	IRRI	L		IR 74371-54-1-1
Ofada	Unknown	Unknown	U	• Aroma	Unknown

Source: F = Fagade et al. (1988); K = Kamara et al. (2011); MF = Maji and Fagade (2002) for origins; S = Singh et al. (2000); W = Wopereis (2012); years of release: Chaudhary et al. (1998, Table 3), for UPIA varieties, IRRI (2014).

Note: [a] Origin: IAR&T = Institute for Agricultural Research and Training; IRRI = International Rice Research Institute; IITA = International Institute of Tropical Agriculture; NCRI = National Cereal Research Institute; WARDA = African Rice Center (formerly West Africa Rice Development Association). [b] Ecology: DW = deep water; I = irrigated; IS = irrigated swamp; L = rainfed lowland; SS = shallow swamp; U = upland rice research needs for irrigated ecology.

WARDA's NERICA varieties show some promise in this regard. However, most NERICA varieties have so far been developed for upland ecology. Breeding of lowland NERICA varieties has been able to use only a few African varieties, such as TOG 5681—selected possibly because of its tolerance to rice yellow mottle virus and African rice gall midge (Rodenburg et al. 2009, 412).[7] Although lowland NERICA is promising, more research capacity is needed to speed up the breeding and crossing of other types.

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[7] The varieties seem to be selected by the WARDA Varietal Nomination Committee (Ndjiondjop et al. 2008). There are currently 60 cultivars developed, among which 57 use IR 64 and TOG 5681. TOG 5681 is a Nigerian variety with low yield potential due to grain shattering and susceptibility to lodging (Jones 1997 et al.) but has long panicle length, high weed-competitiveness ability as a result of early vigor and high tiller number, resistance to rice yellow mottle virus (Ndjiondjop et al. 1999), and resistance to nematodes Heterodara sacchari (Lorieux et al. 2000).

Rice Research Needs for Upland Ecology

Within the rainfed environment, breeding for upland rice has been relatively more extensive for than lowland rice in Nigeria. Since the mid-1980s, more improved varieties seem to have been released for upland ecologies than for rainfed lowland (Table 3.9). Most of the improved upland varieties have been released by IITA and WARDA, although some varieties have been bred by NCRI (such as FARO 40).

Table 3.9 NARS contributions of released varieties in Nigeria by ecology

Ecology	Pre–1970s	1971–1980	1981–1990	1991–1999	2000–2012	Total
Irrigated	0	2	6	4	1	
NARS	0	0	6	0	0	6
Upland	2	1	3	4	7	
NARS	1	1	1	0	0	3
Rainfed lowland	10	10	9	0	6	
NARS	0	4	3	0	0	7

Source: Author's based on Table 3.8.
Note: NARS = National Agricultural Research System.

For the upland ecology, the challenge in developing high-yielding varieties that can adapt to the production environment in Africa has been increasingly tackled by the development of NERICA varieties. NERICA was specifically bred by WARDA (Tiamiyu et al. 2009). WARDA was initially focused on screening and did not start the development of first-generation modern varieties until the 1980s, when WARDA moved to Bouaké, Côte d'Ivoire (Evenson 2003). Development of NERICA initially focused on the upland ecology for several reasons. First, there seemed to have been environmental concern about the sustainability of upland rice production, and there was a need to develop relatively low-input production systems in the upland. NERICA also seemed mainly interested in raising rice productivity in less-favored areas such as the upland in West Africa (von Braun and Bos 2005). In addition, IRRI had transferred relatively few upland varieties compared with lowland varieties (Evenson 2003), and WARDA and IITA might have seen a greater need for developing modern varieties for the upland.

Raising yield for upland rice, however, has been difficult outside Nigeria. Even in Brazil and Indonesia, where the national average yield has risen to 5 tons per ha, upland rice yield had remained below 2 tons until recently (Bierlen, Wailes, and Crammer 1997, Figure 3; Jatileksono 1998, Table 2), even though the Brazilian Enterprise for Agricultural Research has contributed greatly to upland rice research since the 1970s (Pardey et al. 2006). R&D in upland rice can bring benefits to marginal environments, as many of the NERICA varieties were initially intended to do in Nigeria. However, for raising domestic rice production, its potential may not be as great as in rainfed lowland and irrigated ecologies. Therefore, substantial focus needs to be placed on how to raise yield and production intensity of currently irrigated ecology, and how to turn rainfed lowland into irrigated ecology.

Importance of National Research—Soil Diversity as an Example

Enhancing national research capacity is also important given that the production environment such as soil is very diverse in Nigeria. Based on the author's calculations using data from FAO/IIASA/ISRIC/JRC (2012), Nigeria has 178 types of soil according to the FAO soil classification system. Purely based on this criterion, there are only nine countries around the world with more soil types than Nigeria, all of which have much larger land area (Table 3.10). In addition, soil diversity is higher in Nigeria than in many Asian and Latin American countries with significant land area. Nigeria has 1.93 types of soil per 1 million ha of area (Table 3.11). Figures are much lower for many Asian and Latin American countries, indicating that soils in these regions are much less diverse. In environments with higher soil uniformity, transferring successful varieties from one location to another is more promising and multiplication is easier. Unfortunately, this strategy may be less promising for many West African countries, including Nigeria, further indicating that development of improved varieties should be led by a stronger national research system with sufficient decentralization within the country, for which NARS may have more comparative advantage than international agricultural research centers.

Table 3.10 Countries with many soil types

Country	Total area (in million hectare)	Number of soil types based on FAO soil classification
United States	983	380
Canada	998	329
Russia	1,710	321
Australia	774	281
Kazakhstan	272	198
India	329	196
Brazil	851	194
Nigeria	92	178
China	960	171
Mexico	196	167

Source: Author's calculations based on FAO et al. (2012) and FAOSTAT (FAO 2013).
Note: FAO = Food and Agriculture Organization of the United Nations.

Table 3.11 Level of soil diversity by country

Country	Number of soil types per 1 million hectare of land (FAO soil classification)
Nigeria	1.93
Ghana	3.19
Côte d'Ivoire	2.36
Bangladesh	1.74
China	0.18
India	0.60
Indonesia	0.54
Philippines	0.50
Thailand	0.45
Vietnam	0.79
Brazil	0.23
Colombia	0.61
Japan	0.82

Source: Author's calculations based on FAO et al. (2012) and FAOSTAT (FAO 2013).Note: FAO = Food and Agriculture Organization of the United Nations.

Overall, historical patterns and Nigeria's dominant rice ecologies indicate that domestic R&D is crucial in raising the availability of good rice varieties for farmers. While donors continue to play important roles, as they pledged in the Paris Declaration of Support (OECD 2009), and can help in building the capacity of national agricultural research, domestic governments' commitment to funding is necessary in the long run (Pingali 2010).

4. SIMPLE ILLUSTRATIVE ANALYSIS USING HOUSEHOLD MODEL SIMULATION

Variety development may significantly affect the impact of seed-related policies. Here, we provide some illustrative analyses to assess such effects. We use a household model simulation approach. In rice farming in Nigeria, seed typically accounts for a small share of total production costs. Demand for seeds of particular varieties are therefore affected by not only seed price but also how the varieties respond to other inputs like fertilizer, irrigation, and labor costs. The demand is also affected by how other potential varieties and crops perform in a given production environment. Last, demand for seeds also depends on off-farm income-earning activities. Demand for seeds, as well as effects of seed-related policies, therefore must be assessed as part of farmers' integrated decisionmaking on economic and production activities.

These interactions are important factors, particularly in countries like Nigeria. There, a number of crops are grown on the same farm even in a favorable environment with irrigation. Elsewhere, crop specialization can often be more profitable in such environments. Information about such interactions, however, is lacking in Nigeria. At the same time, assessing demand for seed and seed profitability has been difficult using survey data in Nigeria due to various constraints. For example, existing surveys in Nigeria often do not capture detailed attributes of seeds and varieties (fertilizer response, pest resistance, maturity length, milling quality, and so on), farmers' valuations of these attributes, seed recycling behaviors (how many years farmers have been recycling seeds), and purity of seeds used. Varieties are often not distinguished in the survey, with many improved varieties grouped together as a single improved variety. Assessing the effect of attribute changes on farmers' production behaviors is therefore difficult.

Unlike many other inputs, usually farmers have access to several different varieties of seeds, but many of them are not used and thus unobserved. Such access to diverse varieties can create unobserved heterogeneity. Some econometric methods, such as panel data methods, can be used to control for them (if they are time invariant), but it is still difficult to estimate the effect of introduction of new varieties with unique attributes.

Various seed-sector policy issues have been discussed, ranging from seed subsidy to seed multiplication, diffusion, or quality regulation. Little is known about the impacts of these policies, particularly how they depend on the varieties themselves that are provided. Because the production environment is diverse in countries like Nigeria, it must start with the ex ante analysis of various hypothetical production environments to see under what conditions (production environments) seed policies have significant effects.

We specifically focus on rice seeds, for which the public sector's role tends to be more important than seeds of other crops, which are more likely to be provided by the private sector. This study intends to incorporate two aspects into standard seed demand analysis. First, we try to approximate the effects of various seed-related policies as well as variety attributes in measurable units and incorporate them into the household model. We provide some discussions on how such approximations can make sense. Second, we focus our analyses on favorable environments, where private irrigation is possible and farmers have various options for crop mixture both spatially and temporally. We focus in this way because new varieties, and associated seed policies for rice, are likely to have a greater effect in this type of environment. We also assess how the interrelationship between crops and off-farm income-earning activities would affect the impact of seed policies and new varieties on farmers' income. We use an example of lowland rice, given the current low adoptions of improved varieties in this ecology compared with the upland environment, as mentioned above.

Household Model

Using a simple household model, we characterize the decisionmaking mechanism of a rice-growing farm household maximizing its net profit (modified from Alwang, Siegel, and Jorgensen 1996, and Takeshima, Nin Pratt, and Diao 2013). Specifically, the basic structure of the model is described as

$$\max_{H_{ot},H_{rMt},A_{rM},L_{rMt}} \quad V = \Sigma_t V_t \cdot \delta^{t};$$

$$V_t = \Sigma_r\, p_r\, (Y_{rt} \cdot \theta_r - \psi_{rt}) + w_o \cdot H_{ot} - \Sigma_M\, [\Sigma_r\, A_{rM}\, (w \cdot L_{rMt} + C_{rt} \cdot D_r + \mu \cdot M)], \quad (1)$$

subject to

$$Y_{rt} = y_r \cdot \Sigma_M A_{rM} \text{ if } t = \text{harvesting month for } r\text{; otherwise } Y_{rt} = 0 \;\forall\; r, \quad (2)$$

$$y_r = f_r\, (\Sigma_t\, L_{rMt}^{*}, \mathit{nutrient}) \;\forall\; r \text{ (yield function)}, \quad (3)$$

$$H_{rMt} + L_{rMt} = L_{rMt}^{*} \;\forall\; r, M, t$$

$$\text{(labor requirement per ha for each crop and month, under regime } M\text{)}, \quad (4)$$

$$\Sigma_r\, H_{rMt} + H_{ot} \le H^{*} \;\forall\; M, t \text{ (household labor constraint)}, \quad (5)$$

$$Y_{rt} \ge \psi_r \cdot 12 \text{ (subsistence constraints)}, \quad (6)$$

$$\omega_t + p_r s_{rt} = \omega_{t-1} + p_r s_{r,t-1} + \Pi_{t-1} - X \ge 0, \forall\; t \text{ (liquidity constraints)}, \quad (7)$$

$$s_{rt} = s_{r,t-1} - \psi_r + Y_r \ge 0, \forall\; r, t \text{ (crop stock balance)}, \quad (8)$$

$$\omega_{12} \ge \omega_0,\; s_{r12} \ge s_{r0}, \text{ and} \quad (9)$$

$$H_{ot}, H_{rMt}, A_{rM}, L_{rMt} \ge 0 \;\forall\; r, M, t. \quad (10)$$

The household maximizes its annual net profit V, which is the sum of discounted monthly net profits V_t. V_t is determined by crop sales revenue (p_r times output in month Y_{rt} net subsistence consumption ψ_{rt}); income earned from hiring out (hiring-out wage w_o times hours worked by household members H_{ot}); and production costs that depend on area cultivated for crop r (A_{rM}), labor cost per area (wage w times labor use L_{rMt}), mechanization services cost μ, and other production costs per area C_{rt}. For plot areas receiving mechanization services, $M = 1$, and 0 otherwise.

Output Y_{rt} is harvested only in one harvesting month that is specific to crop r. Therefore $Y_{rt} = 0$ for all the other t. Y_{rt} is determined by yield (y_r) and A_{rM} (equation [2]). y_r is determined by use of labor and fertilizer, through function f that varies for r (equation [3]). Labor requirement L_{rMt}^{*} depends on regime M, which needs to be met by household member (H_{rMt}) and hired labor (L_{rMt}) in each month (equation [4]). The sum of family member labor for farming and off-farm income-earning activities (H_{ot}) cannot exceed household member time endowments H^* (equation [5]). For subsistence reasons, the household must produce maize and sorghum that can meet the annual supply for subsistence consumption (monthly subsistence consumption ψ_r *12) (equation [6]). The household also faces liquidity constraints (equation [7]). The sum of liquid assets in t (ω_t) and the value of food stocks (maize and sorghum), which is the price p_r times quantity s_{rt}, equals their sum from t–1 plus any net income from t–1 (Π_{t-1}) net monthly household expenditure X, and must not be negative. Equation (8) constrains the monthly stock balance for maize and sorghum. For sustainability, ending-period liquid assets and stocks of maize and sorghum must be no less than their beginning-period counterparts (equation [9]). Last, equation (10) states the nonnegativity of certain variables. For simplicity, seeding rates are fixed for each crop because information is limited in the literature on yield response to seed use.

Approximating the Effect of Seed Policies and Varietal Attributes of Rice Seeds

Seed is an input with complicated characteristics that can affect the model setup. We make various assumptions in order to approximate these characteristics and incorporate them into the calibration. Seed is rich in attributes, including yield potential, maturity length, and cooking quality, as well as recyclability. Information regarding these premiums is relatively scarce. Some attributes convey only small benefits to farmers and can be approximated.

Risks and Uncertainty

Yields can vary considerably for certain varieties, and farmers in developing countries are often risk averse. In addition, in countries like Nigeria, where the informal seed sector is still active and law enforcement is still weak, seed qualities (such as purity and certification) are sources of further yield uncertainties as well. These types of risks and uncertainties associated with newly introduced varieties have often discouraged farmers from adopting them, even when the expected benefits of these varieties are superior to those of the existing varieties. Literature is still scarce, however, regarding how much these risks matter for farmers' selection of varieties and crops. In our household model, these risks may be relatively small, because we focus on a favorable production environment where irrigation is possible (though still costly). Farmers, however, may still be averse to these risks.

Due to the shortage of empirical information in Nigeria, we express the effects of these risks as the percent reduction in yield for variety *r*, denoted θ_r. Farmers choose between varieties or crops based on not only the expected yield but also θ_r. In our modeling, θ_r captures the yield risks and quality uncertainty as well as farmers' aversions to them. We assume θ_r to be 20 percent for improved rice as well as nonstaple crops like vegetables and sugarcane, and 5 percent for traditional rice varieties as well as traditional staple crops like maize, sorghum, and cowpeas. These percentages are based on the assumption that traditional varieties or staple crops are often resistant to various stresses like drought, pests, and diseases. Their seeds are also often traded informally, with social relations and reciprocity often incentivizing sellers to maintain certain seed qualities. No such discounts are applied to off-farm income-earning activities, which are likely to be less risky than farming.

Maturity Length

In our model, the effect of shorter maturity length, and the consequent freeing up of resources (plots, labor) for other activities, is captured by shortening the duration between land preparation and harvesting months.

Attributes Captured by the Price Premium

Attributes including taste, milling quality, and seed storability are captured by their indirect effects on the output price. For example, prices are higher for particular varieties if consumers in the area prefer their taste and are willing to pay a premium. For crops like rice, due to high multiplication rates, premiums measured in output price are expected to be relatively small. For example, Horna, Smale, and von Oppen (2007) estimated that farmers' additional willingness to pay (WTP) for varieties with larger grain size is \$0.26 per kg of seed. This is in the range of 50 percent of certain seed prices around the time their study was conducted. Rice has a typical multiplication rate of 50, and seed price is approximately 50 percent higher than grain price. So a 50 percent premium for seed price is approximately equivalent to a 1.5 percent premium for grain price (= 0.5 * 1.5/50).

Seeds, particularly of rice, are recyclable for up to several years with minimal loss of attributes. We can approximate such benefits in the model as a premium for output price. Suppose a farmer targets producing X kg of rice every year. With rice seed multiplication rate m, seed storage loss factor λ, loss of attributes (yield loss) α, and the yearly discount factor, in year 0, the farmer saves εX kg of grains for seed for the next season, and forgoes selling it at price p per kg. From the second year on, every year, the farmer has to save $\varepsilon(t)$ kg, and thus lose $p\varepsilon(t)X$. However, the farmer saves \$$wX/m$ by not buying new seed, which would cost \$$w$ per kg. The discounted net benefit of recycling seeds every year is

$$-p\varepsilon X + \sum_{t=2}^{T} \left(w\frac{X}{m} - p\varepsilon(t)X \right) \cdot \delta^{t-1}, \tag{11}$$

where

$$\varepsilon(t) = \frac{1}{m \cdot \lambda \cdot \alpha^t} \tag{12}$$

is the amount of seeds that need to be saved for producing 1 kg of rice in the next season.

We can obtain very rough approximations of this benefit measured in terms of yearly premium on output price:

$$\frac{-p\varepsilon + \sum_{t=2}^{T}\left(\frac{w}{m} - p\varepsilon(t)\right)\cdot\delta^{t-1}}{Tp}. \tag{13}$$

Based on these formulas, given the realistic figures of $m = 50$, $\lambda = 0.9$, $\alpha = 0.8$, $\delta = 0.9$, $p = 0.5$, and $w = 1$, the calculated price premium on p is typically in the magnitude of 1 percent. The premium may be relatively low primarily because seed price w is generally low for rice in Nigeria. This is of course a gross simplification of the actual benefits from recyclability of seed, which needs to be improved in the future studies.

Case without Diffusion Effects

In our model, the seed subsidy is simply reflected as a reduction in seed price. Due to the scarcity of empirical evidence, we assume that the seeding rates per ha remain fixed regardless of the change in seed prices. The subsidy for varieties already grown by farmers will reduce the price of these seeds, as well as output prices, because some grains are also bought as seeds in the market. For most farmers, except certified seed growers, the extent of output prices depends on the change in the aforementioned premium from its recyclability and on the reduced demand for grains as seeds. Given the high multiplication rates for crops like rice, demand for grains as seeds is small relative to demand as food. Reduction in output price is therefore expected to be only a fraction of the reduction in seed price effected by the subsidy. Due to the limited information, we exclude this effect on output price from our model.

Case with Diffusion Effects

There are cases wherein subsidized seeds of new varieties are provided. In such a case, farmers benefit not only from the subsidy but also from the reduced cost of discovering new varieties. Currently, the Nigerian government's seed subsidy under the Growth Enhancement Support Scheme has potentially both seed price reduction and diffusion effects. Seeds of varieties like FARO 44 are provided for free with a quota. While some varieties like FARO 44 are relatively well known to farmers, there may still be areas where these varieties are not known. In such a case, the benefit is how much farmers would have had to spend to discover these new varieties. In one way, the diffusion rate can be low in West Africa, so that low adoption of varieties is partly due to farmers' lack of awareness of them (Diagne 2006). On the other hand, farmers in Nigeria and Benin may be generally willing to pay only \$0.15 (about 20–30 Nigerian naira) to learn about new seeds (Horna, Smale, and von Oppen 2007). This is also consistent with the observation that in Nigeria few private seed companies invest in advertising their seeds (Bentley et al. 2011). In Oyo state, farmers on average are willing to spend only \$3 or so for extension service (Ajayi 2006).

The WTP of \$0.15 found by Horna, Smale, and von Oppen (2007) can be interpreted to mean that farmers pay less for varieties unknown to them, by \$0.15 per quantity of seed, or 0.2 cents per kg for 75 kg of seeds. Assuming a rice seed price of \$1 per kg, the aforementioned WTP is about 0.5 percent of the seed price. Diffusion effects among samples used in Horna, Smale, and von Oppen (2007) are expected to be quite small. The aforementioned studies, however, show the WTP for only certain media of information. Farmers may still invest their time or other resources into other personal sources trying to discover the new varieties that are available. The empirical information is scarce regarding how much farmers would have to spend to discover new varieties. We therefore assess two cases: one without such cost, and the other with $50 worth of benefits. The figure of $50 is taken rather arbitrarily, except that it is typically how much farmers spend on seed itself. More rigorous estimation of this cost should be conducted in future studies.

Other Components of the Model

The model also incorporates various assumptions regarding cropping seasonality, irrigation costs, seasonal labor requirements, yield responses to fertilizer, and labor uses. They reflect the key characteristics of environments in Nigeria where rice is grown, that is, technological levels determined by yield responses of varieties, constraints due to seasonal labor requirements, costs of using irrigation technologies, and competition with other crops. These factors are not central to our analysis, but they still influence how various seed policies affect farmers' behaviors and their incomes. They are also incorporated to avoid any unrealistic simulation results.

Assumptions used in the model are summarized in Figure 4.1 (cropping seasons), Table 4.1 (labor use seasonality), Table 4.2 (irrigation cost), and Table 4.3 (chemical costs). All are based on various literature supplemented by the author's fieldwork in Nigeria. Table 4.1 summarizes labor use seasonality for both manual and tractor-assisted land preparation, which affects a farm household's decision on whether to hire a tractor service.

Figure 4.1 Crop calendar used in the household model

Crops	Season		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice	Wet	IR						▨	▨	▨	▨	▨		
Rice	Dry	IR	▨	▨	▨	▨	▨							
Rice (traditional)	Wet	R						▨	▨	▨	▨	▨		
Maize	Wet	IR				▨	▨	▨	▨					
Maize	Wet	R					▨	▨	▨	▨	▨			
Sorghum	Wet	IR				▨	▨	▨	▨					
Sorghum	Wet	R						▨	▨	▨	▨	▨	▨	▨
Vegetables	Dry	IR								▨	▨	▨	▨	▨
Vegetables	Wet	IR						▨	▨	▨	▨			
Sugarcane		IR		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	

Source: Author's fieldwork in northern Nigeria, May and July 2013.
Note: IR = irrigated; R = rainfed. Production season for cowpeas is confirmed in Phillips (1977, 43).

Table 4.1 Standard labor use in cropping in North Central Nigeria

	Season		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice	Wet	IR						40 (5)	25	25	25	40		
Rice	Dry	IR	40 (5)	20	20	20	40							
Rice (traditional)	Wet	R						25 (5)	25	16	6	11		
Maize	Wet	R				25	25 (3)	16	17					
Maize	Wet	IR					22 (13)	31 (19)	27	5	39			
Sorghum	Wet	R				25	25 (3)	16	17					
Sorghum	Wet	IR						21 (3)	18	11	11	11	13	
Vegetables	Dry	IR	56								135 (57)	67	43	35
Vegetables	Wet	IR					135 (57)	68 (67)	43	35	56			
Sugarcane		IR	50	50	50	80	24	32	39	40	25 (0)	60	10	5 (0)

Source: Ngeleza et al. (2011) and author's fieldwork in northern Nigeria, May and July 2013. Vegetables: Labor use partly modified from Nwalieji and Ajayi (2009) for Anambra state, and production stages are from Adeniran et al. (2010) for Niger state. The changes in labor requirements from manual to mechanized land preparation are assessed from fieldwork and information on Guinea savannah zone by Ngeleza et al. (2011).

Note: IR = irrigated; R = rainfed. Numbers in parentheses are labor use when tilling or harrowing is done by tractor.

Table 4.2 Irrigation cost (fuel, US dollars per hectare), pump-based irrigation system (including labor)

Crop	Season		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice	Wet	IR						5	100	100	100	100		
Rice	Dry	IR	200	200	200	200								
Rice (traditional)	Wet	R												
Maize	Wet	R												
Maize	Wet	IR				25	25	25	25					
Sorghum	Wet	R												
Sorghum	Wet	IR				10	10	10	10					
Vegetables	Wet	IR						82	67	67	67			
Vegetables	Dry	IR	133									163	133	133
Sugarcane		IR	200	200	200							100	200	200

Source: Author's fieldwork in northern Nigeria, May and July 2013.

Note: IR = irrigated; R = rainfed. Some of these figures are also relatively consistent with the difference in water requirements reported in Adeniran et al. (2010) and Bello (1987), and typical pump capacities to lift water reported by Awulachew, Lemperiere, and Tulu (2004).

Table 4.3 Agricultural chemical cost per month (US dollars per hectare)

Crop	Season		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice	Wet	IR						40	40	40	40	40		
Rice	Dry	IR	10	10	10	10	10							
Rice (traditional)	Wet	R						40	40	40	40	40		
Maize	Wet	R												
Maize	Wet	IR				5	5	5						
Sorghum	Wet	R												
Sorghum	Wet	IR				5	5	5						
Vegetables	Wet	IR						50	50	50	50			
Vegetables	Dry	IR	20									20	20	20
Sugarcane		IR						17	17					

Source: Author's fieldwork in northern Nigeria, May and July 2013.

Note: IR = irrigated; R = rainfed.

Nitrogen response functions are assumed to be determined by

$$Y = Y_{max} - \exp\left(-\frac{N}{\sigma}\right) \cdot \frac{Y_{max} - Y_{min}}{\exp(0)}, \tag{14}$$

where the yield, Y, depends on maximum possible yield (Y_{max}), minimum yield (Y_{min}), amount of nitrogen per ha (N), and some positive scalars (σ). This yield response function, though arbitrary, has attractive features; it is bounded by maximum and minimum yields attainable, which are relatively reliably inferred from farmers. It also exhibits decreasing returns to scale in nitrogen use but a marginal change in yield that remains positive, which facilitates the computation of optimal nitrogen uses. The smaller the σ, the faster the marginal returns from nitrogen diminish. Newer improved varieties with greater fertilizer responses therefore tend to exhibit greater σ. In our model, we assume these parameters for each crop and production environment, based on the literature and the author's fieldwork in Nigeria (Table 4.4).

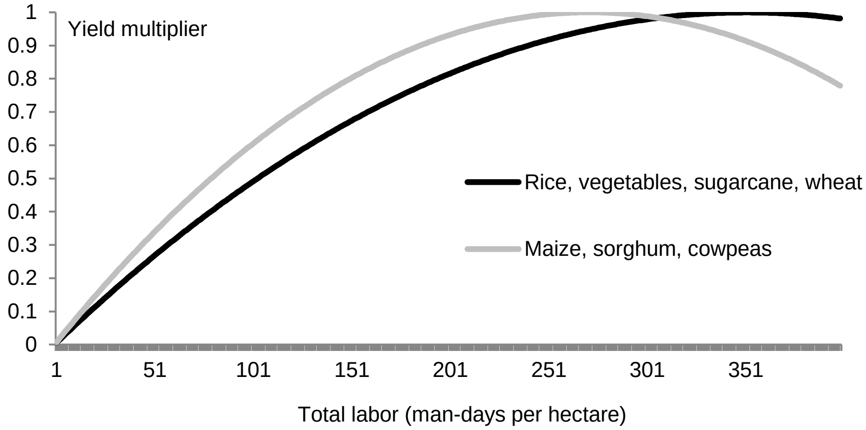
Table 4.4 Assumed crop-specific nitrogen response functions

Crop	Y_{max}	Y_{min}	Scalar (θ)
Rice—rainy season irrigated	3.5	2.0	35
Rice—dry season irrigated	4.0	2.0	40
Rice—improved rainfed	3.0	1.5	20
Rice (traditional)	2.0	1.0	10
Maize	2.5	0.5	30
Maize—irrigated	3.0	1.0	40
Sorghum	1.5	1.0	30
Sorghum—irrigated	1.5	1.0	30
Vegetables—rainy season	4.0	0.1	50
Vegetables—dry season	6.0	0.1	50
Sugarcane	25.0	0.1	50

Source: Author's fieldwork. We also adjusted the figures, incorporating various studies in Nigeria and West Africa, including Bello et al. (2012) for maize; Buah and Mwinkaara (2009) for sorghum; Adekalu and Okunade (2008) and Abayomi et al. (2008) for cowpeas; Ayodele, Oladapo, and Omotoso (2007) and Adekiya and Agbede (2011) for tomatoes; and Phillips (1977) for general agronomic practices in Nigeria.

In developing countries like Nigeria, production still relies much on manual labor. Achieving yields close to the maximum depends on labor inputs. Empirical information for yield responses to labor use is, however, scarce in Africa. Here we apply multipliers for yield that take the maximum value of 1 at optimal labor use. Figure 4.2 illustrates these multipliers calculated based on the regression results of von Braun, Puetz, and Webb (1989, 50) in Gambia for rice and sorghum. Due to the lack of information, we assign the rice function to labor-intensive crops like vegetables, sugarcane, and wheat, and the sorghum function to maize and cowpeas. We assume that farmers change the overall labor use to maximize profit based on Figure 4.2, while maintaining the monthly variations in labor uses (Table 4.1) at the same proportions.

Figure 4.2 Labor response of production



Source: von Braun, Puetz, and Webb (1989, 50) in Gambia for rice, sorghum.
Note: Labor use for vegetables, sugarcane and wheat are approximated assumed equal to labor use for rice, while labor use for maize and cowpeas are assumed equal to labor use for sorghum.

Prices of crops and seeds, and seeding rates are shown in Table 4.5. They are mostly based on the author's fieldwork in 2013 because information was quite scarce in the literature for Nigeria. Since seeding rates were found to be rather stable across households, we assume that the same seeding rates are used regardless of the use intensity of other inputs and technologies.

Table 4.5 Prices of crops and seeds

Crop	Farmgate price (US dollars/kilogram)	Seed price (US dollars /kilogram)	Seeding rate (kilogram /hectare)
Rice	0.4	0.5	75
Rice (traditional)	0.4	0.2	75
Maize	0.25	0.35	50
Sorghum	0.2	0.3	50
Vegetables (peppers)	0.7	9.0	7
Sugarcane	0.4	1.0	400

Source: Author's fieldwork in northern Nigeria, May and July 2013.

Other parameters calibrated to reflect the household are presented in Table 4.6. These parameters reflect a typical smallholder farm household with some access to a private irrigation facility in the North Central zone of Nigeria, who faces family labor constraints and rising hiring-in labor wages, is liquidity constrained, faces high monthly interest rates, and must meet subsistence consumption needs of maize and sorghum. Values of parameters are assessed from the various sources, including similar household models (Takeshima, Nin Pratt, and Diao 2013) based on Living Standards Measurement Study data (World Bank 2013) collected by the World Bank and the National Bureau of Statistics in Nigeria, and the author's fieldwork in Nasarawa state.

Table 4.6 Other characteristics of households

Parameter / constraint	Value
Maximum farm size (ha) that can be cultivated simultaneously	5
Number of working days per month	25
Adult family labor available (days per month)	50
Hiring-out wage rate (dollars per day)	3
Temporary labor (hiring-in) wage (dollars per day)	6.7
Liquid assets in January (US dollars for the household)	1,000
Mechanization service cost (US dollars per ha)	200
Monthly household expenditure (US dollars)	100
Cost of fertilizer per ton (US dollars)	670
Interest rate (discount factor) per month	3%
Subsistence consumption (per month)	Maize—50 kg Sorghum—50 kg
Beginning-of-the-year stock of maize and sorghum	Maize—1 metric ton Sorghum—1 metric ton

Source: Author's fieldwork in North Central Nigeria during summer 2013 as well as Takeshima, Nin Pratt, and Diao (2013).

The dependence on manual labor often leads to decreasing returns to scale in production, particularly in terms of cultivated area. Field observations indicate that such patterns are especially evident for certain crops like vegetables and sugarcane. Due to the lack of empirical information, we simply assume that vegetables and sugarcane will not be cultivated on more than 0.5 ha, while other crops can be cultivated on up to 2 ha each.

Our simulation is constructed using January as the beginning month. The fact that some crops are planted later in the year and harvested early in the year may seem to make the simulation complicated because within the simulation period, the planting decision is made after the harvesting decision. This is, however, fine because we are simulating the equilibrium condition, not only one season's decision. To attain this, we equate the beginning stock of food with the ending-period stock of food.

Scenarios

We simulate (1) the seed subsidy for rice, (2) varietal improvement (a 10 percent yield increase given the same fertilizer level, and a reduced maturity length from 4 months to 3 months), and combinations of (1) and (2).

The seed subsidy for rice is assumed to be 100 percent, which represents the case for certain varieties like FARO 44 that are distributed for free by the government under the ATA. A yield increase of 10 percent is modeled by multiplying the upper and lower limits by 10 percent. This type of yield increase is also likely to raise the optimal fertilizer level and is consistent with the conventional varietal improvement achieved during the Green Revolution. The main benefits of early-maturing varieties may be the reduced production costs per output. We model early-maturing varieties by assuming that they save on labor and land requirements for the fourth month. Similar assumptions were made by White, Labarta, and Leguía (2005), who showed that early-maturing varieties can reduce interperiod weeding requirements. Due to the lack of further information, we assume that other production costs such as irrigation requirements, seeds, and chemicals are unchanged so that they are used more intensively during the shorter production period required for an early-maturing variety.

We combine the fertilizer subsidy currently being implemented under the ATA, whereby farm households are entitled to 100 kg of fertilizer at a 40 percent discount, with the potential impact of reduced mechanization costs for land preparation, whereby it is reduced from $200/ha to $100/ha. The fertilizer subsidy rates as well as mechanization costs may differ across locations depending on state governments' policies. Our purpose here is to gain rough insights into the relative magnitudes of seed-related policies as opposed to the changes in other relevant factors.

Simulation Results

Table 4.7 presents the main results, while Table 4.8 summarizes the impact of seed policies together with some other shocks for comparison. Here we present only the key results: type of rice production systems chosen, production performance, and total farm household incomes. Results here are also illustrative rather than definitive, focusing more on highlighting the interactions of key variety improvements and seed-policy impacts.

Table 4.7 Simulation results of key seed policy outcomes on North Central Nigeria lowland rice producers, mechanization cost US$200/ha

Scenario	Rice area by type (ha)	Rice yield by type (ha)	Fertilizer use for rice (kg/ha)	Total rice production (metric tons)	Total cultivated area including other crops (ha)	Labor income (US dollars)	Farm household income (US dollars)
Baseline	RFM—0.30	RFM—2.26	RFM—189	0.69	1.71	762	2,518
Subsidy with limited rice area	RFM –0.34	RFM—2.11	RFM—191	0.72	1.77	763	2,539
Subsidy (seed + fertilizer) with limited rice area	RFM –0.34	RFM—2.11	RFM—191	0.72	1.78	763	2,561
Reduced mechanization cost (to US$100) + subsidy (seed + fertilizer)	DM—0.48 RFM—0.50	DM—3.56 RFM –2.38	DM—356 RFM—200	2.90	2.38	485	2,633
Variety development (yield enhancing + 10%)	DM—0.43 RFM—0.50	DM—3.97 RFM –2.61	DM—372 RFM—207	3.03	2.33	478	2,574
Subsidy + variety development (max rice area = 0.5 ha)	DM—0.50 RFM—0.50	DM—3.81 RFM –2.61	DM—366 RFM—207	3.19	2.37	392	2,639
Subsidy (seed + fertilizer) + variety development (max rice area = 0.5 ha)	DM—0.46 RFM—0.50	DM—3.93 RFM –2.61	DM—370 RFM—207	3.11	2.39	470	2,663
Variety improvement + reduced mechanization cost (to US$100) + subsidy (seed + fertilizer)	DM—0.50 RM—0.10 RFM—0.50	DM—3.88 RM—3.26 RFM—2.66	DM—369 RM—296 RFM—209	3.60	2.52	454	2,774
Shortened maturity length	RFM—0.30	RFM—2.26	RFM—189	0.69	1.71	762	2,518
Shortened maturity length + seed subsidy	DM—0.37 RFM—0.34	DM—3.62 RFM –2.11	DM—334 RFM—191	2.07	2.12	561	2,556
Shortened maturity length + seed and fertilizer subsidy	DM—0.37 RFM—0.34	DM—3.62 RFM –2.11	DM—334 RFM—191	2.07	2.12	561	2,581

Source: Author’s simulation.

Note: RFM = rainfed, improved; DM = dry season irrigated; RM = rainy season irrigated; ha = hectare; kg = kilogram.

Table 4.8 Simulated impact of variety improvement, seed subsidy, and other factors on annual household income (North Central zone)

	Baseline	HYV	Reduced mechanization cost	HYV + reduced mechanization cost	Early-maturing variety
Baseline	US$2,518	+ 56 (start dry season rice irrigation)	+ 32	+ 159	0
Seed subsidy (100 kilogram, 100%)	+ 21	+ 65	+ 58 (start dry season rice irrigation)	+ 73	+ 38 (start dry season rice irrigation)
+ Fertilizer subsidy (100 kilogram, 40%)	+ 22	+ 24	+ 25	+ 24	+ 25

Source: Author's simulation.
Note: HYV = high-yielding variety.

The results here have important implications. First, varietal improvements (higher yield potential and shorter maturity length) have greater effects on rice production growth and farm household income than does a simple seed subsidy. In the particular example used here, effects of seed subsidies may be greater for varieties with higher yield potential. Under the baseline case with old improved varieties for the particular type of household at hand, a 100 percent seed subsidy for rice would increase annual household income (combining all farm and nonfarm activities) from $2,518 to $2,539 (an increase of $21), and would increase rice production from 0.69 tons to 0.72 tons, coming from a marginal increase in rainfed rice area. Providing newer varieties with a 10 percent higher yield, on the other hand, increases annual farm household income by $56. Moreover, it induces farmers to start dry-season rice irrigation and raise rice production from 0.69 tons to 3.03 tons, shifting much labor from off-farm income-earning activities to rice production. A 100 percent rice seed subsidy provided in such circumstances increases annual farm household income by $65, mostly through greater demand for seeds. As a comparison, these effects are similar to alternative types of shocks such as a $100/ha reduction in tractor land preparation cost, which is substantial. Similarly, compared with the old improved varieties with a four-month maturity length, newer varieties with a shorter maturity length of three months can increase the impact of the seed subsidy to $38. In addition, results here illustrate an example in which a seed subsidy can induce the use of irrigation if the seeds are for early-maturing varieties. These results are robust to changes in various ambiguous parameters, such as the risk perceptions discussed above.

5. KEY MESSAGES AND FUTURE DIRECTIONS

Seed policy is an integral part of food security improvement and poverty reduction, particularly in societies where agriculture plays an important role in that effort. Despite such importance, however, knowledge gaps still exist for what the key seed-policy issues are in Nigeria. In particular, little has been studied about how the varietal attributes such as yield response potentially affect the impact of seed policies.

International and historical perspectives point toward the importance of varietal development in rice seed policies. Improved rice varieties that can be currently promoted with seed subsidies in Nigeria must be of sufficient quality. Since many of them were developed outside Nigeria some time ago, their adaptability to local production conditions may be limited, and yield response to inputs (fertilizer, water) may be inferior to that of newer varieties adopted in Asia or Latin America. Historically, the Nigerian government seems to have invested less in rice research per arable land, per rice area, and per population than Asian and Latin American counterparts. At the same time, while NARS-bred varieties have become dominant in most of these countries, foreign varieties still dominate rice production in Nigeria. Average rice yields have stagnated at a low level for the past three decades in Nigeria. Such associations between stagnating rice yield, low national rice R&D, and heavy reliance on imported varieties indicate that it is time to reconsider the importance of national rice R&D if the Nigerian government wishes to raise rice self-sufficiency.

Although we did not examine this relationship, governments can also play an important role in improving the quality (such as purity) of seeds marketed. Improved seed quality in general reduces the risk that any given farmer will obtain poor-quality seeds in addition to reducing the transaction costs of obtaining pure seeds. The effects of improved seed-quality regulations, including quarantine practices, may be in one way captured by the risk premium that farmers would incur otherwise. The cost of certified seeds can also be reduced by increasing the capacity for certification. Calibrating such effects, however, can be challenging due to the shortage of empirical information in Nigeria. Limited evidence indicates that costs of certification can be relatively low compared with the production of foundation seeds. In mid-1980s India, the cost of producing certified maize seeds was $216/ton (in 1986 US dollars), out of which production and postharvest processing of foundation seed accounted for the majority, while the certification cost accounted for only $5/ton (Pray and Ramaswami 1991). Similar evidence must be gathered in Nigeria to better assess the bottlenecks in the current seed sector.

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