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VARIETAL DEVELOPMENT AND THE EFFECTIVENESS OF SEED SECTOR POLICIES: THE CASE OF RICE IN NIGERIA

By

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ABSTRACT

Seed is an essential input in agriculture, and the availability of quality seed of superior varieties is often critical for improved food security and poverty reduction in developing countries like Nigeria. However, while the Nigerian government recognizes the importance of improving seed availability, its recent focus in the seed sector has mostly been on improving seed quality rather than on varietal development. This report argues that this is partly due to a knowledge gap regarding the relationship between varietal technology levels and the effectiveness of seed sector policies. We first provide a brief conceptual discussion on how the effectiveness of selected seed sector policies, such as certification, subsidies, and private sector promotion, may depend on underlying varietal technology levels. Using rice as an example, we then provide key historical and international perspectives on how varietal technology development by the public sector through intensive rice breeding had preceded the expansion of seed certification and testing, and show that there still is a substantial need for the Nigerian government to develop improved rice varieties through intensified domestic plant breeding in order for its seed certification and seed subsidy programs to be more effective.

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1. BACKGROUND

The Nigerian government has been keen on supporting its agricultural sector through the increased supply of quality seed of staple crops. Under the Agricultural Transformation Agenda (ATA) promoted by the Jonathan administration (2010 to 2015), a substantial quantity of seed of selected varieties of staple crops, like rice and maize, was produced as "certified" seed and provided to farmers at subsidized prices (FMARD 2014). There, however, are concerns regarding the balance of various aspects of overall seed policies in Nigeria. One of the primary concerns is the lack of attention to and relative weakness in efforts to genetically improve the varieties (varietal technologies) of seed produced. In recent years, government appears to have assumed that seed varietal technologies in the country are good enough, since varieties with good genetic traits are already available. Rather, it appears that government views the problem with Nigerian seed systems to stem primarily from improved seed not being affordable for farmers. In consequence, there is low adoption of improved seed, the flow of improved seed to farmers is not effective, and the systems to regulate seed quality are not of much value, all of which results in lower agricultural productivity levels than would otherwise be the case.

For example, under the ATA, the Nigerian government allocated significant resources for the distribution of free certified rice seed. Although the exact extent of the amount distributed is not known, if 50 kg of certified rice seed valued at $50 at the market price is distributed for free to each of 100,000 rice producing farm households, accounting for approximately 5 percent of rice producing farm households in Nigeria, the cost of such a seed distribution alone amounts to $5 million. While the Nigerian government's effort in providing support to the agricultural sector is welcome, given that it in recent years has spent less than 10 percent of its total budget on the agricultural sector, support for local rice breeding activities has been considerably low, only a fraction of $5 million annually[1].

While the exact figures on government expenditure on rice breeding activity are not readily available, the spending was about $100,000 in 1998 (Dalton and Guei 2003), with the spending in 2014 likely to have been even lower (based on the personal communication with NCRI staff).

The purpose of this report is threefold. First, it provides a conceptual discussion on how the level of development of improved crop varieties can affect the effectiveness of interventions in the seed sector. Secondly, it provides some international and historical perspectives to show that significant technological improvement, including that of improved variety development, often preceded seed sector regulation in many countries. Finally, it discusses challenges associated with the development of improved rice varieties in Nigeria, including knowledge gaps. Based on these three lines of arguments, the report aims to provide some evidence on the importance of incorporating stronger support for domestic rice breeding into overall rice seed policies in Nigeria.

This report will be useful for the Nigerian government in its formulation of seed sector policies. Varietal development is regarded by government as an important part of its seed policy (FMARD 2014). By providing insights into the complementarity of varietal technology levels and seed sector policy effectiveness, as well as related historical and international perspectives, the content of this report can serve to guide policymakers in Nigeria as to how varietal development and regulatory policies should be balanced within seed policies.

There are several disclaimers to this report. First, this report is mostly based on observations of rice in Nigeria. The evidence presented may not be easily applied to other countries or to other crops in Nigeria. In sub-

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Saharan Africa, there have been relatively more successful stories on the development of improved varieties, particularly for maize in Eastern and Southern Africa (Byerlee and Heisey 1996). Investigation of how to overcome the factors constraining the development of the maize seed sector in Nigeria would requires a different study to that presented here. Secondly, this paper at times touches on the linkage between basic capacity to engage in the development of improved varieties and somewhat distant issues, such as genetic modification and biofortification. Such discussion should be seen as hypothetical, presented simply to raise issues that warrant future studies, rather than offering any judgments.

While the focus of this report is improved variety development, various other seed sector issues discussed in the literature remain important in the Nigerian setting. The complementarities between varietal development policies and other aspects of seed policy in Nigeria are substantial. A harmonized seed policy should be designed and implemented that incorporates priorities and strategies for the development of improved varieties within a comprehensive vision for an effective seed sector in Nigeria.

2. IMPORTANT RAMIFICATIONS OF THE LEVEL OF DEVELOPMENT OF IMPROVED CROP VARIETIES

This section provides a conceptual discussion on how the level of development of improved crop varieties may affect the effectiveness of various seed sector interventions. To facilitate discussion, the following assumptions are made:

• Substantially improved varieties often exhibit production functions that are more responsive to intensive input use.

• The presence of substantially improved varieties that are distinct from local varieties in genetic potential raises the returns to seed regulation and the dissemination of complementary knowledge, such as improved crop husbandry techniques.

Key underlying factors that often, though not always, accompany improvement in crop varieties is total factor productivity (TFP) growth that is Hicks-neutral, not affecting the balance of labor and capital in the crop production function. This is illustrated simply as:

$$y=\theta\cdot f(x)$$

where y is the output, f is a production function, x is the inputs, and θ is the scalar representing the TFP that is affected by varietal technology level.

The implications of such a technology are that, given the price of inputs, the demand for input use increases as θ rises. In turn, the equilibrium partial productivity with respect to inputs (for example, yield) also rises. If f remains unchanged as θ rises, the rise of θ increases farm profits as well. In addition, as we see later, an increase in θ also increases the returns to various services given the transactions costs.

This idea can be conceptualized in a simple way; suppose there are two equilibria, inefficient equilibrium (equilibrium 0) and efficient equilibrium (equilibrium 1). Each equilibrium leads to private profit (or income) $f1$ and $f0$, respectively, and $f1>f0$. The inefficient equilibrium (equilibrium 0) exists because a fixed transactions costs η needs to be incurred in moving from inefficient equilibrium to efficient equilibrium.

Efficient equilibrium is reached only if $f1-f0$ exceeds η. Moving to the efficient equilibrium is equivalent to overcoming constraints related to market and coordination failures.

The main message of this paper is that African governments and the development community may be focusing too much on reducing transactions costs, $\eta\eta$, instead of focusing on increasing $ff1$ (and thus $f1-f0$). During the Asian green revolution, technological improvement, including the development of improved crop varieties, significantly increased $f1-f0$, which exceeded η, and eventually led to the modernization of the agricultural sector.

3. SEED POLICY

There is generally little discussion in the literature on the interaction between the effectiveness of seed regulation policy and the level of varietal technologies. An important question is whether improvement in crop varieties make seed regulation policy more effective? A few insights can be obtained in the examples here.

3.1 Seed certification / quality control

Improvement in varietal technologies leads to larger differences in average quality between pure and mixed seeds and significant differences in resultant productivity and profit. Under normal circumstances, the higher level of varietal technologies and thus greater heterogeneity in existing seed qualities leads to greater returns from seed certification.

To see this, we focus on two hypothetical regimes – a low varietal technology development regime and a high varietal technology development regime. In each regime, there are two varieties, improved varieties with higher yield and local varieties with lower yields. Table 1 summarizes these two regimes. The illustration here is purely conceptual and may not always apply to the actual conditions on the ground in Nigeria. Nevertheless, it helps us to shed some light on how varietal technology levels may affect the effectiveness of various seed sector policies.

Second, the vector of effect on maize farming of climate change can be via the encouragement of maize disease. This in turn can affect the safety of food and feed for consumers. This is a concern because the types and distribution of pests and diseases are expected to be conditioned by changing climatic conditions (Jarvis et al. 2010). In a European study, Miraglia et al. (2009) found that a major food safety issue is the incidence of mycotoxins on various crops while on the field or during storage. The incidence of aflatoxin is high under conditions of wet spells and hot spells at harvest time (Paterson and Lima 2010). In a study to detect aflatoxin levels in maize storage systems in Nigeria, Udoh et al. (2000) found that 33% were contaminated. In general, one would expect that the probability of adoption of adaptive technologies (such as aflasafe and maize drying) is increasing under hot and humid weather conditions.

Table 1-Benefits relative to the cost of seed certification, given high and low varietal technology levels

	Low varietal technology	High varietal technology
Improved variety yield	2 ton / ha	4 ton / ha
Local (unimproved) variety yield	1 ton / ha	1 ton / ha
Pure improved variety yield)	2 ton / ha	4 ton / ha
Mixed seed yield (50 percent improved and 50 percent local seed)	1.5 ton / ha	2.5 ton / ha
Yield difference between pure and mixed seed	0.5 ton / ha	1.5 ton / ha

Benefit from seed certification (assuming the yield difference)	0.5	1.5
Cost of seed certification	η	η
Net benefit of seed certification	0.5 - η	1.5 - η

The above discussion of climate shocks is particularly relevant to Northern Nigeria. That region is the maize production basket. In the context of the poultry value chain, it caters to feed mills across the entire country. The sector is characterized by smallholders typically operating on farm sizes of less than two hectares (Liverpool-Tasie et al. 2016). In addition, there are distinct socio-economic differences between Northern and Southern Nigeria with the North being more rural and traditional with larger household sizes and exhibiting less education and higher poverty rates on average (Adjognon et al. 2016; Kuku-Shittu et al. 2015). Consequently, there is significant heterogeneity in production and socio-economic characteristics in the North and South.

An important message from Table 1 is that seed certification generates greater benefits in the high varietal technologies regime than in the low varietal technology regime, as seed certification costs do not differ between these two regimes. As a result, seed certification may be more effective in the high varietal technology regime than in low regime, with relative net benefits of 1.5 - η in the high regime compared to 0.5 - η in the low regime[2].

Emphasizing the importance of improved crop varieties does not mean that efforts to strengthen the seed certification system and seed testing facilities (Central Seed Testing Laboratory and the Zonal Seed Testing Laboratories) are less important. Rather, such efforts should be seen as complementary to the effort of improving crop varieties. The point is that the effectiveness of such seed certification and testing services really depends on the relative productivity performance of the improved crop varieties developed.

3.2 Intellectual property rights

Governments, including the Nigerian government, often are interested in strengthening the intellectual property rights associated with varietal technology development. Strengthening breeders' rights is an example. On this issue it is less clear how varietal technology levels affect the effectiveness of breeders' rights. The existing local capacity of breeding is likely to be an important consideration. Specifically, for breeders' rights to be effective, certain levels of local breeding capacity must al-ready be in place[3].

In an environment where the number of breeders is small and skills to develop superior crop varieties are low, the likelihood that intellectual property related to plant breeding will be stolen is limited. This is because any economic returns to stealing in such a context will likely be low, providing less incentive to do so. The low returns to stealing intellectual property in such a context stem from two main reasons. First, the pool of extractable knowledge (e.g., genes that are resistant to certain pests or weeds) is likely to be small because generally low intensities of breeding activities have prevented fast accumulation of such knowledge. Secondly,

[2] Certification costs can be substantial. In Indonesia in 1995, the actual cost of seed certification was calculated to be approximately Rp 33,000 per hectare as opposed to official seed certification fee of Rp 1500 per ha, around $77 per ha (2010 USD, PPP) in 1995, as opposed to the official fee of $3.5 per ha (Lillie and Budhiyono 1995 p158).
Nigeria distributed certified rice seeds from 30,000 ha for rice and 30,000 ha for maize in 2014 (NSAC 2014). Although the total budget disbursed for certification is not available, using the Indonesian figure, the costs of seed certification in Nigeria may be around USD 2 million for rice and for maize each.

[3] An important dimension with intellectual property rights, which we do not discuss here, is that it can negatively affect access to knowledge for seed sector development (e.g., Thomson 2015).

the application of stolen knowledge in the development of superior varieties may be hindered by insufficient infrastructure to effectively conduct plant breeding, such as lack of irrigation facilities, and by the slow accumulation of local knowledge which otherwise would have generated more complementarity with the stolen knowledge[4]. In such environments where it is difficult to engage in significant crop variety improvement, the effect of protecting the rights to whatever intellectual property is generated is likely to be quite limited.

Thus low breeding skills in the first place limit the effectiveness of breeders' rights. But what if strengthened breeders' rights actually induce private firms to master breeding skills? Again, this effect is unlikely to be substantial because of the unique nature of breeding activities[5]. For example, modern breeding is highly capital-intensive, requiring good infrastructure. The fixed costs associated with gaining knowledge on plant-breeding (biology, genetics, agronomy, etc.) are likely to be high, both in terms of theoretical knowledge obtained and experiences accumulated over time. Consequently, effectively building capacity for plant breeding is likely to exhibit increasing returns to scale. The point is that private investment into gaining such skills may be limited unless they are provided with required complementary capital. While offering special rights to breeders is intended to address a market failure that is uniquely inherent to entry into breeding activities, rights alone may not induce new firms to enter into breeding activities. Protecting breeder's rights may work more effectively for existing breeders, but, as noted, the effect may be limited if the number of breeders is small in the first place.

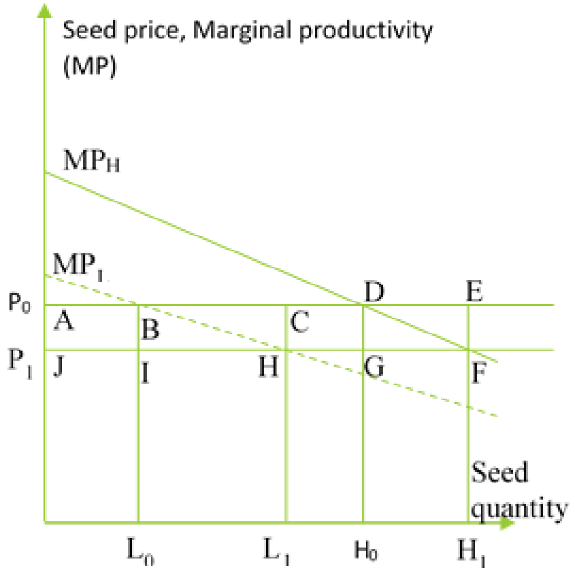
3.3 Seed subsidies

Varietal technology levels can have effects on the benefits and costs of seed subsidies, which often are combined with the provisions of seeds from the formal sector. Figure 1 provides a very simple illustrative example of how varietal technology levels (expressed in the marginal productivity curves) relate to the benefits of seed subsidies. Note that this illustration is purely to show relationships in terms of the marginal productivity curves of inputs. All other potential effects, such as relaxations of liquidity constraints, are ignored.

[4] Of course, if marginal knowledge accumulation speed is decreasing in the level of knowledge, knowledge accumulation speed at low initial knowledge level can be high. However, evidence for this is limited with respect to the knowledge produced through plant breeding.

[5] The number of breeders is fairly small all around the world. Though their numbers are still larger in many other countries than in Nigeria, the point here is that breeders may differ from many other jobs for which the entry of private firms or individuals is fairly easy.

Figure 1- Illustration of relationship between varietal technologies of seeds supplied from formal sector and benefits of seed subsidies.



Source: Authors.

A key condition here, based on the production function presented earlier, is that the slope of the marginal productivity curve is proportionally higher (by the ratio of $\theta\theta$) for improved crop varieties (MPH), rather than local, unimproved crop varieties (MPL). The former also has a steeper slope than the latter (by the ratio of θ). A key implication of this relationship is that if subsidies are provided as reduced prices on seeds (dropping the price from P0 to P1) without a quota, the benefits of subsidies are greater and the deadweight loss is smaller when varietal technology levels are higher, although subsidies may lead to a greater increase in the use of seeds.

In the case of the improved crop varieties (MPH), seed use increases from H0 to H1, which is smaller than the in-crease for the unimproved crop varieties (L0 to L1)[6]. However, the benefits for producers is ADFJ with improved crop varieties, greater than ABHJ with unimproved crop varieties. From the figure, it is clear that when the price discount is marginal, the benefit is close to the discount value times the original seed use (L0 or H0). While the total budget required for subsidies is greater with the seed of improved crop varieties (AEFJ), than with the seed of unimproved varieties (ACHJ), the deadweight loss with improved crop varieties (DEF) is smaller than BCH with unimproved varieties.

3.4 Other seed sector issues

Biofortification. Varietal technologies also affect the effectiveness of biofortification of food crops, which can potentially provide important micronutrients to consumers in developing countries like Nigeria. The availability of locally successful improved crop varieties is necessary for effective biofortification programs.

[6] While total seed demand for certain crops like rice tend to be relatively fixed (as optimal seeding rates per area are limited to certain ranges), quantities of seed from formal sector can change substantially by substituting seeds from informal sector.

Such programs may have limited impact on micro-nutrient consumption in a country if the country lacks basic capacity to breed high-yielding varieties which are adapted to local conditions and which can realize reasonable yields without requiring substantial increases in production costs for farmers. This is because the cost of supplying the micronutrients embedded in the crops still depends substantially on the costs of growing sufficient quantities of these crops.

Genetic modification. The success of genetically modified crops largely depends on whether appropriate genes can be identified, because without appropriate genes to insert into existing crop varieties, transgenic methods will offer producers no benefits. Oftentimes, identifying appropriate genes that can work in environments like Nigeria is difficult, because, for example, pests in Nigeria may be different from pests elsewhere. This has been found to be true even for specific pests. For example, brown hoppers, one of the common rice pests in Southeast Asia, had different biotypes between the Philippines and in Indonesia, so that the IR26 varieties that were resistant to brown hoppers in the Philippines did not work in Indonesia (Barker, Herdt, and Rose 1985, p. 64).

Insufficient knowledge on how best to use genetic modification to improve common staple crops in Nigeria is one of the primary constraints for the genetic modification of these crops. Crops, like cassava, which are not widely grown in countries where genetically modified crops have been most developed are not well researched. Thus, the knowledge of how to effectively create genetically modified improved cassava varieties, for example, is simply limited (Takeshima 2010). However, even for crops like rice or maize, which are widely grown in other parts of the world, the location specificity of suitable genes may constrain the development of successful genetically modified varieties for the Nigeria context. Moreover, it is difficult for transgenic methods to be applied to important staple food crops for Nigeria which are self-pollinating, like rice or sorghum.

Strategic seed reserves. Setting up emergency seed reserves, as pursued by the Nigerian government, may be more effective in contexts where the quality of varietal technologies for commonly grown crops is high because these higher yielding varieties may be more susceptible to natural disaster or climatic shocks, such as drought. In contrast, traditional varieties are likely to be more resistant to these shocks, and, moreover, often are saved by farmers themselves. Therefore, it may make more sense to set up emergency seed reserve when more high-yielding varieties are adopted by farmers.

Encouragement of private sector participation in foundation seed production. Nigeria has recently allowed private sector participation in foundation seed production. Experience around the world indicates that varietal technology levels initially raised by the public sector have proven to be an important inducement for subsequent private sector participation in national seed sectors. Examples of foundation seed companies are most widely documented for hybrid maize in the US, where foundation seed companies were "specialists in developing inbred lines that could be leased and used for the production of private-label hybrid seed. The foundation seed firms produced and tested inbred lines, and the production-sales firms produced, tested, and eventually sold hybrids made with those lines" (Duvick 2001a p.196). "Over time, 'foundation seed companies were formed expressly to breed inbred lines for lease to the small seed companies, thereby filling the role of the public-sector breeders." (Duvick 2001b). According to Duvick (1999), smaller seed companies depended on public inbred lines until about the 1970s and 1980s, when private foundation seed companies began to lease out their own privately developed inbreds, on a large scale.

The experience of foundation seed companies in US hybrid maize production suggests that the availability of superior varieties supplied by the public sector is still an important factor in encouraging the growth of foundation seed companies. For example, a significant majority of maize inbreds handled by foundation seed companies have been those developed by the public sector, including universities. As late as 1999, "among inbreds available from U.S. foundation seed companies in 1999, only 82 out of 381 inbreds (22 percent) had genetic backgrounds other than eight widely used inbreds: B14, B37, B73, B84, Mo17, C103, Oh43 and H99" (Lu and Bernardo 2001), which were all developed originally in public sector agricultural experiment stations in Iowa (B), Missouri (Mo), Connecticut (C), Ohio (Oh) and Indiana (H). It is likely that the availability of these varieties partly raised the returns for companies specializing in the production of foundation seed of these varieties or of hybrid varieties developed using these varieties. Such experiences again indicate that the presence of sufficient varietal technology of high quality is important in stimulating private sector participation in the seed sector.

4. INTERNATIONAL AND HISTORICAL PERSPECTIVES ON SEED CERTIFICATION AND TESTING

Historical and international perspectives provide useful insights into how current conditions in the seed sector in Nigeria may differ from those in other countries in the past. Here, we use the examples of experiences in seed certification and seed testing in other countries and corresponding yield levels. One of the key messages here is that yields of crops, like rice, in-creased substantially first before formal sector seed certification and seed testing activities expanded.

4.1 Seed certification

One of the Nigerian government's goals is to increase the use of certified rice seed with the aim of increasing yields. Current rice yields in Nigeria stand at around 2 mt/ha, considerably lower than in Asian or Latin American countries. Before 2012, the coverage of certified rice seed was low, at around 3 percent of the rice area of the country (Gyimah-Brempong, Johnson and Takeshima 2016). Such a low share of certified seed use is generally considered one of the primary reasons for low rice yields and overall production (Awotide et al. 2013).

While the expansion of use of certified seed is clearly important in the medium to long term, its effect may depend on varietal technology levels, as was discussed in the conceptual framework earlier. While records of the coverage of certified seed are generally difficult to obtain for other countries, there are indications from the evidence available that can still inform Nigeria. Table 2 summarizes the coverage of formal sector supplied certified rice seed in various developing countries in Asia and Latin America. It shows that many developing countries faced challenges in expanding the coverage of the formal seed sector produced certified seed until recently. Even in much of Asia well into the Green Revolution and after substantial rice yield growth had been achieved, coverage of certified rice seed still remained fairly low. In Bangladesh, Chile, India, Pakistan, Sri Lanka, and Thailand, shares of rice area planted to certified seed were less than 10 percent in the 1990s. Even in countries like Indonesia and Turkey, the rice area share under certified seed was around 25 percent in the mid-1990s, when rice yields had already reached more than 4 mt/ha. In Japan, yields had reached 3.5 mt/ha by 1920, long before certified seed production started. Only in Colombia had the area share planted to certified rice seed increased substantially by the mid-1980s[7].

It is important to note that some of the high rice yields achieved in these countries were due to significant irrigation use, so that the yield differences with Nigeria today may not be entirely due to the differences in

[7] FEDEARROZ, one of 18 seed enterprises then in Colombia, produced 60 percent of certified rice seed. The firm had five processing plants located in the main rice areas and 21 sections to distribute seed (Muñoz and Rosero 1988).

varietal technology levels. However, irrigated rice yields in Nigeria are around 3.5 mt/ha (Takeshima and Bakare 2016), and not considerably higher than the averages in other countries presented in Table 2. Therefore, differences in irrigation shares explain only part of the differences in yields. In addition, many countries in Table 2 achieved those yields at generally lower farm gate prices than those in Nigeria today, where farm gate prices have been considerably higher due mainly to high import tariffs and low yields (Gyimah-Brempong, Johnson and Takeshima 2016), despite considerable market margins between farm gate and retail prices (see Appendix A). Many of the countries listed in Table 2 achieved comparable or higher rice yields under relatively less favorable economic environments than is found in Nigeria today. This offers another indication that rice varietal technology levels in these countries were comparable or higher than Nigeria today.

4.2 Seed testing

The Nigerian government plans to establish seed testing laboratories at central, zonal, and state levels (FMARD 2014). This is likely to be an appropriate plan for the medium- to long- term, but it is unclear what is appropriate in the short-term given current varietal technology levels for rice in the country. Compared to the proper sequencing of seed certification in seed sector development, international experiences for seed testing are less clear (Table 3). Despite the lack of clear evidence that the expansion of seed testing capacities leads to significant yield growth, it remains important to continue investigating interactions between varietal technology levels and the contributions of seed testing to productivity growth and increased production.

Importantly, in developed countries, generally the demand for seed testing grew as the quantities and variations of seeds traded in the market grew[8]. In Japan, formal seed testing programs started after the passage of the 1947 seed law, which gave legal authority to the government to test seed in the market (Kobayashi 2005 p.19, p.22). Varietal technology levels had already been fairly high in Japan by this time, with rice yields reaching 4 mt/ha by then. Anecdotal evidence suggests that the start of the Japanese formal seed testing program had been partly induced by the presence of a large number of unknown varieties traded in the market (Kobayashi 2005), which is consistent with the view that as the quality of overall varietal technologies in the market increases, so too does the need to regulate them through testing.

Table 2- Rice yields and share of rice area planted with certified seed in selected countries historically

Country	Period	Rice yield (mt/ha)	Share of rice area planted with certified seed, %
Bangladesh [a]	**Around 2000**	**3.5**	**6**
Brazil	**1996/97**	**2.7**	**5**
Chile	**1993**	**4.5**	**4**
Colombia	**1978**	**4.3**	**47**
Colombia	**1985**	**4.7**	**77**

[8] In the Western world, seed testing often developed as a necessary reaction to unscrupulous practices prevalent in the nineteenth century (Justice 2012).

India	**1980**	**2.6**	**3**
India	**1999**	**3.0**	**10**
Indonesia	**Around 1995**	**4.3**	**24**
Japan (based on seed harvested area) [c]	**1919**	**3.5**	**≈ 2**
	1928	**3.5**	
	1931	**3.6**	
Pakistan	**Mid-90s**	**2.8**	**9** [b]
Philippines	**1970**	**1.7**	**2**
	1975	**1.7**	**8**
	1980	**2.2**	**8**
	1985	**2.6**	**7**
	1988	**2.6**	**15**
Sri Lanka	**1999**	**3.3**	**7**
Thailand	**1999**	**2.4**	**8**
Turkey	**Mid-90s**	**4.0**	**28**
Nigeria [d]	**2012-14**	**1.7 to 2.2** **Irrigated – 3.5**	**4 to 60**

Source: Author's compilation. Rice yields are from FAO (2015).

a) Figures are for all major crops, but rice accounts for about half.
b) The proportion of formal sector seed supply to total seed requirements.
c) For Japan, typical seeding rates for these periods were on the order of 50 kg/ha, based on figures from several western prefectures (Ogiyama 2015, Figure 5). The total area from which rice seed was harvested was around 1,000 ha in 1919, 5,000 ha in 1928, and 10,000 ha in 1931 (Tama 1986 Table 5). Assuming that yield of rice seed was the same as the rice yield during these periods, and using the total rice area of 3 million ha in these periods, the proportion of quantities of harvested seed and seed requirements are computed, e.g., (1,000 ha*3,500 kg/ha) / (50 kg/ha*3 million ha) for 1919.
d) Coverages for Nigeria in 2014 are calculated using the total quantity of certified rice seed supplied (90,000 tons) (NASC 2014), by assuming that 50kg of rice seeds are used per hectare and total rice planted area in 2014 was about 3 million ha in Nigeria (FAO 2015). With this calculation, certified rice seed must have covered 60 percent of total seed requirements (90,000 mt/ (3 million * 50 kg)).

In the US, seed testing gradually grew in the first part of 20th century (Justice 2012). By around 1923, 19 seed testing laboratories were in place, associated with state Departments of Agriculture (Stevens 1923). By 1937, at least 46 states had seed testing laboratories (Whitcomb 1937). Given the large cultivated area in the US, this laboratory network was still less dense than if seed testing labs were established in each of the 37 states of Nigeria. By 1940, yields of rice and maize in the US had reached 2.5 and 1.7 mt/ha, respectively, which is similar or slightly higher to yield levels in Nigeria today. This suggests that varietal technologies had risen in the US before a significant expansion of seed testing facilities occurred.

Table 3- Seed testing facilities in selected countries historically

Country or region	Reference year	Number	Sources
Argentina	1998	More than 100	Henson-Apollonio (2004).
Bangladesh	2012	Public - 28 (Seed Certification Agency: 2, BADC: 26) Private – 1	Jaim and Akter (2012)
Brazil - Rio Grande do Sul	1986 (?)	34 or more	Sfoggia et al. (1986)
Hungary	2008	7 (?)	Polgár (2008)
India	1961	In 1961, USAID began setting up a seed-testing laboratory in each Indian state	Goldsmith (1988)
	1970	Nearly all states in India had seed testing labs	Neergaard (1970)
	1990	62 ~ 90	Agrawal and Tunwar (1990)
	2008	105 state seed testing laboratories, with total annual capacity of 0.72 million samples (Poonia 2013)	Gandhi (2008)
Japan	1947	Seed testing started (1947 seed law gave legal authority to government to test seeds in the market)	Kobayashi (2005 p.19, p.22)
Pakistan	2001	16	Chaudhry (2001)
	2009	28 to 31	Abro and Sadaqat (2010), Salam (2012), Rana (2014)
Philippines	1988	16	Sevilla and Mamicpic (1988 p.39-40)
Sri Lanka	Current	4 that conduct seed distinctiveness, uniformity and stability (DUS) tests	http://www.doa.gov.lk/index.php/institutes/1666
Vietnam	2012	3 – National Center for Plant Testing stations in Van Lam (Ha Noi), Tu Liem (Quang Ngai), and Ba Ria (Ho Chi Minh)	http://eapvp.org/report/docs/02_DUS%20System%20in%20Vietnam.pdf
USA	1923	19 seed testing labs for state Departments of Agriculture	Stevens (1923)
	1937	46 state testing labs, plus one federal lab	Whitcomb (1937)

Source: Author's compilations

5. RICE VARIETAL TECHNOLOGIES IN NIGERIA – ISSUES AND KNOWLEDGE GAPS

Despite significant efforts in plant breeding and other efforts to development improved crop varieties around the world, there are still several knowledge gaps regarding how best to develop such improved crop varieties in Nigeria. A primary factor explaining these knowledge gaps is simply how best to measure varietal improvement. Improved crop varieties tend to be highly heterogeneous due both to differences in genetic make-up and their varying growth performance under differing agroecological conditions or agronomic constraints. Such variations in productivity potential are often difficult to measure accurately.

In Nigeria, comparing past rice varietal development efforts to efforts made in other countries suggests that some of the improved rice varieties that have been released in Nigeria did not always perform as well as those which have been released in other countries. This has been partly due to the limited government support for rice breeding by national programs.

5.1 Measurement issues

Measuring varietal technologies is more difficult than measuring other technologies. For example, agricultural machinery, like tractors, consists of components that are more visible. Private individuals with some mechanical background can often dissemble them and obtain much information. For varietal technologies, however, genes are not visible, requiring sophisticated research infrastructure to analyze. A consequence of this is that, while the number of improved varieties released to farmers is often used to assess the availability of varietal technologies, nevertheless, their adoption rates can remain low, as is often observed in low-income countries. While Nigeria has released more than 60 improved rice varieties in the past, a significant share of them have not been created by incorporating successful local varieties in their make-up or were selected from a relatively small number of crosses developed from local varieties from a small number of locations. In consequence, the improved rice varieties often are not broadly adapted for Nigerian rice growing conditions.

However, even when adoption rates of improved crop varieties are high, this may be an insufficient indicator of over-all varietal technology development in absolute terms. If the improved crop varieties farmers adopt are only marginally improved over local traditional varieties, the overall improvement in varietal technology levels may be slower compared to cases in which substantially improved varieties are released to farmers[9]. Oftentimes, researchers concentrate on supplying improved varieties that address problems which they perceive as significant. However, the resulting varieties, although better performing than previous varieties, may provide only maintenance benefits that sustain the productivity of existing crop varieties in the face of new production challenges (Maredia and Minde 2002 p.91) – such improved varieties can be characterized as "marginally" improved rather than "substantially" improved. Because of these challenges, both the number of released varieties and their adoption rates are insufficient indicators of varietal technology levels. The knowledge gaps for measurement of varietal technology are particularly wide in tropical sub-Saharan Africa.

[9] While some studies including Awotide et al. (2013) provide partial evidence of the economic significance of the adoption of certified rice seeds in Nigeria, they do not check the sensitivity of their findings against the violation of the unconfoundedness assumption.

5.2 Accounting for low varietal technology levels in rice in Nigeria

One of the primary reasons why the performance of improved crop varieties can vary across locations is the location-specificity inherent in the germplasm. In contrast to biological inventions, virtually all mechanical, electrical, or chemical inventions have at least a moderate degree of potential to be successfully transferred from location to location globally (Evenson 1988). While international spillover of improved rice varieties is an important facilitator for improving rice technology levels in Nigeria, the knowledge gap is still large as to how effectively the rice varietal technologies in Nigeria can be raised through such spatial spillover alone. At the same time, there are indications that the quality of so-called "improved varieties" of rice is still low in Nigeria, judged by domestic rice breeding intensity and the performance of these varieties under production.

Past studies on research spillover of improved crop varieties has primarily focused on wheat (Maredia, Ward and Byerlee 1996; Traxler and Byerlee 2001). Such studies may offer only limited insights for tropical countries, like Nigeria, where wheat is not widely grown. Crops that are more widely grown in tropical sub-Saharan Africa, like maize, tend to be more sensitive to physical factors than wheat (Evenson and Westphal 1995 p.55), while wheat production environments and local differences in quality preferences are not as marked as in rice, maize, or beans (Maredia and Eicher 1995).

In addition, despite the considerable insights gained on spillovers from wheat research provided by past studies (Alston 2002; Traxler and Byerlee 2001), knowledge gaps remain regarding whether such spillovers were made possible by public research and development efforts. Moreover, even for wheat, evidence on such spillovers is mixed. For example, some of the seminal papers estimating spillover matrices (Maredia, Ward and Byerlee 1996; Traxler and Byerlee 2001) suggest that substantial variations in yields are still captured by location dummies, which can reflect institutions or policy related factors as well as location-specific biophysical factors[10].

Otsuka and Larson (2016) suggests that, while Asian rice varieties are sufficiently adaptable for use in Africa, significant extension effort is needed to transfer the production management techniques required for profitable production of these Asian varieties. This suggests that relying on introduced Asian rice varieties may not be successful if public sector resources for agricultural extension is limited, which is often the case in sub-Saharan Africa. It is therefore important to examine the alternative option of focusing on developing improved rice varieties from locally adapted rice varieties that do not require novel management techniques.

5.3 Indicators of low varietal technology levels in the improved rice varieties currently used in Nigeria

5.3.1 Fertilizer response

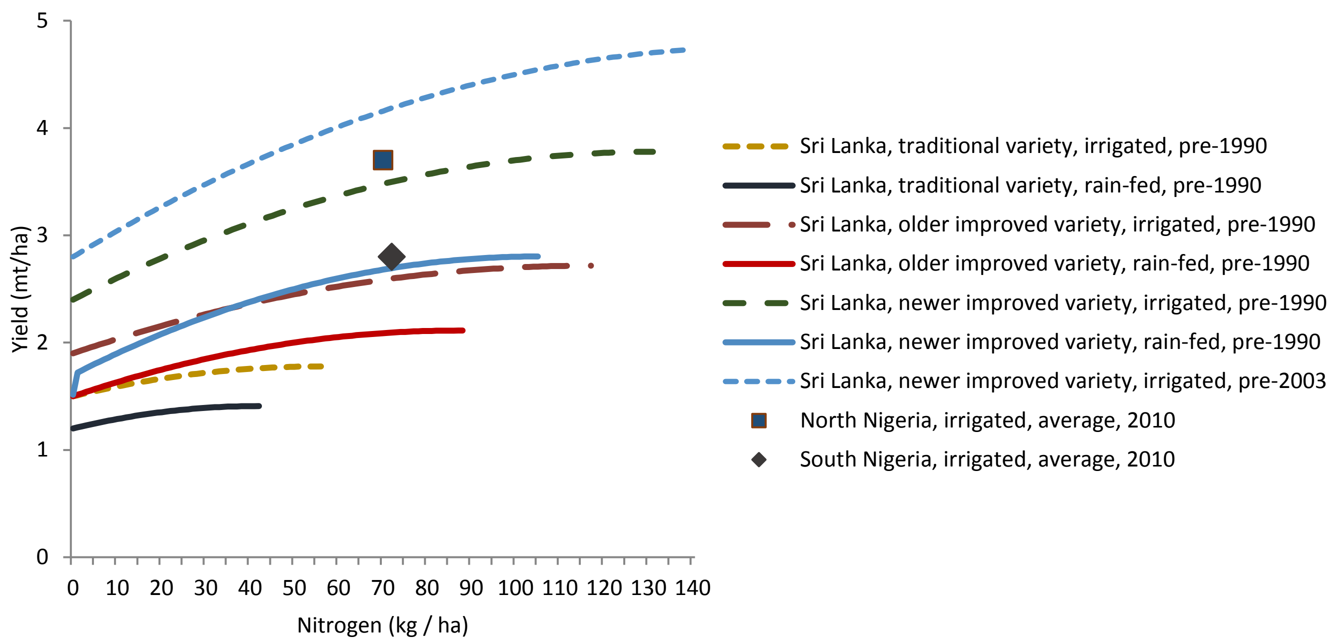
Fertilizer response, the relationship between nitrogen use per hectare and yield, of rice varieties is often used as an indicator to distinguish different generations of modern varieties. Inherent fertilizer response can be affected by various factors, including solar radiation. Using the evolution of several generations of improved rice varieties in a comparable Asian country, Sri Lanka, as a benchmark, we can obtain insights into to which generation current improved rice varieties may belong. Sri Lanka has relatively similar soil types as West Africa

[10] Moreover, these studies set up spillover matrices as being conditional on the current yield level of National Agricultural Research System (NARS) varieties in each location, suggesting that spillover coefficients depend on the level and quality of local research and development efforts.

and solar radiation patterns are more similar to Nigeria than is found in more temperate zones in Asia (Takeshima and Bakare 2006).

Figure 2 illustrates the evolution of nitrogen response in modern rice varieties over generations in Sri Lanka and shows corresponding yield and average nitrogen use of irrigated rice in northern and southern Nigeria in 2010. It is clearly seen that later generations of modern rice varieties in Sri Lanka exhibited higher yield responses. Meanwhile, yield responses of current improved varieties in Nigeria suggest that those in northern Nigeria may be only as good as improved varieties that were introduced prior to 1990 in Sri Lanka, and those in Southern Nigeria may be only as good as improved varieties that had already been considered to be "old" improved varieties by 1990 in Sri Lanka.

Figure 2- Nitrogen response for irrigated rice in Nigeria- comparison with estimates from Sri Lanka



Source: Kikuchi and Aluwihare (1990) for all pre-1990 data. Kikuchi, Maruyama and Hayami (2003) for pre-2003 data. Data for Nigeria from Takeshima and Bakare (2016).

Of course, yield response depends not only on varietal technology levels, but also other factors. However, it is also true that, according to the Nigeria Living Standards Measurement Survey (LSMS) household survey data, chemical fertilizer use in Nigeria, particularly in irrigated rice environments, is higher than conventionally believed, suggesting that barriers to intensive chemical fertilizer use might be less constraining in Nigeria than previously thought. In addition, as is shown in the Appendix, the farm gate price of paddy relative to fertilizer prices has been generally higher in Nigeria than in Sri Lanka, indicating that market conditions in Nigeria for commercial use of inorganic fertilizer have been relatively more profitable than previously assumed. Given these factors, we may conclude that the current improved rice varieties in Nigeria may be actually fairly old by Asian standards of varietal technology in rice.

5.3.2 Domestic rice breeding intensity

The importance of agricultural research and development for agricultural growth has been widely-documented, and it is well-known that the relative size of overall agricultural research and development efforts in SSA has been small compared to the rest of the world (Walker and Alwang 2015). However, relatively little has been documented as to how exactly this can lead to low varietal technology growth. In the case of maize, more recent agricultural research in Africa has been on improved production practices, rather than breeding (Maredia, Byerlee and Pee 2000), despite the fact that the impact of improved production practices on agricultural sector growth are more difficult to assess than is the impact of crop breeding (Traxler and Byerlee 1992). If patterns similar to what is seen with maize breeding research efforts in Africa apply to rice in Nigeria, it would indicate that support for rice breeding may be even lower. Here, we provide more concrete insights, focusing on the intensity of rice breeding in Nigeria from historical and international perspectives.

5.3.3 Relative dominance of domestically-bred rice varieties globally

Rice varietal technology in the world has largely been developed through the complementary efforts of international transfer and domestic adaptive breeding. While international effort by the International Rice Research Institute (IRRI), the International Center for Tropical Agriculture (CIAT), the International Institute for Tropical Agriculture (IITA), the Africa Rice Center, and other organizations to develop and transfer new rice varieties generally facilitated an increased supply of parental varieties, varieties that have been popularly adopted in each country generally originated from crosses made in each country using those parental varieties with local varieties (Hossain et al. 2003; Takeshima 2014).

In Nigeria, however, relatively few domestically-bred varieties are grown. A recent survey by Diagne et al. (2015) found that the five most popular rice varieties in Nigeria are FARO 44, FARO 15, FARO 46, EX CHINA, and FARO 52. Of these, FARO 15 is the only variety that was developed by the national rice program (Takeshima 2014)[11]. While FARO 46 and FARO 52 are newer and relatively popular in certain areas, they were developed by IITA, so are the equivalent of Asian countries releasing IRRI-bred varieties, instead of using them as parents for further adaptive crossing, as has typically been done in rice varietal improvement efforts in Asia. Diagne et al. (2015 p.194) state that "the recent absence of releases from in-country crosses and subsequent selection is more puzzling in Nigeria than in any of the other ten countries [surveyed]. In the 1970s and 1980s, several varieties were released via conventional breeding from both Nigerian and IARC-related parents in Nigeria. The dominance of introduced elite lines in recent varietal-release outcomes is unexpected in a large national program with a steady record of varietal releases in a commodity whose output substitutes for imports."

5.3.4 Low breeding intensity in Nigeria

While the level of varietal technologies is sometimes measured by the number of re-leased varieties, it is an insufficient measure because many of those released varieties may be only marginal improvements over existing varieties, not substantial improvements, as discussed earlier. For rice in Nigeria, this point is important, because in terms of the number of released rice varieties alone, it is often comparable to some Asian countries. For example, Nigeria released about 60 rice varieties over the past 50 years for a total rice area that has grown to about 2 million ha. Meanwhile, Bangladesh, with much larger rice areas, released about

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[11] Furthermore, FARO 15 was released in as early as 1974.
Since only some (not all) individuals among a population of the same crosses have particular desired traits (Witcombe and Virk 2001), the size of popula-tion per crosses further affect the probability of discovering substantially improved varieties of a crop.

70 varieties between 1970 and 2014. However, while the rice yield in Nigeria stagnated below 2 mt/ha during this time, that in Bangladesh has risen from 1.7 mt/ha (average be-tween 1971-75) to 4.4 mt/ha (average between 2011-14). The total number of varieties released in the last half century per million ha of rice area in Nigeria has been higher than in 20 countries in South and South East Asia. However, this primarily is thanks to the efforts international agricultural research centers, such as IRRI, IITA, and the Africa Rice Center (Takeshima 2014; Takeshima 2016).

5.3.5 Number of crosses made

What accounts for this difference between Nigeria and rice-growing countries in Asia? One important difference that has not been documented widely in the varietal technology development literature is that the number of crosses made, from which selected elite varieties are eventually released, has been considerably different between the Asian countries and Nigeria.

The discovery of new varieties is a stochastic process (Evenson and Kislev 1976). The literature on the theory of the optimal number of crosses for rice suggested that one out of 100 crosses typically results in a desirable variety in crops such as wheat and rice (Palmer 1953, Yonezawa and Yamagata 1978). This is consistent with the historical patterns of rice breeding in the world, in which typically less than 1 percent of crosses developed ultimately have been released as varieties (Evenson and Gollin 1997)[12].

Table 4 summarizes the number of crosses made for rice and, in a few cases, for wheat in selected countries glob-ally over varying time periods. It is important to note that many released rice varieties in Asia or Latin America have been elite varieties, selected from a large number of competing crosses. In Bangladesh and India and at IRRI, every released rice variety had been selected from approximately 200 competing crosses and from about 100 in the hills of Nepal (Witcombe et al. 2013). Statistically, the best varieties selected from a large number of candidates are superior to those selected from a smaller number of them. Countries made many such crosses every year since the 1960s – 700 per year in Indonesia (IRRI 1982), 200 in Bangladesh (Witcombe et al. 2013), 2,000 by IRRI, and around 900 crosses in Latin America (Cuevas-Pérez 1992) – from which elite varieties have been selected for release. Similarly, Egypt made 450 crosses a year between 1980 and 1997, during which period rice yields increased from 5.5 to 9.0 mt/ha.

Table 4- Number of crosses of rice and wheat made in selected countries historically

Country, region, or institution	Crop	Reference years	Number of crosses per year	Harvested area (million ha)	Crosses per million ha, per year	Source
Bangladesh	Rice	1972-89	217	11.8		Witcombe et al. (2013)
Egypt	Rice	1980-1997?	450	0.5	1000	Badawi (1997)
Japan	Rice		Several hundreds	1.5		Ministry of Agriculture, Forestry and Fisheries

[12] Since only some (not all) individuals among a population of the same crosses have particular desired traits (Witcombe and Virk 2001), the size of population per crosses further affect the probability of discovering substantially improved varieties of a crop.

Nepal	Rice	1972-2003	93 (61 for Terai, 33 for hills)			Witcombe et al. (2013)
Latin America	Rice	1971-1990	900 (569 for 1971-80, 1,235 for 1981-90)	7.4	121 (79 for 1971-80, 163 for 1981-90)	Cuevas-Pérez (1992, Tables 1/3)
UK	Wheat	1980s	1,200	1.8	680	Bingram and Lupton (1987) cited in Witcombe and Virk (2001)
IRRI	Rice	1961-2010	2,000			Witcombe and Virk (2001)
CIMMYT	Wheat	1990s	12,000			Maredia and Byerlee (1999)
Nigeria	Rice	1961-2010	10	2.0	5	Number of FAROX

Source: Author's compilation from various tables.

Note: In Latin America, the total number of crosses made during specified periods were divided by the number of years, using Cuevas-Pérez (1992, Table 1/3)(for example, between 1971-1990, 18,033 crosses were made, equivalent to approximately 900 crosses per year).

On the other hand, rice crosses made by national programs in Nigeria have been 10 per year on average until recently, albeit with substantial yearly variations. In West Africa, Africa Rice Center alone made around 250 crosses per year in the late 1990s (Ikehashi 2000), while all National Agricultural Research Systems (NARS) combined in the region made less than 100 (Dalton and Guei 2003). While crossing by Africa Rice Center may be comparable to IRRI making 2,000 crosses a year for the much larger rice areas of Asia, sharper differences are observed in the crossing efforts by NARS.

This relatively narrow genetic base of developed varieties also applies to some of the latest varieties, like the New Rice for Africa (NERICA) varieties, which have been bred in an innovative manner by crossing Asian (*O.sativa*) and African (*O.glaberrima*) rice varieties which do not naturally cross. They carry, in theory, both high yielding genes from Asian varieties and resistance to African pests from African varieties, and an increasing number of them have been released in many African countries including Nigeria (Diagne et al. 2011; Kijima, Otsuka and Sserunkuuma 2011). However, most lowland NERICA varieties developed so far have used only a few African varieties. More specifically, 57 out of 60 cultivars developed use IR 64 (*O.sativa*) and TOG 5681 (*O.glaberrima*) as parents. While TOG 5681 is believed to have several preferable traits like long panicle length, high weed-competitiveness, resistance to rice yellow mottle virus (Ndjiondjop et al. 1999), and African rice gall midge (Rodenburg et al. 2009; Ndjiondjop et al. 2008), it still suffers from low yield potential due to grain shattering and susceptibility to lodging (Jones et al. 1997). Most importantly, its performance across diverse production environments in sub-Saharan Africa is not well known. In Nigeria, six out of nine rice varieties released between 2003 and 2012 were NERICA varieties; among them, all four upland NERICA varieties had WAB 56-104 (*O.sativa*) and CG-14 (*O.glaber-rima*) as parents (Takeshima 2014), and two lowland NERICA varieties released in 2012 had IR 64 and TOG 5681 (Kamara et al. 2011). Insufficient NARS breeding activities mentioned above are likely to be responsible for the relatively narrow genetic base of released rice varieties in Nigeria.

It is important to note that recently international donors, like the Bill and Melinda Gates Foundation, have revamped their support for rice varietal development. An Africa Rice Center scientist based in Ibadan made about 350 crosses in 2015 alone for lowland rice. Such efforts need to be documented so that future rice productivity growth in Nigeria can be properly attributed to such past investment in varietal technology development.

5.3.6 Few breeding centers where crosses are made

Another indicator of low rice breeding intensity in Nigeria is the few number of breeding stations where crosses are made, given the total size of the area in which rice is grown. Table 5 shows the number of rice breeding stations where crosses are made in selected countries globally, as well as the number of such stations as a function of total national rice area. These are all national programs and do not include international agricultural research institutes like IRRI, CIAT, IITA and the Africa Rice Center.

In column (c) of Table 5, we present the estimated ceiling of the area on which rice is grown at least once a year. Relative to the total harvested area, the area (c) may be more closely related to the diversity of agroecological conditions which affect the location-specificity of varietal technologies and thus the need for de-centralized rice breeding. This is because if rice production intensity is high, this area (c) is much smaller than the total harvested area. The area (c) is the maxi-mum estimated, and the actual areas may be smaller for countries with multiple rice cropping seasons each year (indicated by "~").

Currently, Nigeria makes rice crosses in only one rice breeding institution, which is NCRI in Badeggi, for rice production area of 3 million ha, or equivalent to 0.3 breeding stations per 1 million ha. This is considerably lower than many Asian countries as well as the US, in which the numbers range from 0.7 (Indonesia and Thailand) to 5.8 (US). The concentration of rice breeding at NCRI in Nigeria is unlikely to be due to specific policies on the institutional structure of agricultural research and development. The fundamental cause of this lack of investment in breeding stations for rice is likely to be insufficient government support for the domestic rice breeding activities.

Table 5- Number of rice breeding stations where rice crosses are made

Country / region	**(a) Number of rice breeding stations**	**(b) Rice harvested area (million ha, 2014)**	**(c) Estimated ceiling of area on which rice is grown at least once a year (million ha, 2014)**	**(d) Number of rice breeding stations per million ha rice area ((a)/(c))**
Brazil – Rio Grande do Sul	1	1.1 (2016)	1.1 (2016)	0.9
Japan	≥ 5 (may be substantially more depending on breeding intensity at prefecture levels)	1.6	1.6	≥ 3.2

India	> 100	43.4	~ 43.4	> 2.3
Indonesia	≥ 6 under Central Research Institute for Food Crops	13.8	~ 9.1	0.7
Sri Lanka	4	0.9	~ 0.7	5.7
Thailand	7 breeding programs in 27 rice research stations	10.8	~ 9.6	0.7
USA	7	1.2	1.2	5.8
Vietnam	8	7.8	~ 5.4	1.5
Nigeria	1 (NCRI, Badeggi)	3.0	3.0	0.3

Source: Various.

Note: Ceiling of area on which rice is grown at least once a year (column (c))is calculated by authors using the fact that (1) total irrigated harvested area is the summation of area on which rice is grown under irrigation times the production intensity. This should not exceed the total area equipped for irrigation. Using AQUASTAT, for the year information is available (say, year X), we calculated what the maximum area on which rice was grown at least once a year in year X. We then applied the growth rate of total harvested area between that year X and 2014 to the estimated maximum area in year X to obtain estimate of the estimated maximum area in 2014.

5.3.7 Importance of domestic breeding in favorable areas with high solar radiation

The importance of domestic rice breeding partly arises due to Nigeria's mostly tropical environment, which can create barriers for transferring varieties grown in more temperate, higher latitude zones around the world. Among these barriers is the relative lower solar radiation during the cropping season in production areas in the south, closer to the equator. However, even in northern Nigeria which straddles relatively higher latitude areas and enjoys greater solar radiation in the main production season than the south of the country, domestic breeding is likely to be important.

The contributions of domestically bred varieties to yield enhancement in areas with higher solar radiation around the world are documented in past studies. For example, Egypt, Turkey, Uruguay, and Rio Grande do Sul in Brazil, all witnessed growth in irrigated rice yields from between 4 to 5 mt/ha in the 1980s to 7 to 9 mt/ha more recently (Table 6). In all cases, such yield growth coincided with increased adoption of domestically-bred rice varieties (Table 7).

Table 6- Rice yield growth in areas with high solar radiation, 1981 to 2013

		Rice yield (mt/ha)						
	Solar radiation sunniest month (kW·h/(m2·day))	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000	2001 to 2005	2006 to 2010	2011 to 2013
Egypt	**7.7**	**5.7**	**6.3**	**7.8**	**8.7**	**9.6**	**9.7**	**9.5**
Peru	**7.5**	**4.6**	**5.0**	**5.4**	**6.1**	**6.7**	**7.1**	**7.5**
Turkey	**7.1**	**4.5**	**5.1**	**4.8**	**5.3**	**6.4**	**7.6**	**8.2**
Uruguay	**6.9**	**5.0**	**4.8**	**5.0**	**6.2**	**6.4**	**7.6**	**8.0**
Brazil – Rio Grande do Sul	**6.9**	**4.0**		**5.2**				**7.3**
Bakolori, Nigeria	**7.0**							**5.4**
Southern Nigeria (irrigated)	**< 6.0**							**2.8**

Source: FAOSTAT. Solar radiation figures are from Takeshima and Adesugba (2015, Table 4.1). Irrigated rice yield in southern Nigeria is from Takeshima and Bakare (2016, Table 3.6).

Table 7- Domestically bred rice varieties that spread during high yield growth periods in Egypt, Turkey, Uruguay and Brazil

Country / region	Key rice varieties
Egypt	- Giza 176: released in 1989, spread to 30 percent of rice area by 1991 (Badawi 1997) - Giza 177: released in 1994, spread to 15 percent of rice area by 1995 (Badawi 1997)
Turkey	- Osmancik-97: cross between the Italian variety Rocca (the most popular rice variety in the mid-1990s) and EUROPA (unknown origin), developed at Thrace Agricultural Research Institute. In 2012, Osmancik-97 accounted for 80 percent of national rice production (Gaytancioglu and Sürek. 2000; Beşer and Sürek 2012).
Uruguay	- Three varieties – El Paso 144, INIA Tacuari, and INIA Olimar – account for 95 percent of the rice area. El Paso 144 is resistant to pathogens; released in 1985. INIA Tacuari has cold tolerance; released in 1992. INIA Olimar is high yielding; released in 2002 (Ferrando, Mañay and Scavino 2012).
Rio Grande do Sul (Brazil)	- Since early 1990, domestically bred varieties (beginning with IRGA 416) spread in Rio Grande do Sul. - IRGA 417 released in 1995, was adopted over 29 percent of rice area by 2002 - IRGA 424 released in 2007, led to significant yield growth (Martínez et al. 2014; Rabelo et al. 2015).

Source: Authors' compilations from various sources.

When compared to these other regions, it becomes clear that seemingly high rice yields in parts of northern Nigeria, such as the Bakolori irrigation scheme that realizes rice yields of 5.4 mt/ ha (Takeshima and Adesugba

2015), are actually still well below potential, given the relatively high solar radiation in the north. Such shortfalls in yield are associated with the scarcity of domestically bred varieties being grown in these regions[13].

Inflow of rice germplasm – mixed evidence. While low domestic breeding intensity may be partly due to the low inflow of improved rice germplasm from abroad, the evidence for this is rather mixed. Until the early 2000s, sub-Saharan Africa regularly received large numbers of foreign varieties at levels comparable to the numbers of varieties sent to other regions. Be-tween 1989 and 2002, Nigeria received 22,335 rice germplasms, or 1,595 germplasms per year from IRRI, the 12th highest destination for IRRI germplasm in the world (Javier and Toledo 2013).

Table 8- Average annual number of rice germplasms received from IRRI, slected countries, 1989 to 2002

Country	Number	Country	Number	Country	Number	Country	Number
India	15,890	Bangladesh	3,221	**NIGERIA**	**1,595**	Colombia	1,345
Thailand	10,277	Egypt	3,161	Philippines	1,512	Iran	1,296
South Korea	7,787	Indonesia	2,663	Nepal	1,503	Australia	1,271
China	6,173	Pakistan	2,160	Japan	1,484	Brazil	1,011
Vietnam	4,288	Myanmar	1,836	Sri Lanka	1,402		

Source: Javier and Toledo (2013).

However, Africa as a whole had received fewer rice germplasms from outside than did other regions, like Latin America, up to 1991. According to Evenson and Gollin (1997, Appendix), based on the available record of varieties ex-changed up to 1991, Latin America received 405 rice varieties from outside as parental varieties (among which INGER was used for 178 varieties). During this period, Africa received 168 from outside as parental varieties, of which INGER was used for 113 varieties. The rice area in Latin America was between 6 and 7 million ha in the early 1990s, similar to that of Africa during this period. Therefore, compared to Latin America, Africa as a whole received less than half the number of varieties from outside on a rice area-weighted basis up to 1991.

In addition, obtaining foreign germplasms is becoming increasingly difficult in recent years, despite efforts by international rice research agencies to supply them. This is due to the growing recognition of intellectual property rights on germplasms held in each country (Gotor, Caracciolo and Watts 2010). Consequently, breeder-to-breeder exchanges are becoming the primary source of acquiring germplasms for research. Consequently, the number of breeders in a country may significantly affect the level of access to foreign germplasms for the country.

[13] According to Takeshima and Adesugba (2015), the rice varieties grown in Bakolori Irrigation Scheme are mostly FARO 44 or indigenous varieties. Few domestically-bred varieties are grown.

6. CONCLUSIONS

Seed is an essential input in agricultural production. The Nigerian government aims to improve the provision of better quality seed at lower costs to farmers through seed certification, seed subsidies, promotion of private sector participation in foundation seed production, and so forth. However, knowledge gaps still exist regarding how the varietal technology level of available improved rice varieties in Nigeria affect the effectiveness of these seed policies.

In this report, we first illustrated conceptually how the effectiveness of seed certification, seed subsidies, and other related seed sector programs can depend on overall varietal technology levels. These discussions suggested that these policies may generally be more effective if varietal technologies are higher. We then provided historical and international perspectives using the example of certified seed production of rice. Consistent with the conceptual discussion, we showed that many countries around the world achieved advancement in the varietal technology level of improved rice varieties before certified rice seed production expanded.

We then provided further historical and international perspectives on the low domestic rice breeding intensity in Nigeria in terms of the number of crosses made, the number of breeding stations, and yield responses to fertilizer. These indicated that, despite more than 60 rice varieties having been formally released in Nigeria, rice varietal technology levels have remained low because insufficient government support had been provided for intensive domestic crossing to raise the likelihood of discovering varieties that are substantially (rather than marginally) higher yielding and yet as adaptable to local production environment as traditional varieties. The low current average rice yield, despite higher paddy prices induced by the historically high current rice tariff, is consistent with a story of low varietal technology levels. Yields are seemingly high in northern Nigeria, but even there yields are considerably lower than their potential compared to similarly favorable environments outside Nigeria. This yield difference is associated with the scarcity of domestically-bred rice varieties in Nigeria.

All this evidence suggests that it is important to provide substantial increases in public resources directed towards raising the varietal technology levels of rice grown in Nigeria. Successfully doing so is likely to raise the effectiveness of Nigerian government's various seed program and rice intensification efforts. However, it requires increased support for not only raising the intensity of domestic breeding, but also other complementary activities. First, increased efforts are needed to enhance access to improved germplasms from both within and outside Nigeria. As noted, the number of rice breeders in the country significantly affects the level of access to foreign germplasms for the country. Increasing the number of breeders through increased support for training is important, given that Nigeria has only two national rice breeders, a level of expertise considerably lower that found in countries in Asia (Diagne et al. 2015). In addition, domestically, increased effort to identify and select superior germplasms across the country is warranted. In Ghana, various successful aromatic rice varieties were selected through such effort in the early 2000s, varieties which later contributed to raising the rice productivity of several irrigation schemes (Takeshima et al. 2013).

Second, it is important to put in place the capacity to conduct field testing of promising varieties in multiple agroecologies across Nigeria. While currently promising rice varieties are tested in seven locations (Takeshima 2016), this number is too low given the number of agroecologies in which rice is grown in the country. Moreover, many of the field-testing sites are not properly equipped. Equipping the field testing sites with sufficient irrigation infrastructure, in particular, will permit field-testing twice a year instead of only once a year in the rainy season, as is now the case. This will double the speed at which the selection process of successful rice varieties is conducted.

Third, improving the collection of information on Nigeria's diverse agro-ecologies is critical, as this information is needed to determine the appropriate locations for conducting rice breeding and field testing and to establish the criteria for determine what types of rice varieties should be developed. For example, while sources like FAO et al. (2012) generally indicate that soil types in Nigeria are diverse, the information still tends to be available at aggregated level, and may not fully capture agro-ecological heterogeneity at local level. The available information may also be limited and outdated regarding existing pests, diseases, and weeds, particularly if the current capacity of local extension offices and research institutes is limited. It is important to raise the capacity to regularly gather such information and to share it efficiently across breeding and other research institutions.

Lastly, while these policy recommendations recognize that there is considerable value in decentralizing breeding and other research activities within the national rice research system, such decentralization should not be done to such a degree that it results in a loss of the economies of scale in research through excessive fragmentation. Increasing the economies of scale in research output was part of the justification for efforts to centralize the national rice research system, as well as re-search systems for various other crops, in Nigeria in the 1970s and 1980s (Roseboom et al. 1994). Appropriately decentralizing the Nigerian rice breeding and research system without jeopardizing any economies of scale in the current system inevitably requires substantially increasing the support provided for building capacity for rice research overall, rather than simply restructuring the system.

APPENDIX: HISTORICAL PRICES FOR UREA AND RICE (PRODUCER) IN NIGERIA COMPARED TO INTERNATIONAL PRICES, 1966 TO 2002

Years	Bangladesh	Colombia	India	Indonesia	Philippines	Sri Lanka	Thai-land	Côte d'Ivoire	Benin	Nigeria				
										At official exchange rate		At parallel market exchange rate		
										Subsidized	Unsubsidized	Subsidized	Unsubsidized	Notes
Price of urea (current USD/mt of nutrients)														
1966-70		261	279		263	178		202						
1971-75	251	542	385	277	177	332		554	235					
1976-80	291	594	429	315	529	222	359	613	359	162	610	162	610	
1981-85	383	705	475	242	646	254	599	639	385	262	1055	129	493	
1986-90	332	329	355	214	386	284	375	646	570	130	529	87	329	
1991-95	304	548	235	256	504	434	574	894	738	206	857	103	429	
1996-00	255	446	212	273	447	262	434	744		1,324	1560	410	469	
2001-02	220	463	214	212	367	220	327							
Farm gate price of rice paddy (current USD/mt)														
1966-70		122	95		82	123		74		175		175		Nigeria rice import restriction
1971-75	159	112	142	82	109	200	79	163	89	291		291		
1976-80	146	180	164	175	141	161	118	273	192	452		452		10 to 20 percent tariff, partial restrictions
1981-85	160	213	184	179	157	153	118	194	254	647		345		
1986-90	172	202	147	138	161	151	132	226	326	498		357		Import ban
1991-95	161	202	149	172	213	168	151	212	329	710		409		
1996-00	128	260	134	153	236	173	159	199		874		284		50 to 100 percent tariff
2001-02	111	208	124	123	166	142	113	182						
Urea-rice paddy price ratio														
1966-70		2.1	2.9		3.2	1.4		2.7						
1971-75	1.6	4.9	2.7	3.4	1.6	1.7		3.4	2.6					
1976-80	2.0	3.3	2.6	1.8	3.8	1.4	3.0	2.2	1.9	0.4	**1.5**	0.4	1.5	
1981-85	2.4	3.3	2.6	1.3	4.1	1.7	5.1	3.3	1.5	0.4	**1.6**	0.8	3.5	
1986-90	1.9	1.6	2.4	1.5	2.4	1.9	2.8	2.9	1.7	0.3	**1.0**	0.4	1.4	
1991-95	1.9	2.7	1.6	1.5	2.4	2.6	3.8	4.2	2.2	0.3	**1.3**	0.8	3.2	
1996-00	2.0	1.7	1.6	1.8	1.9	1.5	2.7	3.7		1.5	**1.7**	4.5	5.3	
2001-02	2.0	2.2	1.7	1.7	2.2	1.6	2.9							

Source: Gyimah-Brempong, Johnson and Takeshima (2016 Table D.4).

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