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Insect-Resistant Cowpea in Nigeria

An Ex Ante Economic Assessment of a Crop Improvement Initiative

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Abstract

Insect-Resistant Cowpea in Nigeria: An Ex Ante Economic Assessment of a Crop-Improvement Initiative

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Since oil prices' decline in 2014, agriculture has received renewed interest in Nigeria as a key sector for achieving sustainable growth and generating foreign exchange. One of the identified obstacles to achieving these goals is the need to improve agricultural productivity. Cowpea is one of the priority crops identified for productivity improvement. Currently cowpea yields are below 900 kg/ha, but it has been shown that with the right technology, these yields could potentially double. One of the main biotic constraints for cowpea is the infestation of the insect pod borer (*Maruca Vitrata*). No conventional variety has been developed to resist this pest, but with the use of biotechnology and the sustained collaboration of national and international partners over many years, there is now a genetically modified pod-borer-resistant (or more generally insect-resistant) cowpea. This paper estimates the potential economic benefits of adopting this new technology and the cost that Nigeria will incur if this adoption is delayed. The analysis is conducted using an economic surplus partial equilibrium model run with the newly developed DREAMpy software, data drawn from the Nigeria General Household Survey 2015–2016, estimations using these data, and other local sources. The estimations show that if the insect-resistant cowpea is planted in 2020, the net present-value benefits for producers and consumers would be around US$350 million, 70 percent of which would be accrued by producers. The distribution of benefits by region show that Sudan-Sahel will accrue the most benefits, given the relative concentration of cowpea in this region and the estimated higher adoption rates and yield changes. Almost half of producers' total benefit will go to large producers, who represent only 20 percent of all cowpea producers, while small producers, representing half of all cowpea producers, will receive 24 percent of the benefit. Additionally, the analysis shows that a five-year regulatory delay will decrease the estimated benefits by around 35 percent. While Nigeria already has in place a competent biosafety system that will most likely ensure that these regulatory delays will not materialize, these estimations highlight the importance of having an evidence-based, efficient, predictable, and transparent regulatory system to ensure that the expected economic benefits are realized.

Keywords: GM crops, GMO, genetically modified, cowpea, insect resistant, Nigeria, Maruca, pod borer, economic surplus model, DREAMpy

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We acknowledge the contribution of crop and technology experts, particularly Professor Ishiyaku, currently the Executive Director of the Institute of Agricultural Research (IAR) in Nigeria, who generously shared his time and expertise as principal investigator of the cowpea project. We also received valuable input from Directors and/or representatives of the Federal Ministry of Agriculture and Rural Development, National Biosafety Management Agency, National Bureau of Statistics, Central Bank of Nigeria, and National Biotechnology Development Agency, all members of the Steering Committee established for this project. In addition, the National Agricultural Extension Research Liaison Services, Zaria provided access to their regional Agricultural Performance Survey. Their input was critical in all estimations presented in this document. PBS country coordinator Matthew Dore provided timely and valuable support and advice. The authors are grateful to Margaret Karembu and Bibiana Iraki of the International Service for the Acquisition of Agri-biotech Applications; Donna Ramaeker Zahn, Global Outreach Strategist, PBS; and Alex Abutu, outreach consultant, for the support and advice provided for the outreach work done as part of the BioRAPP project.

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1. INTRODUCTION

The relatively recent decline in oil prices has renewed agriculture's relevance as a key sector for Nigeria's economy in sustaining growth and generating foreign exchange, as outlined by the federal Agriculture Promotion Policy (FMARD 2016). Improving productivity is a key component of this policy, which identifies cowpea as one of the targeted crops.

Increasing agriculture's productivity in Nigeria faces a number of obstacles. The observed agricultural growth in recent years (2001-2016) has been sustained by area expansion, a growing animal stock and rapid growth in the use of fertilizer and feed, rather than productivity increases (USDA-ERS, 2019). Some of the factors challenging agricultural productivity growth are declining soil fertility, poorly funded agricultural research and extension systems, inadequate availability and distribution of purchased inputs, and poor or lack of access to financial services for the procurement of needed inputs and services (Phillip et al. 2013). To sustain agricultural productivity growth in the coming years, Nigeria will need to boost innovation, including higher investment in research and development (R&D), to develop new technologies domestically and to adapt proven technologies developed elsewhere, such as genetically engineered (GE) crops that have benefited producers and consumers in adopting countries around the world (Klumper and Qaim 2014). While evidence on the benefits of genetic engineering continues to grow, assessments that focus on the benefits of such technology to potential adopting developing countries continue to be limited, particularly for the newer product characteristics emerging from the R&D pipeline.

In Nigeria, the National Biosafety Management Act of 2015 made it possible to implement the use of modern biotechnology as a policy instrument to improve agricultural productivity. In tandem with the implementation of its biosafety policy, the Nigerian government would like to have locally generated studies that evaluate the potential economic benefits of GE products. This paper builds on that premise to produce a timely economic assessment of such a technology.

In this paper we estimate the potential economic benefits of the introduction and adoption of insect-resistant (IR) cowpea in Nigeria. The estimations are based on the economic surplus model, or ESM (Norton, Alston, and Pardey 1995) using DREAMpy, an IFPRI-developed open-source software that implements the model in the evaluation of the economic impacts of agricultural research and development projects.

The discussion paper is organized as follows. The next section details the economic relevance and agronomic characteristics of cowpea and the development and status of the IR cowpea project in Nigeria. Section 3 describes how, among other technologies, IR cowpea was selected as the focus of this study. Section 4 briefly describes the ESM and the DREAMpy tool used. Section 5 details the data sources and describes how specific input variables were estimated using available household data. Section 6 presents the results of the modeling exercise along with a summary of a sensitivity analysis and a consideration of the cost of possible delays. Lastly, we offer our overall conclusions and some focused recommendations regarding the importance of having functional regulatory systems in place for the timely delivery of GM technologies.

2. COWPEA ECONOMIC RELEVANCE AND TECHNOLOGY CONSTRAINTS

Cowpea Economic Relevance

Cowpea (*Vigna unguiculata* [L.] Walp.), a native crop of Africa and now planted in semiarid regions around the world, is the most important grain legume crop in Nigeria and West Africa (Langyintuo and Lowenberg-DeBoer 2006; Langyintuo et al. 2003). Cowpea is a key cash crop and plays a critical nutritional and food security role as a source of cheap protein and animal feed and as a source of cash, while also contributing to soil fertility improvement. Nigeria is the largest African producer, followed by Niger, Burkina Faso, Cameroon, and Tanzania (FAOSTAT 2018). In 2015, Nigeria produced an estimated 2.2 million metric tons of cowpea and consumed 2.6 million metric tons (authors' estimation based on the Nigeria General Household Survey 2015–2016 [GHS 2015–2016]).[4] Alene et al. (2009) estimate that 65 percent of poor households produce and consume cowpea in Nigeria, where the poverty headcount ratio is estimated at 62.6 percent (NBS 2010).

The crude protein content of the dry grain is 22 to 30 percent (Quin 1997, Singh et al. 2003; FAO 2004, IITA 2010, AATF 2012, Awurun and Enyiukwu 2013, African Centre for Biotechnology 2015). Some other estimates have put cowpea's protein content as high as 35 percent (Tarawali et al. 1997). Cowpea grain is also rich in vitamins and minerals including iron and zinc (Garrow et al. 2000; African Centre for Biotechnology 2015). All parts of cowpea are used as food: (a) the leaves, green peas, green pods, and dry grain are consumed as different dishes; (b) its parts supply vitamins and minerals, especially micronutrients; and (c) the grain is especially rich in the amino acids lysine and tryptophan (AATF 2012). Cowpea is harvested during the dry season, when wet season crops are scarce, helping to mitigate hunger and scarcity (Dabat, Lahmar, and Guissou 2012; Ugbe et al. 2016).

Aside from its nutritional grain value, cowpea forage contributes significantly to animal feed (Coulibaly and Lowenberg-DeBoer 2014; FAO 2004; Abdullahi and Tsowa 2014; Tarawali et al. 1997; Moussa et al. 2011; IITA 2010). Inaizumi et al. (1999) estimate that the preservation

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[4] The GHS is a nationally representative survey administered every two to three years. It is a result of a collaboration between the National Bureau of Statistics and the World Bank's Living Standards Measurement Study. For information on the GHS 2015–2016, see http://microdata.worldbank.org/index.php/catalog/2734/study-description.

and sale of cowpea fodder can increase farmers' annual income by 25 percent at the peak of the dry season.

In addition to supporting the subsistence needs of farm families, cowpea is grown for cash or kept as seed for planting (Langyintuo and Lowenberg-DeBoer 2006; Moussa et al. 2011). Furthermore, cowpea production provides rural employment for men and women. Although some research suggests that women play a key role in processing and marketing cowpea (Dabai et al. 2015; Sanginga and Bergvinson 2014), the data extracted from the GHS 2015–2016 show that women play a minor role in processing and marketing cowpea, with their participation in those activities barely reaching 5 percent.

Additionally, cowpea plays an important role in soil fertility improvement (Sanginga and Bergvinson 2014; Falokun et al. 2011). Cowpea is very prominent among the various crop mixtures favored by smallholder households in Nigeria (Coulibaly and Lowenberg-DeBoer 2014; Blader 2005; Ishiyaku et al. 2010). As a legume, cowpea plays a crucial role in replenishing nitrogen-depleted soils, thus increasing soil fertility, mainly to the benefit of the cereals in the cropping system (African Centre for Biotechnology 2015; Widders 2012; Moussa et al. 2011; FAO 2004; Ugbe et al. 2016; IITA 2010). By its spreading habit, cowpea helps to mitigate erosion and suppress weeds (AATF 2012; FAO 2004; Okigbo 1978).

Consumption of cowpea in Nigeria appears to have grown substantially over the last 20 years. Konnawa et al. (2000) documented an annual consumption of 6.9 kg/cap. Langyintuoa et al. (2003) estimated annual consumption to be 18 kg/cap, and more recently Coulibaly et al. (2015) calculated a consumption of 23 kg/cap. The interviews conducted across 25 states during the fieldwork stage of the present study (July–August 2018) suggest an annual consumption of 14 kg/cap. Comparing these numbers with the data extracted from the GHS 2015–2016 confirm the latter's average annual consumption of 14 kg/cap, based on a total consumption of 2.6 MT and a population of 181 million for the year 2016.

Although figures for Nigeria's international trade in cowpea are not available, it is well recognized that there is an ongoing cross-border exchange of goods and services among West African neighboring countries, largely unregistered and rarely captured by official trade statistics. Recognizing that fact, Langyintuo et al. (2003), based on their estimate of 18 kg/cap cowpea consumption, estimated that annual cowpea imports to Nigeria amounted to 385,830 metric tons for 1999. Langyintuo, Lowenberg-DeBoer, and Ardnt 2005, 13) also estimated that "ninety five percent of Nigeria's imports originated from Niger accounting for 98% of the latter's marketable surplus". Sanginga and Bergvinson (2014) estimate that Nigeria spends more than US$628 million on cowpea imports. The COMTRADE database confirms that there are no reported data for exports or imports from Nigeria, underscoring the informal character of the border trade. COMTRADE does indicate that five European countries plus Canada and South Africa report small amounts of cowpea imported from Nigeria. On average, over the period 2012 through 2017, the annual amount of cowpea imported from Nigeria by these seven countries barely reached 4.2 t. These exports from Nigeria have faded over the years due to phytosanitary considerations.

Estimates based on GHS 2015–2016 household data demonstrate a difference of 697 kt between Nigeria's national cowpea consumption of 2.6 t and its estimated national production of 2t. This difference must be supplied by the unreported cross-border imports, which are assumed to come mainly from Niger. Although import figures cannot be checked against official published statistics, these numbers show that cross-border imports not only continue to be relevant but have grown over the years. With an estimated annual population growth rate of 2.6 percent coupled with consumption of cowpea increasing with income, the country will need to expand production to meet its growing domestic demand and to exploit opportunities in international markets. For example, India recently opened its doors for the import of pulses, including cowpea from Nigeria, to the value of US$1 billion, under a proposed assistance to small-scale farmers in Nigeria (Safina Buhari 2017).

Production Limitations and Technology Constraints

Cowpea is targeted by multiple insect pests and diseases from planting to storage (Hampton et al. 1997; Agbicodo et al. 2010; Sangoyomi and Alabi 2016). Sanginga and Bergvinson (2014) show that the most critical stages of insect attack are during flowering, pod development, and storage. Postflowering insect pests such as the legume pod borer (*Maruca vitrata*), flower thrips (*Megalurothrips sjostedti*), and pod-sucking bugs (*Clavigralla tomentosicollis*, *Anoplocnemis curvipes,* and *Riptortus dentipes*) can cause grain yield losses from 55 to 100 percent if not controlled (Alghali 1992; Oyeniyi et al. 2015; Cisneros 1984; Ononuju and Nzenwa 2011; Coulibaly et al. 2008).

The breeding of conventional high-yield, disease-, insect-, and *Striga*-resistant cowpea varieties has slowly evolved since the 1980s as the result of collaborative research between the International Institute of Tropical Agriculture (IITA), Purdue University, and national research centers (Coulibaly et al. 2008). Nevertheless, conventional improved cowpea varieties have had limited success so far in controlling for the pod borer *Maruca vitrata*. *Maruca* is a lepidopteran insect, and its larvae damage cowpea through the planting cycle, from flowering to pod maturity (African Centre for Biotechnology 2015). Coulibaly et al. (2008) estimated that farmers still need to spray two to three times to control for this pod borer. Because the insecticides that are effective against *Maruca* are expensive, many resource-poor farmers apparently resort to highly toxic but more affordable cotton insecticides to control cowpea insect pests (Coulibaly et al. 2008). This practice has been linked to accidental deaths and health problems among cowpea producers and consumers (Ajayi and Waibel 2003; Drafor 2003; Maumbe and Swinton 2003).

To address both cowpea *Maruca* constraint and insecticide misuse, the African Agricultural Technology Foundation (AATF) has been leading since 2001 a cowpea project that uses genetic engineering to incorporate insect resistance into improved cowpea varieties in different African countries. The expected outcome of this project is to reduce production costs and to eliminate or substantially reduce the number of insecticide sprays. As one of the early proponents of the biotechnology option, Larry Murdock, suggested: “We can put insect protection into the seeds the farmers plant through genetic engineering” (2002, 3). According to Coulibaly et al. (2008), *Maruca*-resistant cowpea varieties have the potential to contribute significantly to increased production and incomes, improved nutrition and health for farmers and consumers, enhanced soil fertility, and environmental protection through reduced pesticide use, and thus they can contribute to Nigeria’s national goal of increased production.

Aside from insect pests, other constraints limit cowpea grain yields, including use of low-yielding local varieties, low soil fertility, drought, and poor management practices (Langyintuo and Lowenberg-DeBoer 2006; Blade et al. 1997; Dieh and Sipkins 1985; Montimore et al. 1997; Sawadogo, Nagy, and Ohm 1985; Semi-Arid Food Grain Research and Development 1998; Singh, Chamblis, and Sharma 1997). Even though a *Maruca*-resistant cowpea addresses only one of the many production constraints (pod borer) in Nigeria, a successful GE solution could be worth the research and extension investment if such technology protects against a potential 55 to 100 percent yield loss, results in the reduction of insecticide sprays, and potentially adds economic, health, and environmental benefits.

There is growing regulatory and political support for R&D on and adoption of GE crops in Nigeria. Nigeria's biosafety laws and regulations allow for research on, testing of, and release of GE crops (National Biosafety Management Agency Act 2015). Thus, AATF's designation of cowpea as a crop that would benefit from biotechnology improvement (USAID 2003) is in step with recent regulatory developments in Nigeria.

3. CROP–TECHNOLOGY SELECTION AND STATUS OF TECHNOLOGY

IR cowpea was one in a list of crop and trait combinations considered for this economic study. The selection of crop–technology combinations followed a process, which included discussions among national key stakeholders who considered not only the economic and food security relevance of a range of crop–trait options but also the progress to date of the research and regulatory processes. Using these criteria, stakeholders in Nigeria selected IR cowpea, NEWEST rice, biofortified sorghum, and IR maize as the most promising candidates. This selection was presented to a wider group of government representatives and crop and technology experts and was narrowed down to IR cowpea and NEWEST rice. However, for reasons having to do with logistics, financing, and timing, only IR cowpea was retained for ex ante assessment of the benefits of introducing a GM crop in Nigeria. A key factor in the decision was that IR cowpea presented the most visible progress toward the development and general release of a GE product among the commodities shortlisted.

The following is a time line of key implementation activities for BioRAPP Nigeria:

- May 2016—Inauguration of the BioRAPP project
- 2017—Agricultural Research Council of Nigeria identified as partner organization
- September 2017—National steering committee meeting at Kaduna
- 2017—Country lead economist identified
- May 2017—Training of country lead economists, Tanzania
- June 2018—Stakeholder planning meeting convened
- June 2018—Selection of two crops, cowpea for insect resistance and maize (WEMA)
- July–September 2018—Data collection and management
- October 2018—Training of lead economists, IFPRI headquarters
- October 2018—Final focus on only cowpea

The Institute for Agricultural Research has bred multiple cowpea varieties, some of which are listed in Table 1. Significant progress has been made in developing cowpea resistance or tolerance to a wide range of yield-reducing stress factors. However, none of the improved varieties, including those shown in Table 1, is resistant to *Maruca vitrata.*

Table 1 Cowpea varieties, Institute for Agricultural Research

Trait	Cowpea variety
Disease resistance	TVU 12349
Striga resistance	B 301, IT81D-994
Alectra resistance	B 301
Aphid resistance	TVU 3000, IT84S-2246-4
Storage weevil resistance (*Bruchids*)	TVU 2027
Thrips	Santzi
Drought resistance	TVU 11878
Seed size	Kanannado, IT81D-994
Very early maturing, insect tolerant	Sampea 8
Medium maturing, resistant to several diseases, dual purpose—grain and fodder	Sampea 9
Early, *Striga* and *Alectra* resistant	Sampea 10
Nematode resistant, large seed, good for dry season	Sampea 11
Early, disease resistant, *Striga, Alectra,* and drought tolerant	Sampea 12
Medium maturing, erect, insect tolerant, brown seeded	Sampea 13
Early maturing, *Striga* and *Alectra* resistant, resistant to major diseases and tolerant to insects	Sampea 14, 15, 16

Source: Ishiyaku (2017).

The development of *Maruca*-resistant cowpea began in 2001 as a multistakeholder project involving organizations within and outside Nigeria with "the establishment of the Network for the Genetic Improvement of Cowpea for Africa (NGICA), the Rockefeller Foundation, USAID, the Bean/Cowpea Collaborative Research Support Program (CRSP) and AATF" (Murdock, Sithole, and Higgins 2013, 226).

Table 2 summarizes the goal, objective, and key steps in the development of an IR cowpea that has been evaluated to be tolerant to *Maruca vitrata* (Ishiyaku 2017), and Table 3 shows operational milestones achieved since the AATF *Maruca*-resistant cowpea project started in Nigeria in 2008. The process of introducing the IR gene into a local cowpea variety to enable the crop to protect itself against insect attacks by *Maruca* is almost finalized in Nigeria. National experts working on the project expect that by the end of 2019 IR cowpea will be available for release, pending a decision by local authorities (Ishiyaku 2018).

Table 2 Development of *Maruca vitrata*–resistant cowpea varieties, Institute of Agricultural Research

Project	Description
Goal	Improved productivity of cowpea on smallholder farms
Objective	Development, testing, and deployment of *Maruca*-resistant cowpea in Africa
Step 1	Genetic transformation of cowpea using cry1Ab gene
Step 2	Test efficacy of gene under field conditions
Step 3	Introgress transgene into preferred local varieties
Step 4	Commercial release of insect-resistant varieties following regulatory requirements

Source: Ishiyaku (2017).

Table 3 Development of *Maruca vitrata*–resistant cowpea: Milestones and time line, 2008–2016

Year(s)	Milestone
2008	Project start-up
2009	Permit for confined field trials granted by the Biosafety Office, Ministry of Environment
2010	Confined field trials, Zaria
2012	Larvae infestation of transgenic/nontransgenic varieties
2013–2016	Farmer-managed multilocation trials • Locations: Samaru, Bakura, and Minjibir • Farmers: Six in each location o Each farmer tests local, transgenic, and nontransgenic o Each farmer applies two insecticide sprays only o Each farmer manages crop his or her own way

Source: Ishiyaku (2017) and AATF (2012).

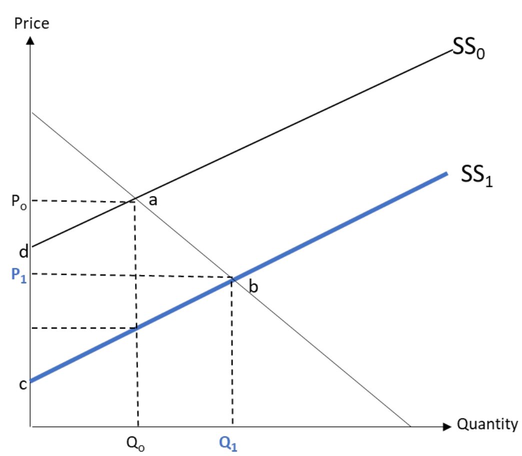
4. MODEL AND ANALYTICAL APPROACH

The ex ante economic analysis of IR cowpea presented in this study is conducted using a multiregion economic surplus model (ESM) as described by Alston et al. (1995). The ESM has been used extensively to evaluate research investments and investment allocation. The ESM has an advantage over other more sophisticated methods in that it is parsimonious in terms of data requirements and model handling, both key in the implementation of this project.

According to Alston et al. (1995) the main drawbacks of their proposed ESM approach are that it ignores transaction costs, externalities, and general equilibrium effects, but they say that most of those factors can be at least partially addressed by incorporating them into the estimated cost and benefits variables. This study offers different scenarios to account for the variability in key parameters, such as adoption rates and expected yield changes. As we note in the next section, many of the parameters required to estimate the ESM are drawn from, and in some cases estimated using, the Nigeria GHS 2015–2016.

Alston et al. (1995) describe in detail the ESM implemented in this report; the equations described below refer only to the basic model in a closed economy. The introduction of a technology—in this case, a GM technology—if effective, will enable producers to decrease their unit cost by reducing their input use and/or increasing their yield. This change is reflected in the shift of the supply curve from SS_o to SS_1, as depicted in Figure 1. .

Figure 1 Measuring welfare effects of a technology through the induced shift of the supply curve



Source: Authors' linearized schematic interpretation.

The technology-induced shift in the supply curve will result in a lower clearing price, moving the equilibrium price down from P_0 to P_1, with increments in quantities from Q_0 to Q_1. Producers gain because even though they are selling at a lower price, they can produce more due to the technology-induced cost change. Consumers gain because they benefit from the reduction in price. The net welfare effects of the technology-induced shift of the supply curve is measured as the net change in consumer surplus (ΔCS) and producer surplus (ΔPS), represented by the area *abcd* in Figure 1.

Following the Alston et al. (1995, 210) notation, the net welfare effect in a closed-economy model can then be estimated according to equations 1 through 3, which use prices, quantities, elasticities, and the research-induced unit cost change due to yield increase or input cost reduction.

$\Delta CS = P_0 Q_0 Z\,(1 + 0.5 Z\eta)$ Change in Consumer Surplus (1)

$\boldsymbol{\Delta PS = P_0 Q_0 (K - Z)(1 + 0.5\, Z\, \eta)}$ **Change in Producer Surplus** **(2)**

$\boldsymbol{\Delta TS = \Delta CS + \Delta PS}$ **Change in Total Surplus** **(3)**

Where $Z = \left(K - \frac{K\,\varepsilon}{\varepsilon + \eta}\right)$ is the price reduction due to supply shift,

K = proportionate vertical shift of the supply curve induced by a cost reduction

ε, and η = elasticity of supply and demand, respectively.

This basic closed-economy ESM approach (equations 1 through 3) can be modified to estimate a multiregion technology adoption with associated regional production characteristics, used in this report and described by Alston et al. (1995, 212–218).

To conduct the ex ante assessment of IR cowpea, this report uses DREAMpy (Dynamic Research Evaluation for Management, Python version), an IFPRI-developed open-source software that implements the ESM.

5. DATA SOURCES AND ESTIMATIONS

Regional data for cowpea production, yield, cost of production, and consumption were all drawn from Nigeria's GHS 2015–2016. That survey dataset has several advantages but also some disadvantages, as follows:

Advantages:

- Detailed information on production at the plot level
- Plot-level data for input use, including pesticide
- Total costs and labor use
- National consumption (all households) and specific urban and rural consumption by region
- Allows us to calculate imports
- Information on gender and detailed household characteristics

Disadvantages:

- Not nationally representative for cowpea production
- Northern regions are overrepresented in the survey while southern regions, with a small share of total production, are clearly underrepresented

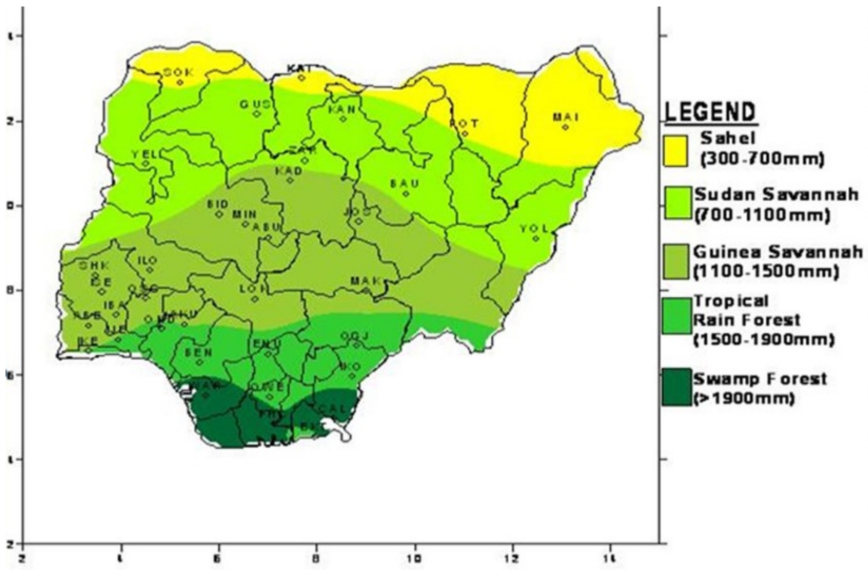
To use these data as the main source for the analysis, we proportionally adjusted household weights in over- and underrepresented regions so that output shares of all regions matched value shares of those same regions as reported in the annual Agricultural Performance Survey conducted by the National Agricultural Extension Research Liaison Services (Ahmadu Bello University, Zaria) in conjunction with state-run agricultural development programs. Regional cowpea imports were estimated using the data derived from this survey. National producers' prices were drawn from Nigeria's National Bureau of Statistics, and we used secondary data to estimate regional producers' prices. Data for R&D costs were supplied by local experts. Detailed information for all these data follows.

Geographical Zones

We follow Aremu et al. (2017) and divide Nigeria into five agroecological zones (AEZs), that is, geographic areas with similar climatic conditions: swamp forest, tropical rain forest, Guinea savannah, Sudan savannah, and Sahel savannah (Figure 2). The swamp forest and tropical forest AEZs occupy the southern part of the country, and they show a bimodal seasonal rainfall distribution, although the rainfall pattern in the tropical forest demonstrates less intensity and a clear distinction between wet and dry seasons. Average rainfall in the swamp forest is about

2,500 mm and in the tropical forest about 1,500 mm. The two zones show no differences in temperature with an average annual temperature of about 26°C. Located roughly in the middle part of the country, the Guinea savannah covers the largest area and has a unimodal rainfall distribution with an average rainfall and temperature of about 1,000 millimeters and 27.3°C, respectively. Finally, two major zones are found in northern Nigeria: the Sudan savannah and the Sahel savannah. The former extends as an arc from west to east and has annual average rainfall of 700 to 1,100 mm and a prolonged dry season of six to nine months. The Sahel region is mostly located in the extreme northeastern part of the country, with average annual rainfall of between 300 and 700 mm and a dry season that can last as long as nine months.

Figure 2 Agroecological zones of Nigeria with locations of weather stations



Source: Aremu, Bello, Aganbi, and Festus (2017). Used under the Creative Commons 4.0 International License.

As rainfall and humidity play a major role in the regional distribution and virulence of *Maruca vitrata,* we aggregated the five AEZs into three main zones based on their annual precipitation levels and precipitation distribution. The first zone includes the swamp forest and the tropical rain forest, and we will call this the forest zone. This region has a bimodal seasonal rainfall and annual precipitation of more than 1,500 mm. The second zone is the Guinea savannah, with unimodal rainfall distribution and annual precipitation between 1,100 and 1,500 mm. The third region results from aggregating the Sudan savannah and the Sahel; this zone has annual precipitation of less than 1,100 mm. Table 4 shows the characteristics of these three aggregated AEZs.

Table 4 Main characteristics of production regions

	Forest-derived savannah	Guinea savannah	Sudan-Sahel savannah
Average annual temperature (°C)	26.6	26.0	26.4
Annual rainfall (mm)	2,100	1,304	813
Rainfall in most humid quarter (mm)	746	597	544
Rainfall in 2015	1,557	1,176	796
Rainfall in most humid quarter 2015 (mm)	659	557	579
Distance to road (km)	4	5	7
Distance to a town of 20,000 (km)	16	20	31
Distance to market (km)	47	85	62
Distance to border (km)	403	289	144
Distance to state capital (km)	43	52	79

Source: Authors' elaboration based on GHS 2015–2016 data.

According to Agunbiade et al. (2012) the implementation of effective cultural, chemical, and biological control strategies to limit *Maruca vitrata* damage to cowpea crops in West Africa depends on a basic understanding of the insect population structure and migration and their relationship to agroecologies. For this, it is important to distinguish between the humid regions, where infestation of *Maruca* is endemic throughout the year, and the drier, migratory regions. In the north (the Sudan-Sahel savanna in our regional classification), resistance to control methods may spread only slowly among *Maruca vitrata* populations because they eventually die out during the long dry season of six to nine months. On the other hand, insect populations in endemic humid zones (forest zone) act as source populations. In this zone, *Maruca* can be found on different host plants throughout the year, migrating to the Guinea and the Sudan-Sahel when rainfall and humidity conditions favor growth of insect populations in those zones.

When infestation of the crop occurs, larvae feed on flowers, buds, and pods, which protect the larvae from natural enemies and other adverse factors, including insecticides. Infestation starts in the terminal shoots (21 days after planting) but later spreads to the reproductive parts. Losses in grain yield have been estimated to range from 20 to 80 percent. Seasonal variation in yield losses is illustrated in 1980s Nigeria, where cowpea yield loss was 72 percent in 1985 and 48 percent in 1986 (Sharma 1998).

Production and Yields

Table 5 summarizes yields, area, and production of cowpea in the three aggregated AEZ zones. The average yield for the country is 0.67 t/ha. The Guinea and Forest zones show similar average yields that are close to the national average, while yields in the Sudan-Sahel zone are higher (0.74 t/ha). The Guinea and Sudan-Sahel zones produce a similar share of national cowpea output (40 percent), while the largest area of the crop is in the Sudan-Sahel region—44 percent compared to 39 percent and 17 percent of output in the Guinea and forest regions, respectively.

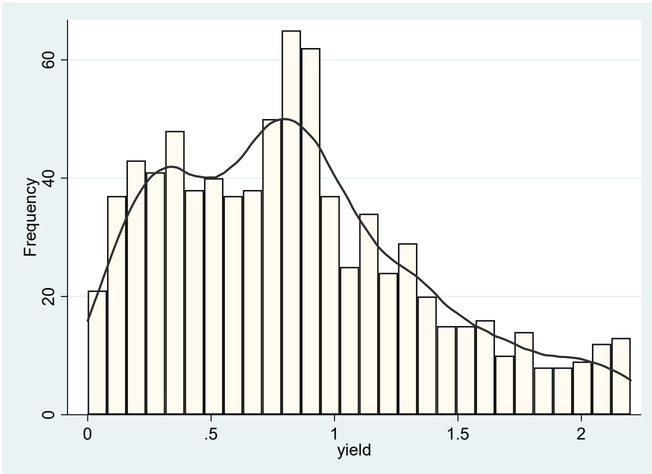
Table 5– Yield, area, and production of cowpea by aggregated AEZ, 2015–2016

AEZ	Yield (t/ha)	Area (ha)	Area share (%)	Production (t)	Production share (%)
Forest-derived savannah	0.63	661,969	19	482,318	21
Guinea	0.61	1,235,003	36	866,046	37
Sudan-Sahel savannah	0.74	1,523,612	45	984,167	42
Country	0.67	3,420,584	100	2,332,530	100

Source: Authors' elaboration based on GHS 2015–2016 data.

Yields were assumed to range between 0 and 2.3 t/ha, so higher yields in the survey were adjusted based on the level of inputs used by each household. To do this, yield was regressed against inputs per hectare (herbicide, fertilizer, labor, value of animal stock, and machinery) and two categorical variables taking a value of 1 if the household used certified seed or used pesticide, and 0 otherwise, including only households with yields below 2.3 t/ha.,. This regression was used to predict out-of-sample yields of households with yields higher than 2.3 t/ha, adjusted to each household use of inputs. The distribution of yields is shown in Figure 3.

Figure 3 Distribution of cowpea yields, 2015–2016



Source: Authors' elaboration based on GHS 2015–2016 data.

Costs of Production

Table 6 shows the average cost structure of cowpea production per kilogram of output and per hectare in naira. The Sudan-Sahel savannah is the region with the lowest costs of production—almost half of cost levels observed in the Guinea savannah and one-third of those in the forest region. Land and labor represent almost 90 percent of the cost in the forest region and two-thirds of total cost in the Sudan-Sahel savanna. Costs of pesticides, herbicides, land, and labor are much lower in the Sudan-Sahel savannah than in other regions and explain the comparative advantage of this region in cowpea production.

Table 6 Costs of production by aggregated AEZ, 2015–2016

	Cost (in naira) per kg of output			Cost (in naira) per ha		
Cost category	**Forest-derived savannah**	**Guinea**	**Sudan-Sahel savannah**	**Forest-derived savannah**	**Guinea**	**Sudan-Sahel savannah**
Pesticide	15.28	6.03	4.98	11,133	4,227	3,216
Fertilizer	0.44	12.93	12.09	319	9,069	7,810
Herbicide	10.99	6.13	3.24	8,006	4,300	2,094
Machinery—rental	2.99	5.76	1.37	2,175	4,040	886
Machinery—owned	0.47	0.32	0.49	346	221	318
Animal traction	0.09	2.00	7.82	67	1,401	5,054
Labor[1]	152	139	36	111,032	97,166	23,169
Land	77	26	22	55,894	17,976	14,374
Total	259	197	88	188,974	138,399	56, 920

Source: Authors' elaboration based on GHS 2015–2016 data.

1 Cost of hired labor.

Consumption

The GHS 2015–2016 provides a complete picture of cowpea consumption in Nigeria, summarized in Table 7. With a population estimated at 179 million people, total consumption of cowpea in 2015–2016 was 2.6 t.

Table 7 Rural and urban consumption of cowpea by region, 2015–2016

	Population (millions)	**Consumption (kt)**	**Consumption per person (kg)**
Rural			
Forest-derived savannah	35	350	10.1
Guinea	23	326	14.1
Sudan-Sahel savannah	52	922	17.8
Subtotal	*110*	*1,598*	*14.6*
Urban			
Forest-derived savannah	29	408	13.9
Guinea	27	415	15.4
Sudan-Sahel savannah	13	191	14.9
Subtotal	*69*	*1,014*	*14.7*
Total			
Forest-derived savannah	64	759	11.9
Guinea	50	741	14.8
Sudan-Sahel savannah	65	1,113	17.2
Nigeria	**179**	**2,613**	**14.6**

Source: Authors' elaboration based on GHS 2015–2016 data.

Imports

Total annual human consumption of cowpea in Nigeria amounts to 2.6 t, while total output in 2015–2016, as calculated from the Living Standards Measurement Study (LSMS) survey, was 2.2 Mt. Of the total output, postharvest losses and use for seed or feed account for 0.33 Mt. The final output available for human consumption is then 1.9 t. Using these figures, it is estimated that Nigeria imports almost 725 thousand t of cowpea to make up the difference between domestic production and consumption, as Table 8 shows.

Table 8 Cowpea production, human consumption, and import demand (t)

	Forest-derived savannah	Guinea	Sudan-Sahel savannah	Total
Production	482,318	866,046	984,167	2,332,530
Consumption	758,846	740,951	1,112,898	2,612,695
Seed	17,499	92,259	126,957	236,715
Feed	-	3,297	7,967	11,263
Postharvest losses	26,388	74,328	95,801	196,517
Final supply	438,431	696,162	753,443	1,888,036
Demand—final supply	-320,416	-44,789	-359,455	-724,659

Source: Authors' elaboration based on GHS 2015–2016 data.

Prices

Market prices for the year 2016 by state were obtained from Nigeria's National Bureau of Statistics. As no detailed data on regional producer prices were available, we used information on marketing margins from Ejiga and Robinson (1981) and Akpan, Udoh, and Udo (2014) to calculate producer prices, assuming a 30 percent margin for northern regions and 25 percent for southern regions. Table 9 shows the results of these estimations.

Table 9 Average prices of output and selected inputs

	Forest-derived savannah	Guinea	Sudan-Sahel savannah
Cowpea (N/kg)	224	174	149
Fertilizer (N/kg)	161	143	123
Pesticide (N/L)	891	967	1,048
Labor (N/day)	610	368	279
Land (N/ha)	52,103	21,942	21,183

Source: National Bureau of Statistics, Nigeria, and authors' elaboration.
Note: Price of white black-eyed beans sold loose. N = naira; kg = kilogram; L = liter; ha = hectare.

R&D Costs

The IR cowpea research cost was obtained from the IR cowpea project office at the Institute for Agricultural Research at Ahmadu Bello University, Zaria (courtesy of professor M. F. Ishiyaku, the project's principal investigator.)

National and regional extension costs were unavailable, but they were estimated using information on cowpea from a project (Mussa et al 2011) that estimated research and extension costs in two West African countries. Moussa et al. (2011) observed cowpea research cost as $1.94 million and cowpea extension cost as $0.31 million; thus, for our purposes, we estimate that the share of extension in the total cost is 13.9 percent, as follows [0.31/(1.94+0.31)]*100.

Estimates for seed multiplication costs were calculated from Negreri and Melaku (2001) who estimated the cost of hybrid maize seed production and commercialization .

Changes in Yields and Costs

To evaluate the impact of introducing IR cowpea we use the information available in the GHS 2015–2016 database on the relationship between yields and the use of pesticide and other inputs. The strategy we follow is first to determine the yield response to levels of pesticide and other inputs and, second, to use information on yield response to determine the impact of introducing a new variety by making the following assumptions:

- We assume that the yield farmers will get with the new IR variety is equivalent to the average yield of the 20 percent of households with the highest yields observed at present in each region.
- To obtain that yield with the new IR variety, producers in all regions will still need to spray twice to protect the crop from other pests.
- Adoption of IR cowpea will increase the cost of seed above the cost borne by those using non–IR improved or local varieties. How much that cost will increase is not clear at present, so for this purpose we use information on seed cost per hectare for IR cowpea, local, and improved varieties as discussed in Ezeaku, Mbah, and Baiyeri (2017).

These assumptions mean, for example, that the expected benefit for producers using high levels of pesticides and obtaining high yields from adopting the IR cowpea variety is the reduced cost of pesticides, as no increase in yields is expected. On the other hand, we assume that when producers with lower yields adopt the IR cowpea variety, yields will increase to the level of those in the top two tenths of the yield distribution if they still spray two times, as discussed above. Benefits from adoption for these producers result from the increase in yields and from the difference in the level of pesticide use before and after adoption. For example, a producer not using pesticide at present is assumed to increase yields (benefit) as long as he or she starts using pesticide at the recommended levels (increased cost). Table 10 summarizes the effect of introducing the IR cowpea variety on costs and yields.

If the average producer in each region were to adopt the new technology, the expected yield increase would be 67 percent in the forest region, 120 percent in the Guinea savannah, and 88 percent in the Sudan-Sahel savanna. The fifth row in Table 10 shows the area under improved varieties derived from the GHS 2015–2016 survey. This area is low, constituting a maximum of 17.5 percent in the Guinea savannah and 6.8 percent in the Sudan-Sahel savannah; in the forest region it is below 1 percent.

Table 10 Yields, seed costs, and pesticide costs in cowpea production and assumptions for the new technology

	Forest-derived savannah	Guinea	Sudan-Sahel savannah
Yield (kg/ha)			
Actual average yields	637	755	892
Potential yields with IR variety	1,065	1,663	1,675
Yield change per hectare (%)	67	120	88
Area under improved seed (%)	0.0	17.5	6.8
Seed cost (naira/ha)			
Local	3,644	2,671	2,280
Improved	9,504	9,140	8,515
Actual (defined in text below)	3,516	4,899	2,959
IR variety	17,876	17,669	14,924
Increase in seed cost %	508	361	504
Area under pesticide (%)	74	50	41
Average use including nonusers (L/ha)	5.7	3.1	2.3
Average use users only (L/ha)	7.7	6.2	5.7
Recommended use (L/ha)	6.7	4.3	3.6

Source: Authors' elaboration based on GHS 2015–2016 data and Ezeaku, Mbah, and Baiyeri (2017).

The cost of seed per hectare of local, improved, and IR varieties shown in Table 10 is from Ezeaku, Mbah, and Baiyeri (2017). We used those costs to calculate the actual costs in the LSMS survey by assigning those costs to each producer based on his or her declared use of improved or local varieties. The average cost of seed observed at present is shown in the "Actual" row in Table 10 and ranges from around 3,000 to almost 5,000 naira per hectare. The increase in seed cost is the difference from the defined "actual" cost and the cost of IR variety from Ezeaku, Mbah, and Baiyeri (2017), as shown in Table 10. This increase is smallest in the Guinea savannah because that region has the highest adoption of improved varieties at present.

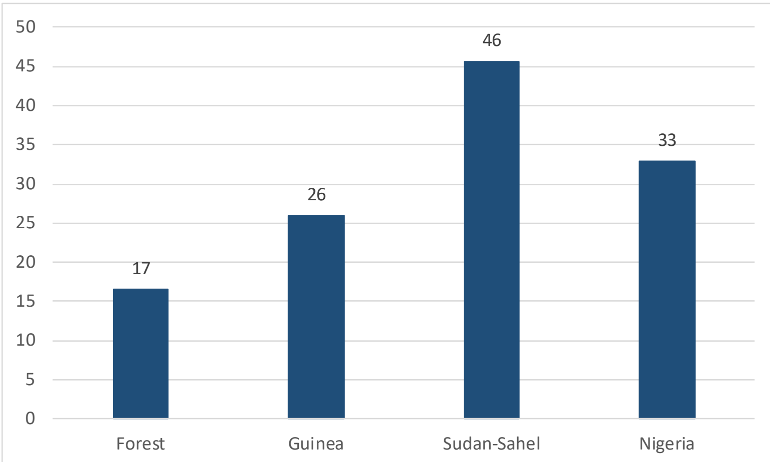
Finally, the last four rows in Table 10 show the 2015–2016 area under pesticide use, the estimated number of liters of pesticide used per hectare both including and excluding nonusers of pesticides as well as the recommended dosages. The area under pesticide is related to average precipitation. In the Sudan-Sahel savannah only 40 percent of the area under cowpea is under pesticide use; that figure rises to 50 percent in the Guinea savannah and 74 percent in the forest region. Notice that adoption of the IR variety by pesticide users could result in a significant reduction in total pesticide use. However, if nonusers of pesticide adopt this practice together with the IR variety, the total use of pesticide could increase with respect to present use.

Expected Adoption of the New Technology

The final key assumption for the ex ante evaluation is the expected adoption rate of the new variety. The literature reports high ex post adoption rates of an improved cowpea variety in the semiarid savannas of Nigeria as discussed by Gbègbèlègbè et al. (2015). However, those authors point out that a weak seed industry could hinder the adoption of improved cowpea technologies. Furthermore, Aluko et al. (2016) found that the Boko Haram insurgency has drastically affected the supply and distribution of agricultural produce, especially cowpea, from northeast Nigeria to the markets in the south due to unwillingness of traders to go to the troubled zone. Given the difficulty in defining a likely rate of adoption of the new technology, we estimate an ex ante probability of adoption using the GHS 2015–2016 data.

The closest precursor to our study is that of Kristjanson et al. (2005), where the authors examine the impact in Nigeria of the adoption of improved varieties of dual-purpose cowpea, developed by IITA and the International Livestock Research Institute. They analyze factors affecting the adoption and impact of the technology across different socioeconomic domains as defined by degree of market access and population density. They do this by linking participatory research methods, geographic information system techniques, village- and household-level surveys, and a tobit analysis. In this study, we depart from Kristjanson et al. in several ways. First, as we do not observe the adoption of IR cowpea, we look at the adoption of pesticide as an ex ante proxy for the adoption of the IR variety. As the new cowpea variety is a partial alternative to the use of pesticide, we expect that farmers already using pesticide will consider adopting IR cowpea. Similarly, as farmers need to buy chemical pesticides, we assume that farmers that have difficulties accessing markets to buy pesticide will face similar problems in buying seed of the improved variety. Second, we employ a different approach than the one used by Kristjanson et al. (2005) use, as we use a probit maximum likelihood regression model. A description of the variables included in the model and the econometric results of the estimation can be found in Appendix A. Figure 4 shows the ex ante average estimated probabilities of adoption for households in different AEZs. .

Figure 4 Probability (%) of adoption of the new technology by AEZ



Source: Authors' elaboration based on GHS 2015–2016. .

Supply and Demand Elasticities

We found the best available information on supply elasticities in the work by Langyintuo and Lowenberg-DeBoer (2006), where the authors use a spatial and temporal price equilibrium model to assess the potential impacts of farmers in West and Central Africa adopting IR cowpea. A supply elasticity of 0.20 used by Langyintuo and Lowenberg-DeBoer (2006) is also used by Gbègbèlègbè et al. (2015).

We found the most reliable and up-to-date information on demand elasticities in the study by Alene (2016), where the author estimates household food demand using a two-stage censored demand system with a focus on cowpea in Nigeria using nationally representative household survey data collected by the World Bank's LSMS in 2012–2013. The study's main findings are that cowpea consumption is more frequent among urban than rural households and among better-off households compared with poor ones and that per capita consumption of cowpea increases with income among both rural and urban households. The results show that whereas cowpea demand is price inelastic (-0.24 for urban and -0.44 for rural households), cowpea demand is income elastic, where a 1 percent increase in household income leads to more than a 1 percent increase in demand. According to Alene, given the high food expenditure elasticities and high population and per capita income growth rates in Nigeria, the growth rate of demand for cowpea is expected to be high (4.8 percent per year). In comparison, Langyintuo and Lowenberg-DeBoer (2006) uses a demand price elasticity of -0.2 for all regions.

Table 11 summarizes the different parameters used in the estimations of the ESM and inputted into DREAMpy. While some parameters are common to all regions (base year, simulation years, and discount rate), most are disaggregated and were in many cases estimated at the regional level, to account for differences in population growth in AEZs and the adoption effects of IR cowpea across these regions. The exchange rate listed in Table 11 is for the base year and was used to convert all estimations into US dollars, as the model was run in naira, the Nigerian local currency.

Table 11 Key parameters and assumptions

Parameter	Unit	Region				Niger
		All	Forest-derived savannah	Guinea	Sudan-Sahel savannah	
Base year		2016				
Simulation years	Number	25				
Discount rate	%	9.89				
Exchange rate	Naira/USD	254				
Supply elasticity		0.125	0.125	0.125	0.125	0.125
Demand elasticity			-0.369	-0.351	-0.400	-0.4
Supply growth	%/year		4.48	5.01	3.73	2.0
Demand growth	%/year		5.17	5.25	3.86	
Cost change	%					
Yield change	%		5.28	8.47	15.18	
Combined shift	%		5.28	8.47	15.18	
Prob. of success	%		80	80	80	100
Max adoption rate	%		15	24	45	
Years to max adoption	Number		9	8	5	

Source: Authors’ elaboration based on GHS 2015–2016; World Bank (2019) for 2016 exchange rate, Central Bank of Nigeria for discount rate.

6. RESULTS DISCUSSION

The results we present here are based on the data, estimations, and assumptions detailed in the previous section and use the ESM modeled in DREAMpy, described in Section 4. We also present comparative results using the extreme values of key parameters obtained from the sensitivity analysis (for more information see the later subsection "Sensitivity Analysis"). To do this we use the upper limit of the yield change and adoption rate distribution as well as the most optimistic year of adoption to estimate what we label the "optimistic scenario," depicted in the infographic presented in Appendix C and produced and distributed before this paper was finalized.

Potential Welfare Effects of IR Cowpea Adoption

The estimated present value of the net benefits for producers and consumers of adopting IR cowpea is US$350 million, 70 percent of which is accrued by producers, as summarized in Table 12. The distribution of these benefits is very dissimilar across the three regions, which is congruent with the distinct characteristics of the regions as described in the previous section.

Table 12 Benefits to consumers and producers—present value in million US dollars

Region	Producer	Consumer	Total
Forest-derived savannah	2.3	28.4	30.8
(max min scenarios)	*(7.8 0.8)*	*(98.2 1.5)*	*(106 2.3)*
Guinea	45.1	27.9	73.0
(max min scenarios)	*(148.4 4.7)*	*(96.4 1.5)*	*(244.7 6.2)*
Sudan-Sahel savannah	210.9	34.7	245.6
(max min scenarios)	*(624.5 8.4)*	*(121.6 1.7)*	*(746.1 10.1)*
All	258.3	91.1	349.4
(max min scenarios)	*(780.7 13.9)*	*(316.2 4.7)*	*(1,096.8 18.7)*

Source: Authors' summary based on DREAMpy simulations.
Note: Numbers are for the modeled scenario. We labelled numbers in parentheses and in italics as the optimistic (max) and pessimistic (min) scenarios. These scenarios se the modeled estimations and assumptions, except for having the highest (optimistic) and lowest (pessimistic) values for yield change and adoption.

The Sudan-Sahel savannah region produces more than 40 percent of all cowpea and is where we have estimated that IR cowpea will have both the highest adoption rate and the maximum induced change in cowpea yields, as Table 12 shows. On the other end, with the lowest adoption rates and induced yield, is the forest region. Since the forest region contributes only 20 percent of national production but demands 40 percent of all cowpea traded in Nigeria, the expected benefits are relatively low and mostly gained by consumers, given the projected lower prices due to the adoption of IR cowpea.

Aside from the modeled scenario, Table 12 also presents minimum and maximum projected benefits for each of the regions. These values are the result of using the same assumptions and estimations of the main scenario (called hereafter “most likely”) except for changes in three parameters that are considered critical. Results of a sensitivity analysis to changes in these parameters are presented later in this section.

Benefits to Producers

As Table 12 shows, the total benefits accruing to producers from the adoption of the IR cowpea variety amount to US$258 million. We now look at how those benefits are distributed among different types of producers using household data and the estimated probability of adoption from the Nigeria GHS 2015–2016. To do this, we classify all cowpea producers into three categories of typical farm area as shown in Table 13.

On average, cowpea producers have an average farm size of 0.94 ha and produce 0.22 t of cowpea in 0.33 ha with an average yield of 726kg/ha and 575 kg per worker.

Of the 10.4 million households that produce cowpea, 5.4 million are classified as small with a total farm area of only 0.17 ha, harvesting a total of 0.19 ha of cowpea. Yields of small producers are the highest (821 kg/ha) while labor productivity is 559 kg per worker. The group of large producers, on the other hand, has an average farm area of 3.23 ha, producing almost 500 kg of cowpea in 0.76 ha with an average yield of 760 kg/ha. Labor productivity of large producers is the highest among the three groups (844 kg per worker). Small producers sell 22 percent of output and consume 52 percent. In contrast, large farmers sell 34 percent of output and consume 29 percent. Between these two groups of households we define an intermediate group that closely represents the average cowpea producer. Female-headed households make up on average 21 percent of all producer households; they represent 35 percent of small producers but only 2 percent of large producers. Table 13 presents the estimated benefits of IR cowpea adoption for the different types of cowpea producers.

Table 13– Main characteristics of cowpea producers grouped by farm size

	Small	Average	Large	Total
Average farm area (ha)	0.17	0.85	3.23	0.94
Average cowpea production (t)	0.145	0.215	0.457	0.223
Average cowpea area (ha)	0.19	0.30	0.76	0.33
Yield (kg/ha)	821	770	693	726
Labor productivity (kg/worker)	559	433	844	575
Share of sales in output (%)	21.8	26.9	34.1	26
Share of seed in output (%)	8%	15%	18%	12%
Share of consumption in output (%)	52%	36%	29%	43%
Cost per kg (naira)	168	125	81	139
Cost per worker (naira)	31,001	23,180	32,381	28,960
Cost per hectare (naira)	92,847	56,381	31,849	70,815
Number of households (1,000s)	5,436	3,067	1,938	10,440
Households with female head (%)	35%	16%	2%	21%
Number of household members (1,000s)	33,900	24,100	17,600	75,600
Total cowpea area (kha)	951	2,599	6,258	9,808
Total cowpea production (kt)	788	660	885	2,333

Source: Authors' elaboration based on GHS 2015–2016.

Table 14 illustrates findings regarding the benefits accrued to different types of households based on the estimated probability of adoption. The total benefit of adoption equals US$25 per cowpea-producing household, which is equivalent to US$3 per person. If we consider only adopting households, adopters gain US$80 per household or US$10 per person. According to the results in Table 14, almost half of the total benefit of adoption of IR cowpea will go to large producers, who represent only 20 percent of all cowpea producers, while small producers, who represent half of all cowpea producers, will receive only 24 percent of the benefit. This is equivalent to US$11 on average for all small producers, US$43 for small producers that adopt the new technology, or US$6 per person of adopting small-producer households. The equivalent figures for large producers are US$63 on average for each large producer, US$166 for large producers that adopt the new technology, or US$18 per person of adopting large-producer households. The benefit per hectare of cowpea (total area including area of nonadopters) is highest for small producers (US$65); it is US$20 for large producers, while average producers gain US$28.

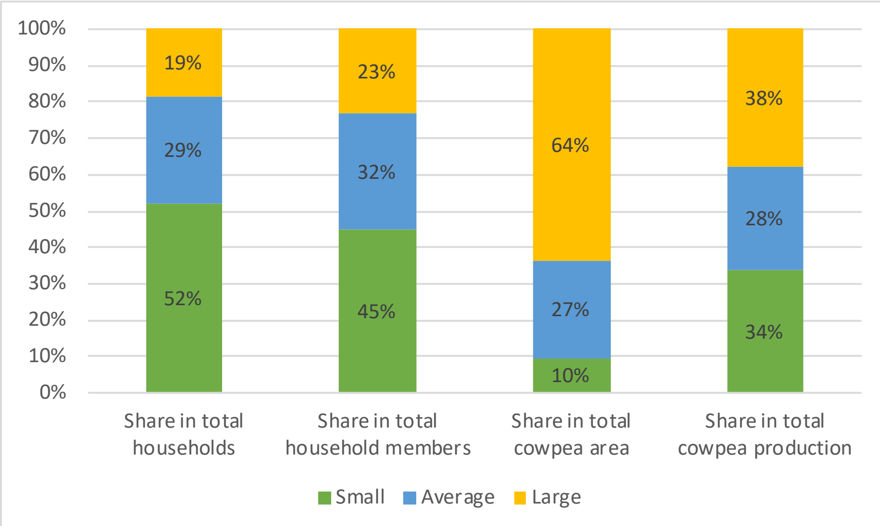
Table 14 Benefits of adoption of insect-resistant cowpea by type of producer

	Small	Average	Large	Total
Adopters and nonadopters				
Number of households (millions)	5.44	3.07	1.94	10.4
Number of household members (millions)	33.90	24.10	17.60	75.6
Adopters				
Number of households (millions)	1.44	1.04	0.74	3.2
Number of household members (millions)	10.10	8.64	6.87	25.6
Benefits				
Benefits (millions of US$)	61.8	73.7	122.8	258
Share in total benefits (%)	24	28	48	100
Benefits per household (all) (US$)	11	24	63	25
Benefits per household member (all) (US$)	2	3	7	3
Benefits per adopting household (US$)	43	71	166	80
Benefits per person of adopting households (US$)	6	9	18	10
Benefits per hectare of cowpea (US$)	65	28	20	26

Source: Authors' elaboration based on GHS 2015–2016.

Figure 5 shows the distribution of cowpea producers, household members, cowpea area, and cowpea production among the three groups of households. Small producers work only 10 percent of the total cowpea area and produce 34 percent of total output, but they make up almost half of all households producing cowpea and their household members constitute 45 percent of total household members. The group of large producers, instead, represents only 19 percent of households and 23 percent of household members but works 64 percent of total cowpea area producing 38 percent of output. The average-size group constitutes 29 percent of households and accounts for 27 and 28 percent of cowpea area and output, respectively.

Figure 5 Share of the number of households and household members, cowpea area, and output by household group



Source: Authors' elaboration based on GHS 2015–2016.

As shown in Figure 5, each of the three household types represents roughly the same proportion in the Guinea and the Sudan-Sahel savannahs. Large farmers constitute a slightly higher proportion in the Guinea savannah (30 percent) than they do in the Sudan-Sahel (25 percent). And we see a higher proportion of small households in the Sudan-Sahel than in the Guinea savannah (39 percent as opposed to 36 percent). The forest region shows a markedly different structure, as 90 percent of cowpea producers are classified as small farmers.

Table 15 illustrates the impact of adoption of IR cowpea on costs and yields for the different household types. The results show that IR cowpea adoption could result in increased costs per hectare with the largest proportional increases benefiting large producers. A cost increase from 33,100 naira per hectare before adoption to 39,500 naira with the IR cowpea variety represents a 20 percent increase in costs for large producers. In contrast, costs for small producers adopting the IR cowpea variety are estimated to increase by only 5 percent (from 106 to 111 thousand naira per hectare). These increases in costs per hectare are driven by the higher costs of labor and seeds. The costs of pesticide, on the other hand, are reduced substantially, by almost 40 percent (from 7,500 to 4,500 naira) in large producers and by 25 percent in small producers (from 11,100 to 8,300 naira). Increases in costs are compensated for by higher average yields as a result of reduced losses due to *Maruca vitrata,* as yields rise from 0.94 to 1.3 t/ha in the case of small producers and from 0.68 to 1.0 t/ha in the case of large producers. The final impact of adoption of IR cowpea is reflected in the cost per kilogram of output. Small farmers see their costs fall from 141 to 112 naira per kilogram (a 25 percent reduction); costs for average producers fall from 103 to 87 naira per kilogram (a 19 percent reduction); and costs for large producers decrease from 83 to 69 naira per kilogram—equivalent to a 20 percent reduction in costs per kilogram. .

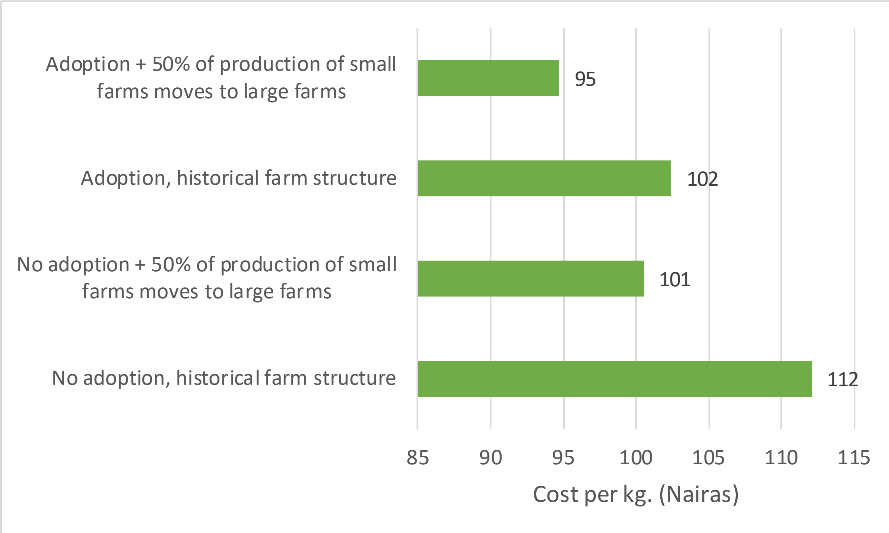
Table 15 Costs and yields with conventional and IR cowpea varieties by type of household (naira)

	Small		Average		Large	
	Standard variety	**IR cowpea**	**Standard variety**	**IR cowpea**	**Standard variety**	**IR cowpea**
Cost/kg	141	112	103	87	83	69
Labor cost/kg	79	60	28	28	14	13
Pesticide cost/kg	11	6	12	6	23	11
Seed cost/kg	6	7	27	18	15	12
Cost/ha	106,218	111,276	47,306	52,868	33,092	39,485
Labor cost/ha	53,549	54,082	16,540	17,606	4,445	6,081
Pesticide cost/ha	11,125	8,345	9,569	6,887	7,483	4,511
Seed cost/ha	3,266	5,402	3,563	5,241	3,654	5,250
Yield (kg/ha)	941	1,343	821	1,199	684	1,010

Source: Authors’ elaboration based on GHS 2015–2016. .

Notice how cost per kilogram of output varies between household types, with large farmers producing at lower costs per unit of output than small farmers. The effect of farm structure on the efficiency of cowpea production is shown in Figure 6. Farm structure and differences in cost-efficiency between producers have a significant effect on production costs and on the competitiveness of domestic production with imports. That could have policy implications given the focus of Nigeria’s goals, in terms of defining the most efficient way of supplying the domestic demand for cheap protein. Without changes in farm structure, the adoption of IR cowpea, as assumed in this study, reduces the production cost per kilogram from 112 to 102 naira. Almost the same cost reduction can be achieved by promoting production by larger and more efficient farmers without adoption of the new variety (101 naira per kilogram if 50 percent of total output produced by small farmers were instead produced by larger farmers). By combining adoption and a bigger share of large producers in output, costs per kilogram could reach 95 naira.

Figure 6 Effect of adoption of the insect-resistant cowpea variety and of farm structure on production cost per kilogram of output (naira)



Source: Authors' elaboration based on GHS 2015–2016.

Sensitivity Analysis

As we explain in the previous sections, the ex ante estimations summarized earlier in Table 12 rely on key parameters, some of which are based on current data on adoption of modern varieties, characteristics of cowpea production in Nigeria's regions, and, in some cases, experts' opinions. Given the reliance of these estimations on predicted or estimated parameters (such as expected adoption), it is critical to identify how sensitive estimated benefits are to changes in the value of these different parameters. To assess the sensitivity of our results, we determine triangular probability distributions for each of the key parameters by defining a range of values (maximum and minimum values) around the expected value, between which we allow parameter values to vary.

The sensitivity analysis can be done for many parameters, but to illustrate how sensitive these estimations are to variation, we use only the ones identified as most critical (listed in Table 16): yield change, maximum adoption, years to maximum adoption, and first year of adoption. The parameters *min* and *max* values listed in this table, used to generate the probability distribution, are the same parameters that we use to run the "pessimistic" and "optimistic" scenarios summarized in Appendix B.

Table 16 Parameter values for sensitivity analysis

Parameter	Scenario	Forest-derived savannah	Guinea	Sudan-Sahel savannah
Yield change	Estimated, "Most likely"	5.28%	8.47%	15.18%
	Min, "Pessimistic"	4.53%	6.30%	5.84%
	Max, "Optimistic"	9.63%	15.35%	27.48%
Max adoption	Estimated, "Most likely"	15%	24%	45%
	Min, "Pessimistic"	3%	5%	9%
	Max, "Optimistic"	24%	38%	64%
Years to max adoption	Estimated, "Most likely"	4	4	4
	Min, "Pessimistic"	7	7	7
	Max, "Optimistic"	3	3	3
First year of adoption	Estimated, "Most likely"	2020	2020	2020
	Min, "Pessimistic"	2023	2023	2023
	Max, "Optimistic"	2019	2019	2019

Source: Authors' elaboration and estimations based on GHS 2015–2016 and experts' opinions.

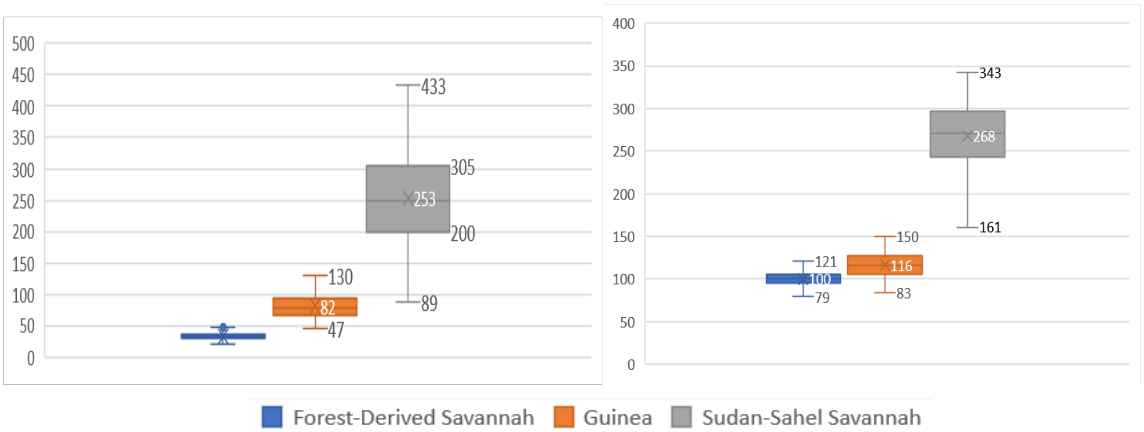
Yield Input Variation

The size of the producer surplus is determined by the technology-induced vertical shift of the supply curve—given by a cost reduction, a yield increase, or the combination of both. The estimated benefits to consumers and producers estimations shown in Table 12 rely on inferences made from the GHS 2015–2016 that the costs of production will remain unaffected overall while the "most-likely" yields will increase between 5 and 15 percent, as Table 16 shows.

Using the statistical parameters and percentiles of the distributions generated, Figures 7 and 8 illustrate the variation of benefits and internal rate of return (IRR) across regions due to variations in the estimated changes in yields. The median for each of the regions is, unsurprisingly, very close to the "most likely" estimate presented in Table 12, with interquartile range equally distributed around that median. Given the parameters of the distribution generated, Figure 7 shows that for the Sudan-Sahel savannah region, the most relevant region in terms of adoption, the probability that the estimated net benefits are above 200 million is 75 percent.

Figure 7 Insect-resistant cowpea: NPV and IRR sensitivity due to changes in yield input variable

a. Net present value b. Internal rate of return



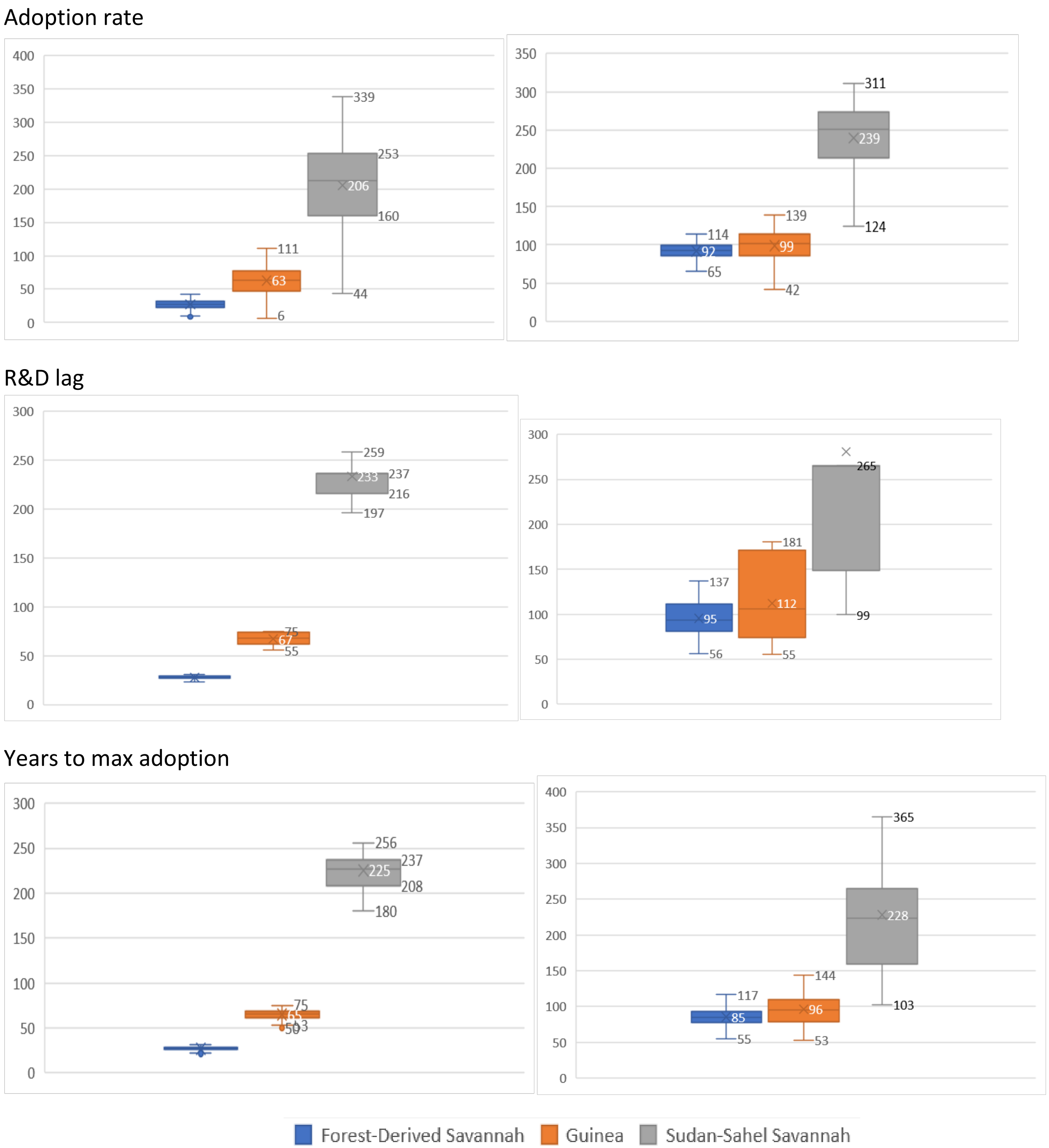
Source: Authors' elaboration based on DREAMpy simulations. Placement horizontally and the widths of the interquartile ranges displayed is arbitrary.

Other Input Variation

We performed a similar exercise as the one described for yields for other input variables. That exercise is summarized in Figure 8. Comparing across these different figures, we reveal that results are more sensitive to variations in yield and adoption rate of the new variety.

Figure 8 Insect-resistant cowpea: NPV and IRR sensitivity analysis due to changes in other input variables

a. Net present value b. Internal rate of return



Source: Authors' elaboration based on DREAMpy simulations.

Cost of IR Cowpea Adoption Delay

Under the most likely scenario, the estimated gains from the adoption of IR cowpea for consumers and producers will reach US$380 million. This assumes that the technology will be in farmers' fields in 2020 and that farmers will continue to increase their adoption over the next years, reaching the maximum adoption in the following five to nine years, depending on the region. If farmers cannot adopt due to delays in the approval process, for example, these benefits will be reduced by 37 percent, as Table 17 shows.

Table 17 Insect-resistant cowpea: Cost of a five-year regulatory delay

Region	Unit	Producer	Consumer	Total
Forest-derived savannah	Million USD	1.1	10.2	11.5
	%	47.8	35.9	37.3
Guinea	Million USD	17.0	10.1	27.0
	%	37.7	36.2	37.0
Sudan-Sahel savannah	Million USD	79.0	13.5	92.5
	%	37.5	38.9	37.7
All	Million USD	97.1	33.9	131.0
	%	37.6	37.2	37.5

Source: Authors' elaboration based on DREAMpy.

7. CONCLUSION AND RECOMMENDATIONS

The potential benefits for IR cowpea to producers and consumers in Nigeria were estimated using household disaggregated data and experts' opinions, which made it possible to model the potential adoption of the technology at a regional level. The gains at the farm level of IR cowpea are derived mainly from the expected protection against the endemic and widespread pod borer attacks, protection that will result in an increased production through higher yields. For consumers, the gains will come through a price reduction.

The estimates show that producers and consumers could gain US$ 350 million, largely in the Sudan-Sahel region, the predominant cowpea production region in the country. Given that these are ex ante estimates of a technology that has not been commercialized, these estimates rely on parameter values and assumptions that are likely to change. Using a sensitivity analysis, we find that the adoption rate and projected yield increases are the factors likely to most affect our estimated benefits.

Since the estimated benefits are calculated over a period of 25 years and discounted at an annual rate of about 10 percent, delays in the adoption of the technology will result in significant reduction of these benefits. We estimate that a 5-year regulatory delay will reduce benefits by more than 37 percent, equivalent to $137 million.

These findings underscore the opportunity for policymakers and decision makers to invest in policies that affect these critical variables, particularly to foster conditions to increase farmers' and consumers' uptake of these technologies. Investment in effective extension practices and seed delivery might be one such policy that could merit the attention of decision makers.

These finding also highlight the importance of having a functional biosafety system that can efficiently manage the regulatory process. In this regard, Nigeria made important strides by adopting the National Biosafety Management Agency (NBMA) Act in 2015, followed by the NBMA's launch. Since then, NBMA has established itself as the prime regulator, working through formal memoranda of agreement with other specialized agencies in the areas of environmental safety, food / feed safety and variety registration. Through this coordinated framework, several applications for GM crop field trials and GM commodity imports were approved and, more recently, general releases of GM insect-resistant cotton and cowpea were authorized. Thus, Nigeria managed to address several common challenges that countries face in implementing efficient biosafety decision-making procedures, such as those outlined below.

Regulatory decision-making is often a rate-limiting step in the product development cycle of agriculture GM technologies, and this can be especially problematic in developing countries, which have limited experience with actual products under large-scale cultivation. In such cases, development and implementation of regulatory policy often occurs in a product vacuum and may result in policies and processes which are counter-intuitive to those needed to safely evaluate these products in a timely, transparent, and scientifically sound manner. Issues may develop from the inclusion of non-science elements in the safety evaluation process (e.g., socioeconomic considerations, ethics) that may be difficult to define and thus extend the regulatory cycle, resulting in further delays of economic benefits. Inter- and intra-ministerial confusion about regulatory authority, often due to conflicting legislative mandates, can also add time to the process. In addition, capacity and confidence of regulators is important to ensure consistency in how regulatory policies and processes are applied and to ensure predictability in the application of regulatory laws and standards. The ability to develop systems that are locally affordable and enforceable can also affect regulatory review and monitoring which, in turn, may affect timely product evaluation and release, adoption and sustainability in the marketplace. Finally, public awareness of the safety evaluation system and the potential benefits of the novel biotechnology products is also a key component to foster public understanding in decision-making environments, which often focus solely on risk. In summary, competent biosafety systems such as firmly established in Nigeria, are necessary to ensure that the expected economic benefits are realized. While regulatory policy is not singular in terms of its impact on the adoption of innovation, it is an important component that must be critically evaluated in connection with the new products of biotechnology. Ultimately, an evidence-based, efficient, predictable and transparent regulatory system, which is well understood by stakeholders and well implemented, can potentially outweigh the financial costs associated with regulatory review, especially when evaluated against the potential economic gains of individual products.

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APPENDIX A ECONOMETRIC ESTIMATION OF ADOPTION MODEL

Probabilities of adoption of certified seed, pesticides and herbicides were estimated using probit maximum likelihood single regression and also as simultaneous models allowing for correlation across error terms among the input technologies (multivariate simultaneous Probit Regressions) . Results from both model estimation approaches were largely robust across the two estimators. The model estimates the categorical dependent variable *D* (*D* = 1 if using pesticide, 0 otherwise) on $X\hat{\beta}$. controlling for regional fixed effects. Variables used for the estimation of adoption are shown in Table A1.

Table A1–Summary statistics of Variables used at plot level

	Observations (number of Plots)	Mean	Std. Dev.	Min	Max
Plotuse certified seed	1,072	0.722	0.448	0	1
Plotuse pesticide	1,076	0.395	0.489	0	1
Plotuse herbicide	1,076	0.316	0.465	0	1
Plotuse animal traction	1,076	0.533	0.499	0	1
Plotuse machinery	1,076	0.0586	0.234	0	1
Cropping monocropping	1,076	0.113	0.317	0	1
Cropping intercropping	1,076	0.024	0.153	0	1
Crop relay	1,076	0.016	0.125	0	1
Cropping other	1,076	0.003	0.053	0	1
Cropping mixed	1,076	0.865	0.342	0	1
Own livestock	1,038	0.880	0.326	0	1
Log value of production assets	1,038	7.404	1.794	0	12.27
Access extension	1,038	0.215	0.411	0	1
Access Financial loan	1,038	0.146	0.354	0	1
Female headed household	1,038	0.045	0.208	0	1
Log adult males	1,038	1.047	0.364	0	2.77
Log adult females	1,038	1.160	0.387	0	2.48
Have mobile phone	1,038	0.950	0.218	0	1
Log distance to all weather road	1,038	9.880	8.053	1	31
Log distance to market	1,038	67.185	34.872	2.6	215.3
AEZ_Sudan Sahel	1,076	0.840	0.367	0	1
AEZ_Guinea	1,076	0.099	0.299	0	1
AEZ_Forest	1,076	0.025	0.156	0	1

Source: Authors’ elaboration based on GHS 2015–2016

Table A2–Binomial Probit Maximum Likelihood regression estimates (Marginal Effects) predicting adoption of pesticides, certified seed

	Use Certified Seed	Use Pesticide	Use Herbicide
Plot level Factors:			
Used animal traction	-0.068**	0.067**	-0.049
Used machinery	0.045	0.135**	0.182***
Cropping monocropping (Reference=Mixed cropping)	0.013	0.101*	0.184***
Cropping intercropping	0.11	0.02	0.244**
Cropping relay cropping	0.083	0.323***	0.175
Cropping other	-0.077	-0.068	0.447**
Household Assets			
Own livestock	-0.073*	-0.027	-0.097**
Log Value of production Assets	0.037***	-0.019**	0.034***
Access to Rural Services			
Access to Agric extension	0.045	0.234***	0.037
Access to Financial loans	0.106***	-0.055	0.243***
Household demographics			
Female headed Household	-0.041	0.021	-0.079
Log number of adult males	0.013	-0.006	0.095**
Log number of adult females	0.004	0.006	-0.041
Have mobile phone	-0.084	0.110*	0.007
Market Access and Access to Public Infrastructure			
Log distance to all weather road	-0.005***	0.003	-0.001
Log distance to market	0.000	-0.001**	0.001
Biophysical Conditions (Reference=Forest)			
Agroecological zone=Sudan Sahel	0.612***	0.248***	0.063
Agroecological zone=_Guinea	0.260***	0.144	0.290**

Source: Authors' estimation.

APPENDIX B SUMMARY DREAMpy RUNS

Table B1 Input for all scenarios [change 1000 mt to kt]

Region	Production	Consumption	Price	Supply Elasticity	Demand Elasticity	Supply Growth	Demand Growth
	(1000 mt)	(1000 mt)	1000 NGN/mt			%/year	%/year
Forest-Derived Savannah	482.32	758.85	224	0.125	-0.369	4.48%	5.17%
Guinea	866.05	740.95	174	0.125	-0.351	5.01%	5.25%
Sudan-Sahel Savannah	984.17	1,112.90	149	0.125	-0.400	3.73%	3.86%
Niger	726.40	-	149	0.125	-0.400	2.00%	0.00%

Source: Production, consumption, and price are authors' calculations using GHS 2015–2016.

Table B2 Scenarios summary, main changes due to expected yield changes and technology adoption

Scenario	**Regions**	**Yield change**	**Adoption rate**	**Years to maximum Adoption**	**R&D lag**
Most Likely	**Forest-Derived Savannah**	**5.28%**	**15.00%**	**9**	**4**
	Guinea	8.47%	24.00%	8	4
	Sudan-Sahel Savannah	15.18%	45.00%	5	4
	Niger	0.00%	0.00%	0	0
Optimistic	Forest-Derived Savannah	9.63%	14.00%	7	3
	Guinea	15.53%	38.00%	6	3
	Sudan-Sahel Savannah	27.48%	64.00%	3	3
	Niger	0.00%	0.00%	0	0
Pessimistic	Forest-Derived Savannah	4.53%	3.00%	16	7
	Guinea	6.30%	5.00%	15	7
	Sudan-Sahel Savannah	5.84%	9.00%	12	7
	Niger	0.00%	0.00%	0	0

Source: Authors using information provided by farmers, scientists, and industry experts.

Table B3 Results for most likely scenario

	Forest-Derived Savannah	Guinea	Sudan-Sahel Savannah	Total
Producers' Benefits, Present value (PV), US$ mill.	2.33	45.09	210.86	258.28
Consumers' Benefits, PV, US$ mill.	28.44	27.93	34.70	91.07
Total Benefits, PV, US$ mill.	30.77	73.01	245.57	349.35
Cost of Research, US$ mill.	2.38	4.58	6.29	13.24
Net present value (NPV), US$ mill.	28.39	68.43	239.28	336.11
Benefit/Cost, Ratio	12.96	15.93	39.06	26.38
Internal Rate of Return (IRR), percentage	67.81	70.78	129.41	104.69

Source: Authors' estimation using DREAMpy.

Table B4 Results for most likely scenario + five years R&D

	Forest-Derived Savannah	Guinea	Sudan-Sahel Savannah	Total
Producers' Benefits, Present value (PV), US$ mill.	1.15	28.12	131.94	161.21
Consumers' Benefits, PV, US$ mill.	18.16	17.85	21.20	57.20
Total Benefits, PV, US$ mill.	19.31	45.97	153.15	218.42
Cost of Research, US$ mill.	1.64	3.16	4.29	9.10
Net present value (NPV), US$ mill.	17.66	42.81	148.85	209.32
Benefit/Cost, Ratio	11.75	14.55	35.67	24.01
Internal Rate of Return (IRR), percentage	41.94	44.07	62.00	54.25

Source: Authors' estimations using DREAMpy.

Table B5 Results for optimistic scenario

	Forest-Derived Savannah	Guinea	Sudan-Sahel Savannah	Total
Producers' Benefits, Present value (PV), US$ mill.	7.80	148.37	624.49	780.66
Consumers' Benefits, PV, US$ mill.	98.15	96.38	121.64	316.17
Total Benefits, PV, US$ mill.	105.95	244.75	746.13	1,096.83
Cost of Research, US$ mill.	2.77	5.36	7.39	15.52
Net present value (NPV), US$ mill.	103.18	239.39	738.73	1,081.31
Benefit/Cost, Ratio	38.23	45.68	100.91	70.66
Internal Rate of Return (IRR), percentage	140.55	142.22	-	228.25

Source: Authors' estimations using DREAMpy.

Table B6 Results for optimistic scenario + five years R&D

	Forest-Derived Savannah	Guinea	Sudan-Sahel Savannah	Total
Producers' Benefits, Present value (PV), US$ mill.	6.83	120.23	471.46	598.52
Consumers' Benefits, PV, US$ mill.	76.76	75.49	88.81	241.06
Total Benefits, PV, US$ mill.	83.59	195.71	560.27	839.57
Cost of Research, US$ mill.	1.90	3.66	5.00	10.56
Net present value (NPV), US$ mill.	81.69	192.06	555.27	829.01
Benefit/Cost, Ratio	44.05	53.51	112.02	79.53
Internal Rate of Return (IRR), percentage	62.82	65.28	90.81	79.83

Source: Authors' estimation using DREAMpy, 30-year simulation.

Table B7 Results for pessimistic scenario

	Forest-Derived Savannah	Guinea	Sudan-Sahel Savannah	Total
Producers' Benefits, Present value (PV), US$ mill.	0.81	4.69	8.40	13.90
Consumers' Benefits, PV, US$ mill.	1.51	1.49	1.75	4.75
Total Benefits, PV, US$ mill.	2.33	6.18	10.15	18.65
Cost of Research, US$ mill.	1.50	2.88	3.87	8.24
Net present value (NPV), US$ mill.	0.83	3.30	6.28	10.41
Benefit/Cost, Ratio	1.55	2.15	2.63	2.26
Internal Rate of Return (IRR), percentage	16.87	20.91	24.85	22.21

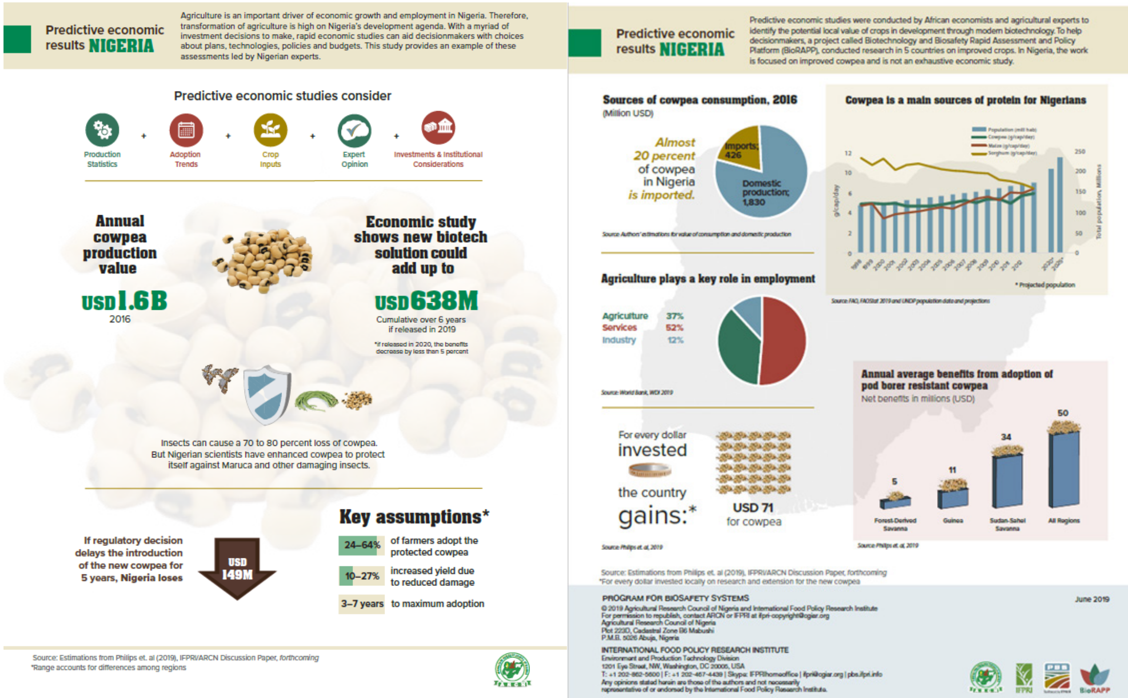
Source: Authors' estimation using DREAMpy.

Table B8 Results for pessimistic scenario + five years R&D

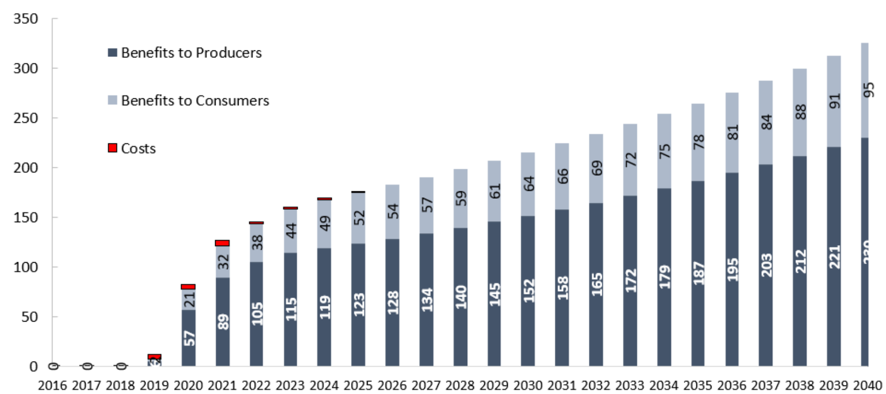
	Forest-Derived Savannah	Guinea	Sudan-Sahel Savannah	Total
Producers' Benefits, Present value (PV), US$ mill.	0.34	2.22	4.35	6.91
Consumers' Benefits, PV, US$ mill.	0.77	0.76	0.86	2.38
Total Benefits, PV, US$ mill.	1.11	2.98	5.21	9.29
Cost of Research, US$ mill.	1.01	1.97	2.74	5.72
Net present value (NPV), US$ mill.	0.09	1.01	2.47	3.58
Benefit/Cost, Ratio	1.09	1.51	1.90	1.63
Internal Rate of Return (IRR), percentage	11.98	15.49	18.55	16.52

Source: Authors' estimation using DREAMpy.

APPENDIX C INFOGRAPHIC: OPTIMISTIC SCENARIO



PBR cowpea, Nigeria
Benefits Net Present Value, million USD
Optimistic scenario



Equivalent to US$638 million ← First 6 years of benefits

Equivalent to US$1,080 million ← Annual net benefits are brought to present value using a discount annual rate of 10%

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