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Adoption of GM crops in Ghana

Ex ante estimations for insect-resistant cowpea and nitrogen-use efficient rice

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Adoption of GM crops in Ghana. Ex ante estimations for insect-resistant (IR) cowpea and nitrogen-use efficient (NUE) rice

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ABSTRACT

This paper uses an innovative research process to quantify the potential impacts of releasing and adopting insect-resistant (IR) cowpea and nitrogen-use efficient (NUE) rice in Ghana using an economic surplus partial equilibrium model. The premise of the research process was to build national capacity to produce timely and robust estimates, based on secondary data and qualified experts' informed opinions, collected in country. Ghana's stakeholders selected the two genetically modified (GM) technologies discussed here based on their assessment of these GM products' regulatory advancement and their economic and political importance. Using assumptions regarding the expected changes from the adoption and commercialization of these crops, collected from national and international crop and technology experts, the authors estimate that the benefits of adopting IR cowpea are between US$5.5 million and US$125.3 million, and between US$1.9 million and US$153 million for NUE rice. The analysis also shows how a five-year regulatory delay may erode these benefits, reducing them by between 29 and 39 percent for IR cowpea and between 28 and 57 percent for NUE rice. Additionally, the authors make preliminary estimates of sex-disaggregated benefits and calculate the unequal distribution of benefits between female and male producers and consumers owing to gender disparities in production and consumption. The welfare estimations are based on an economic surplus model that were estimated using the DREAM software. Although this partial equilibrium model has limitations regarding market-clearing assumptions and is specific to a product, it is a data-parsimonious method that can produce results in a short time frame, which might better suit policymakers' and decision makers' demands for rapid estimations.

Keywords: Ex ante assessment, biotechnology, rice, cowpea, Ghana, Africa, economic surplus model

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1. INTRODUCTION

Agriculture continues to be a critical sector for economic development and poverty reduction in many developing countries (Christiaensen and Martin, 2018). A well-known empirical regularity in development economics and economic history is that, as economies grow, the share of agriculture in total national output falls (Johnston, 1970; Johnston and Kilby, 1975; Timmer, 1988). Indeed, in Ghana, as in other sub-Saharan African (SSA) countries, agriculture's value-added share of gross domestic product (GDP) has been falling—by approximately a percentage point from 1981 to 2016—and currently is around 20 percent (World Bank, 2018).

In many countries, agricultural productivity growth has contributed to agriculture's declining share in the national output (Timmer, 2009; Herrendorf et al., 2014; Jayne and Ameyaw, 2016). Nevertheless, as in other SSA countries, Ghana's agricultural productivity record (as measured by crop yields, for example) is poor. Over the past decade (2007–2016), cereal yields in Ghana averaged only about 46 percent of the world average (1.7 ton per hectare [t ha^{-1}] compared with 3.7 t ha^{-1}). The apparent transformation story seen in the falling agricultural GDP share has not been driven by productivity growth in agriculture. In fact, one of the main reasons for the recent fall in Ghana's agriculture GDP share is the steady increase in oil production. Indeed, since Ghana started exporting oil in 2011, agriculture GDP share has been falling by about 1.9 percent per year, compared with the SSA annual average of only 0.04 percent over the same period. More than 40 percent of the economically active population is still employed in agriculture (Dzanku and Udry, 2017), which speaks of the sector's low productivity as well as a slower pace of transformation than the agriculture GDP share story suggests.

Agricultural transformation remains a strong policy priority for the government of Ghana. Although raising agricultural productivity is not a panacea for poverty alleviation (Fischer and Hajdu, 2015), it is a key contributing factor (Dzanku, 2015; Smale, 2017). For the better part of two decades, Ghana has emphasized "agricultural modernization" in its national agricultural policies (NDPC, 2003; MoFA, 2007, 2010; Dzanku and Aidam, 2013; Dzanku and Udry, 2017).

It has long been recognized that the "type of agricultural technologies adopted" is critical for agriculture transformation in "late-developing countries" in particular (Johnston and Kilby, 1975). Although yield growth in most upper-middle and high-income countries has occurred at the intensive rather than extensive margin (Hertel, 2011), the sluggish growth in crop yields in Ghana indicates that it will be critical to improve these yield growth rates. Moreover, if sustainable agriculture and its quest to reduce the use of nonrenewable inputs, such as pesticides and inorganic fertilizers, is a policy goal, input-saving technologies become particularly relevant. In this context, genetically modified (GM) crops should be considered as an option (Fedoroff, 2015)—one that has been adopted effectively in developing economies.

In spite of the demonstrated positive effect of GM crops on yields, reduction of insecticide applications, and cost of production (Smale *et al.*, 2009; Finger *et al.*, 2011; Areal *et al.*, 2013; Klümper and Qaim, 2014), only 2 of the 26 countries that planted biotech crops in 2017 are in Africa (South Africa and Sudan), with only 2 percent of global biotech area (ISAAA, 2017). Analysts (Paarlberg, 2008; Chambers *et al.*, 2014) have different explanations for African countries' slow adoption of GM technologies. One often-cited and documented explanation is the persistence of overly precautionary biosafety regulatory frameworks, which impede efficient and predictable evaluation of GM crops. African countries also lack local evidence, particularly locally generated assessments, of the potential benefits of GM crops, and consequently have been unable to assess these technologies in a timely manner in response to questions from local policymakers and decision makers.

This discussion paper focuses on gathering this local evidence and proposes the use of a methodology that would produce timely estimates. To do so, it assesses the potential producer and consumer impact of commercializing two locally identified priority GM technologies: insect-resistant (IR) cowpea and nitrogen-use efficient (NUE) rice, based on secondary data and the use of an economic surplus model.

After this introduction, the second section presents information on the selected crops and offers information on the crop traits to be evaluated. Section 3 presents an overview of ex ante assessment of agricultural technologies. Section 4 presents the model and analytical approach underpinning the results. Section 5 describes the process followed to collect secondary data and elicit relevant information for the analysis and presents the model-specific data and assumptions. Section 6 presents and discusses the results of the study, and section 7 outlines its advantages and limitations and suggests future ex ante assessments. The conclusion provides policy recommendations based on the results.

2. IR COWPEA AND NUE RICE SELECTION

Consistent with the GOG's crop prioritization decisions, national stakeholders selected two GM crops, IR cowpea and NUE rice, as the focus of the presented ex ante assessments. These crops were selected for their economic importance and for the research and regulatory status of the specific technologies associated with them. This section describes the importance of these crops and the relevance of the technologies selected.

2.1 Cowpea and Rice Economic Relevance

Cowpea is the most widely produced grain legume in Ghana and a key food security crop. In northern Ghana, where most of Ghana's cowpea is produced, the crop helps households overcome the annual hunger gap between planting and harvesting times. This is important for regions that have a monomodal rainfall distribution with a long lean season. Cowpea, which contains about 23–25 percent protein by weight (Abudulai et al., 2017; Spriggs et al., 2018), is a relatively cheap source of protein and an essential source of fats, carbohydrates, dietary fiber, sodium, and potassium. Current per capita cowpea consumption is estimated to be around 5 kilograms (kg) per year, 25 percent higher than in the 1990s (MoFA, 2016). Cowpeas are also an important complement in many traditional Ghanaian meals and homemade weaning foods for children (Boukar et al., 2010). Notably, cowpeas are a vital component of meals prepared in all senior high schools as well as governments' School Feeding Programs.

Although Ghana has overcome the cowpea production deficits of the 1990s, mainly by adopting improved varieties (Al-Hassan and Jatoe, 2002; MoFA, 2016), realized yields are still much lower than potential yields. Potential yield in rainfed conditions is about 2.5 t ha^{-1} on average across varieties (MoFA, 2016). Yields over the past decade (2006–2016) have averaged 1.2 t ha^{-1} (Table 1.)

Indeed, similar to other crops, yields reported from survey household and plot data are much lower than those reported in Table 1, sometimes by more than 50 percent (Dzanku and Udry, 2017). Yield growth has shown some progress over the last decade, with production growth outpacing area growth. In addition, in the past five years (2012–2016), Ghana has recorded an annual average cowpea surplus of about 41,000 tons (MoFA, 2016).

Table 1 Cowpea and rice: Production and yields, 2006–2016

Year	Cowpea		Paddy Rice	
	Production (000 Mt)	Yield (ton ha^{-1})	Production (000 Mt)	Yield (ton ha^{-1})
2006	167	0.90	250	2.00
2007	119	0.86	185	1.70
2008	180	1.12	302	2.27
2009	205	1.26	391	2.41
2010	219	1.31	492	3.03
2011	237	1.30	463	2.35
2012	223	1.32	481	2.54
2013	200	1.24	570	2.64
2014	201	1.21	604	2.69
2015	203	1.25	641	2.75
2016	206	1.41	474	2.92

Source: Statistics Research and Information Directorate, MoFA (various years), and FAOSTAT (2016)

Cowpea production occurs in rainfed conditions, and it is constrained by insect pests during field cultivation and after harvest (Dzemo et al., 2010; Abudulai et al., 2017). Depending on the location, year, and cultivar, insects could cause total crop loss if no measures are taken to combat them (Asiwe et al., 2005; Tanzubil et al., 2008; Dzemo et al., 2010). The appropriate market-available insecticides are expensive and hazardous to farmers and the environment. Although cowpea naturally fixes nitrogen, it requires complementary fertilizer application, especially during seeding, for optimum yield (Karikari et al., 2015). Cowpea production also may be constrained by nematodes and parasitic weed infestation, inadequate access to improved seeds, underdeveloped value chains, low adoption of improved postharvest technologies, and problems with infrastructure such as storage and value addition (CSIR-SARI, 2017)

Rice is a staple food across Ghana. Some estimates suggest that rice is the most consumed cereal per capita after maize, although others indicate that rice has overtaken maize in per capita consumption (Tobita and Nakamura, 2018). Estimated per capita consumption was 13.9 kg per capita in the 1990s and increased to an estimated 32 kg per capita by 2015, with a 5.6 percent annual growth rate (MoFA, 2016).

Across the country, Ghana's climate and topography make it a suitable rice production environment. Rice production is dominated by individual small-scale farmers, with mean and median holdings of approximately 1 ha and 0.4 ha, respectively.[1] Valley-bottom rice production is dominant in the northern regions of Ghana, which has large valleys that support production. Upland rice production takes place in the mountainous stretch between the Volta Lake and the Togolese border in the Volta region. Irrigated/controlled flooding rice production is under the auspices of the Ghana Irrigation Development Authority.

Estimates by Ghana's MoFA suggests a rice yield gap of about 54 percent, meaning that only 46 percent of achievable yields under rainfed conditions have been realized. The yield gap is even wider when calculated from household survey data. For example, although MoFA (2016) reports mean yield of about 2.5 t ha^{-1} the Ghana Living Standards Survey (GLSS) data from 1991 to 2013 hardly recorded mean yields above 1 t ha^{-1}.

Unlike cowpea, rice domestic supply (production) is insufficient to meet domestic demand, even though rice production has been growing steadily (Table 2). Improved domestic rice production continues to be an important developmental target for Ghana, not least because the country still relies heavily on imports to meet domestic demands (MoFA, 2010).

Table 2 Ghana: Rice milled supply and demand, 2011–2016

Year	Supply (000 Mt)	Demand (000 Mt)	Deficit (000 Mt)
2011	302	645	−343
2012	313	660	−346
2013	393	685	−292
2014	417	703	−286
2015	443	721	−279
2016	474	741	−266

Source: Ghana Statistics Research and Information Directorate, MoFA

Note: These demand figures are implied from the deficit quantities provided by MoFA. There are some gaps, however, with respect to total import quantities available and total quantities available, so that the imported share of total quantity of rice available is higher than the supply and demand figures imply.

2.2 Crop/Trait Selection Process

Because not even a handful of existing GM crop ex ante assessments focused on Ghana, the crops and traits reviewed in this study required careful consideration. The national stakeholders who made the selections based their choices on several factors. First, they considered whether the specific crop/trait was under development and was relatively closer to commercialization.

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[1] Sixth round of the Ghana Living Standards Survey (GLSS).

Second, they evaluated whether the GM crop was of economic relevance to Ghana in terms of its contribution to food security, import substitution, or the GDP, among other aspects. The stakeholders met several times in early 2016 to discuss the choice of crops. These meetings involved farmers and farmer groups, government officials and technocrats from relevant ministries, private sector actors, and participants from academia and research institutions. The stakeholders selected rice and cowpea for the ex ante evaluation, not least because these crops are priority crops in Ghana's agricultural policy (MoFA, 2007, 2015).

There was overwhelming support for the choice of rice for the reasons presented in section 2.2. There was some support to select maize, as it is more widely grown than any other crop in Ghana and is more important to the country's economy, but at the time, there was no GM variety of maize in development and field-testing. Moreover, it was argued that it might be strategic to select crops from the different categories listed in Ghana's agricultural policy document: in this case, to select a cereal crop and a legume. Cowpea is by far the single most important legume in Ghana in terms of popular production and consumption. The stakeholders thus reached a consensus to select rice and cowpea for the ex ante economic assessment.

2.2.1. Insect Resistant (IR) Cowpea

Cowpea production is hampered by several pests, one of the most important of which is the pod borer insect *Maruca vitrata* (hereafter *Maruca*). *Maruca* infestation is a major known constraint to increasing cowpea production from smallholder farmers across West Africa (Sharma, 1998). *Maruca* infestation not only can result in 90 percent yield loss depending on pest pressure (Murdock et al., 2002; Bett et al., 2017), but also produces lower-quality grains (CSIR-SARI, 2017), which is likely to affect market outcomes as consumers respond to grain quality characteristics (Langyintuo et al., 2004). To obtain a good harvest in the presence of *Maruca*, farmers must spray multiple times to control the pest. However, resource-poor farmers are constrained in credit markets and are unable to afford enough insecticide for effective control. Aside from the credit constraints, farmers sometimes resort to ineffective insecticides because the recommended types are not always available (CSIR-SARI, 2017).

The African Agricultural Technology Foundation (AATF) has developed GM cowpea lines that contain the *Maruca*-resistant *cry1Ab* gene, hereafter called IR cowpea. Confined field trials for the IR cowpea—or *Bacillus thuringiensis* (Bt) cowpea—have been completed in Ghana as part of a larger project aimed at expanding the release of the IR cowpea into Nigeria and Burkina Faso. Scientists at the Council for Scientific and Industrial Research–Savannah Agricultural Research Institute (CSIR-SARI) successfully carried out confined field trials in Ghana, where the *Maruca*-resistant Bt gene was introgressed into the Songotra cowpea variety. The CSIR-SARI released the Songotra variety in 2008, and it is available and commercialized mainly in Ghana's northern region.

Field trials results under high artificially introduced *Maruca* infestation showed significantly higher seed weight and health for the IR-transformed Songotra variety compared with the non-IR Songotra. Most importantly, there was much lower pod damage (about 28.6 times lower) in the IR cowpea than in the non-IR cowpea.[2] The IR cowpea yield was 1.925 t ha^{-1} compared with only 0.94 t ha^{-1} for the non-IR Songotra (CSIR-SARI, 2017). Further trials were conducted under farmer field conditions under low pest pressure with insecticide spray to control for other pests. In two out of the three trials, pod damage was still significantly higher for the non-IR cowpea under low *Maruca* pressure, although the difference was not large enough to translate into statistically significant differences in yields. Finally, the experiment was carried out under three different spraying regimes (0, 2, and 5 sprays). Irrespective of spraying regime, the non-IR cowpea still showed significant *Maruca* damage. Apart from the potential cost reduction and yield increases for farmers from the IR cowpea, the *Maruca*-resistant variety may also have substantial health and environmental benefits, as it could significantly reduce the number of insecticide sprays needed for crop cultivation (van der Werf, 1996).

2.2.2. Nitrogen-Use Efficient (NUE) Rice

Despite the importance of rice to the economy of Ghana, large yield gaps persist even when evaluating the best yields on farmers' fields where production conditions are not optimum (Tittonell and Giller, 2013). For example, the 95th percentile mean rice yields from the GLSS 6 survey (after removing outliers) is about 2.5 t ha^{-1} (maximum yields equal 4.9 t ha^{-1}) but the mean across all rice farmers is only 0.9 t ha^{-1}. Factors that account for low yields include

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[2] Pod damage due to *Maruca* alone is zero for this IR cowpea, as also shown by Addae (2016).

nitrogen deficiency, drought (in the presence of poor irrigation infrastructure), and high salinity in some growing areas (AATF, n.d). Arcadia Biosciences has provided a royalty-free license for its NEWEST—nitrogen -use efficient, water-use efficient and salt-tolerant—rice technology to be used in Africa to produce transgenic rice varieties that address the above mentioned constraints (AATF, n.d). As the regulatory environment allows, confined field trials are underway in Uganda, Nigeria, and Ghana, where these traits are being introgressed into farmer-preferred rice varieties.

Nitrogen deficiency is one of the most yield-limiting factors in rice production (Samonte et al., 2006). Owing to resource constraints, the confined field trials being carried out by the Crop Research Institute of the CSIR (CRI-CSIR) in Ghana have so far involved only the NUE trait. The NUE trait was introgressed into a rainfed upland variety NERICA4 (New Rice for Africa 4). Nitrogen deficiency generally is more acute in upland areas (Saito et al., 2018; AATF, n.d). The confined field trials compared the transgenic NERICA4 to the non-transgenic control at nitrogen application rates of 30, 60, and 90 kg ha^{-1} with the results showing yield advantages of 25 percent, 14 percent, and 19 percent, respectively. Other studies with the NUE gene also show a yield advantage with no inorganic nitrogen application (Selvaraj et al., 2017). NUE varieties not only may be able to increase yields beyond those of conventional varieties, but also may provide environmental benefits by preventing or mitigating the negative environmental consequences of excess nitrogen use (Glass, 2003; Qiao et al., 2015).

3. EX ANTE ASSESSMENTS OF AGRICULTURAL TECHNOLOGY: AN OVERVIEW

Ex ante evaluations are an important factor in assessing the potential cost-effectiveness of proposed research investments and in setting investment research and development (R&D) priorities; they help make better-informed resource allocation decisions (Norton and Pardey, 1987; Alston et al., 1995). There are different methods to perform ex ante assessments. The economic surplus model (ESM) used in this study, and described in the following section, has been adopted by many other authors. One advantage seldom mentioned about the ESM, as compared to other more sophisticated and data demanding methods, is that it can be parsimonious in terms of data requirements, as estimations can be made with secondary data and changes in key variables can be drawn from experts' opinions.

Multiple authors have used the ESM framework to assess the potential benefits of crop biotechnologies in developing economies. Smale et al. (2009) reported detailed results for eight ex ante assessment studies for GM crops in developing economies, of which the following used the ESM: De Groote *et al*. (2003, 2005); Hareau *et al*., (2005, 2006); and Qaim (2005). Following the publication of the Smale *et al.* (2009) analysis, which covers the literature up to 2006, others GM crop ex ante assessments using the ESM have been published (Falck-Zepeda *et al.*, 2008; Horna *et al.*, 2008; Vitale *et al.*, 2008; Kostandini *et al.*, 2009; Napasintuwong and Traxler, 2009; Kumar *et al.*, 2010; De Groote *et al.*, 2011; De Groote, 2012; Mulwa *et al.*, 2013; La Rovere *et al.*, 2014).

Most prerelease economic assessment studies for GM crops have taken place outside the African continent. A small proportion are related to SSA, of which only three focus, at least partially, on Ghana: La Rovere et al. (2014), and Horna et al. (2008), Langyintuo and Lowenberg-DeBoer (2006). La Rovere et al. (2014) carried out an ex ante assessment of the potential impact of adopting drought-tolerant (DT) maize in Ghana and 12 other African countries. The authors estimated an economic surplus of US$650–$1,500 million for the different countries. For Ghana, they estimated that the adoption of the DT maize technology could yield regional benefits of US$10.80–$19.59 million, estimated to lift between 23,433 and 44,384 people out of poverty in 2016. This estimate of the number of people lifted out of poverty was calculated based on the population size, total benefits estimated from the adoption of DT maize, agricultural GDP, growth rates, and poverty reduction elasticity with respect to agricultural GDP growth. Horna et al. (Horna *et al.*, 2008) carried out an ex ante assessment including information from a survey to estimate the potential impact of adopting three GM vegetables (tomato, cabbage, and garden egg). They found that even though adopting an IR variety may not automatically reduce the amount of insecticide applications (because of secondary pests), the GM varieties had the potential to increase the profitability of vegetable production through potential yield and price changes, even when the technology came at a cost to farmers. But there is some heterogeneity (by crop) in the potential channel of impact. For cabbage, the potential reduction in the cost of insecticide applications through the adoption of the GM variety was important (Horna *et al.*, 2006).

Langyintuo and Lowenberg-DeBoer (2006) focused on the effects of the adoption of IR cowpea on African regional trade and the differential welfare effects among consumers and producers and trade effects between adopting and non-adopting African countries and/or regions. The authors used a spatial partial equilibrium model to run different scenario. The first one assumes that adoption of IR cowpea takes place earlier in countries that, at the time, participated in a cowpea initiative. The second scenario assumed that IR cowpea adoption will extend only to limited areas/regions but would result in a 10 percent overall change in yield. Finally, the third scenario assumes that all producing regions adopt the technology with a similar yield increase assumed in scenario 2. The results show that only when all producing cowpea regions and countries (including Ghana) adopt the technology will regional benefits increase and have equitable distribution welfare effects among producers and consumers. Under scenario 1&2, the results show that regions or country that are left behind will be at risk of losing out.

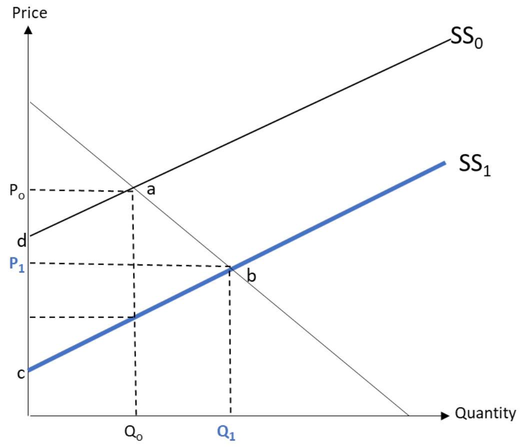
4. MODEL AND ANALYTICAL APPROACH

The estimations presented in this study derived from the implementation of a multiregion ESM, as described by Alston et al. (1995.) The ESM has been used extensively to evaluate research investments and allocate resources. The main advantage of using ESM over other more sophisticated methods is that it is parsimonious in terms of data requirements and model handling, both key in the implementation of this project. Alston et al. (1995, 53) detailed the main drawbacks of their proposed ESM approach: "ignoring transaction costs, externalities, general equilibrium effects and certain measurement errors," but clarify that most of these can be at least partially addressed by incorporating them into the estimated cost and benefits variables. Scatasta *et al.* (2006) add to this assessment the fact that welfare measurements derived from ESM are highly sensitive to changes in key variables, particularly the choice of demand and supply elasticities, estimated changes in yield and input costs. Smale et al. (2009) underscore the problems of any partial equilibrium model, including that prices and quantities of other products remain constant, changes in input prices are not considered, and farmers are assumed to be risk-neutral and price takers.

All these drawbacks are important when looking at the results presented. This report offers different scenarios to account for the variability in key parameters (Table 6, Table 7) and assumes that there are extension costs. Additionally, the project took the time to validate and document all assumptions.

Alston et al. (1995) present a detail description of the ESM implemented in this report; the following section presents 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' elaboration

The technology-induced shift in the supply curve will result in a lower clearing price, moving the equilibrium price down from P_o to P_1, with increments in quantities from Q_o 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 technical change 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 be estimated using eq. 1-3, which uses prices, quantities, elasticities, and the research induced unit cost change due to yield increase or input cost reduction.

$\Delta CS = P_0 Q_0 Z\,(1 + 0.5Z\eta)$ Change in Consumers Surplus [eq.1]

$\boldsymbol{\Delta PS = P_0 Q_0 (K - Z)(1 + 0.5\,Z\,\eta)}$ Change in Producers Surplus [eq. 2]

$\boldsymbol{\Delta TS = \Delta CS + \Delta PS}$ Change in Total Surplus [eq. 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

All estimations presented in this report use the IFPRI-developed software DREAM (Dynamic Research Evaluation for Management 3.1, https://harvestchoice.org/tools/dream-dynamic-research-evaluation-management-31).[3] The basic closed economy ESM approach presented above [eq. 1-3] is modified to be able to estimate a multi-region technology adoption with associated regional production characteristics, used in this report and described by Alston et al. (1995, 212-218).

5. RESEARCH PROCESS, DATA, AND ASSUMPTIONS

An important objective of this evaluation was to make the process—from data collection to analysis—as transparent as possible to enable others to use and assess the secondary data collected, evaluate all underlying assumptions, and replicate or produce different ones. This standard scientific approach to insure credibility and integrity of the results has relevance given the controversial nature of the subject. Another reason for emphasizing transparency is that the ex ante assessments require the use of assumptions and, in this case, elicitation of informed opinions from scientists or experts involved in the development the technologies being evaluated, and it is important to validate such opinions from as many experts in the field as

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[3] A detailed presentation of DREAM ESM modeling, as well as all relevant documentation, can be found in the Harvard University Dataverse at https://dataverse.harvard.edu/dataset.xhtml?persistentId=hdl:1902.1/18230.

practically possible (including related opinions and findings in the literature) to ensure coherence. This process was achieved in several steps.

First, a group of economists, scientists (cowpea and rice experts), policymakers, and farmers' groups met in Ghana to elicit informed opinions on the likely values of the underlying assumptions required to estimate the potential costs and benefits of adopting the IR cowpea and NUE rice technologies. These include GM seed prices, R&D and regulatory timelines, potential adoption information, and probability of R&D and regulatory success. Such expert opinions were combined with secondary data from surveys and the related literature. The assessment incorporated production, consumption, and price data for conventional varieties to produce preliminary estimates of the potential economic benefit of the GM technologies.

Second, the results of the preliminary estimates were presented to scientists with all the values for all underlying assumptions. This presentation served as a validation exercise, particularly for the opinions that the experts had provided about the technologies. In some cases, it turned out that the questions posed by the economists were not well understood during the initial meeting. Some of the variables in the preliminary estimates therefore had to be revised based on the updated information provided by the scientists and other experts. The time lag between the first prior elicitation and the second also allowed the scientists to reconsider the questions that the economists posed in the first meeting.

Third, the updated results of the assessment were presented to the project steering committee: a small group of farmers, policymakers, scientists, communication experts, and economists. Further comments from this exercise were incorporated into the final output. The estimates were also subjected to preliminary peer review in the form of presentations to other economists who have experience with ex ante assessment of agricultural technologies.

5.1. Data Sources and Description

The economic assessment of the biotechnologies relied on primary and secondary data. Primary data were obtained from scientists, industry experts, and farmer interviews. The implementation of the ESM required two broad data types: (1) market-related data, focused on the conventional crop variety to which the GM crop is being compared, and (2) the potential supply changes for the selected commodities (cowpea and rice) because of the new technologies (IR and the NUE traits).

The market-related data include production (supply) and consumption (demand) quantities, as well as market prices. This information was obtained from MoFA and collected at regional and national levels. Because regional consumption data were not available, they were estimated using population and per capita consumption. Population and per capita consumption figures were obtained from the Ghana Statistical Service (GSS). The model used three-year average (2013–2015) values for the quantity and price variables. The analysis was done at the regional level to account for production and consumption differences. Although sub regional data were collected for both cowpea and rice, this report disaggregates production areas and aggregates consumer areas. For this reason, the areas for cowpea and rice are different, as shown in Table 3.

Table 3 Cowpea and rice**:** Supply, demand, and prices, 2013–2015 averages

Crop	**Region**	**Supply** (MT)	**Demand** (MT)	**Price** (GH¢/MT**)**
Cowpea	Northern	96,400	18,900	2,010.31
	Upper East	12,220	7,900	2,165.78
	Upper West	73,950	5,300	1,977.23
	Brong Ahafo	8,010	17,600	2,211.28
	Other regions	11,940	138,200	2,605.37
Rice	Northern	168,410	159,100	2,000.00
	Upper East	114,700	67,100	2,450.00
	Volta	184,280	135,900	1,789.00
	Other regions	137,670	1,220,100	1,965.56
	Rest of World (ROW)	47,910,430	46,933,200	1,817.18

Source: Authors' elaboration using MoFA (various years) and FAO (various years) data.
Note: GH¢ = Ghanaian cedi

On average, 90 percent of the cowpea produced in Ghana during the study period came from the three northern regions. However, cowpea is consumed all over the country, with 71 percent of the total being consumed outside the three northern regions—although per capita consumption is about two times higher in the three northern regions than it is in the rest of the country. Ghana also produced about 7 percent more cowpea than was consumed over the period.

The story is different for rice, however. Although some regions produce more rice than they consume (Northern, Upper East, and Volta regions), on average about 37 percent of the rice consumed is produced domestically, and the rest is imported, mainly from Asia. Ghana's dependence on rice imports means that world demand and supply affect the domestic rice market. Therefore, as explained in section 4, this is considered by the "rest-of-world" (ROW) production and consumption figures (Table 3). In the estimations, rather than using total world production and consumption of rice, we use the Asian market supply and demand because around 93 percent of Ghana's rice imports for the benchmark year (2014) came from Asia (mainly Vietnam, Thailand, India, and Pakistan). For the period 2013–2015, 91 percent of all rice imported into Ghana, on average, came from Asia.[4]

Along with the market-related variables, this study evaluated the price elasticities of supply and demand for the two commodities. Although such information could come from sources such as (a) the literature, (b) a system of equation estimates using empirical data, or (c) approximations informed by economic theory, the authors followed the suggestion by Alston et al. (1995) to use a combination of (a) and (c) for ex ante assessments. In most cases, the study uses estimates from the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) from IFPRI (Robinson et al., 2015). It also examines elasticity estimates from studies by the International Fund for Agricultural Development (IFAD), Kuwornu et al. (2011), and Nimo (2012).

Because the model projects into the future from the base period, the estimation requires values for projected exogenous (i.e., not due to the technology) changes in commodity supply and demand. Estimates for exogenous supply growth rates use time series data of previous years' supply. Exogenous growth in demand (G^S) is assumed to depend on population growth rate, income growth rate, and income elasticity of demand for the commodity. Using GLSS data from the period 1992–2014, G^S is calculated from eq. 4 as:

$$G^S = \textit{population growth rate} + (\textit{income elasticity} \times \textit{income growth rate}). \qquad \text{[eq.4]}$$

This means both the supply and demand growth rates are region-specific. As shown below, we carry out several sensitivity analyses using various elasticities and growth rates to check the robustness of our estimates because these could have major impact on our conclusions.

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[4] See the Observatory of Economic Complexity at https://atlas.media.mit.edu/en/.

The estimations also need to consider the opportunity cost of private and public funds in such ex ante evaluation. Ideally, one needs to use the long-term real interest rates (i.e., after accounting for inflation). With Ghana's long-term (10-year) bond interest rate of about 17.5 percent and baseline average inflation rate (i.e., over the period 2013-2015) of 14.6 percent, the real discount rate is about 2.9 percent.[5] Experts often suggest real discount rates in the range of 3-5 percent. Yet, in Ghana, as in other countries, public investment projects use much higher discount rates—about 10 percent in some cases.[6] As investments in GM technologies are essentially public investments, this study uses the 10 percent discount rate but calculates net returns using a discount rate of 5 percent.

The next set of information required for the ex ante assessment using the ESM relates to the expected change (or shift) in cowpea and rice supply due to the advancement and adoption of the specific GM technology. These possible changes include the following:

1. *R&D and regulatory time lags.* The time required for the biotechnologies to become available in the market.
2. *Probability of R&D and regulatory success.* This factor combines the probability that the R&D will be successful and the probability of regulatory success. Successful R&D does not guarantee regulatory success; if the latter fails, then the net effect will be null, because farmers will not have access to the technology. Assessing the probability of regulatory success is complex, as success is defined by numerous science and non-science-based factors.
3. *Adoption lag.* This measures time between commercial release of the technologies and the anticipated maximum rates of adoption.
4. *Maximum adoption rate.* The anticipated percentages of total area of cowpea and rice cultivated to the area of IR cowpea and NUE rice cultivation are used as proxies for the percentage of total output that comes from the adoption of the new technologies.

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[5] See the Bank of Ghana's current treasury bill rates at http://www.bog.gov.gh/markets/treasury-bill-rates#.

[6] See, for example, the International Development Association Project Appraisal Document on a proposed SDR 10.8 million credit to the Republic of Ghana for an economic management strengthening project, World Bank, August 9, 2016, http://documents.worldbank.org/curated/en/114071471034257836/pdf/Ghana-PAD-Economic-Mngt-Strengthening-July-2016-08112016.pdf.

5. *Years at maximum adoption and dis-adoption.* These specify whether the technologies will be dis-adopted or not, and if so how long it is anticipated that adoption remains at the assumed maximum level before dis-adoption.
6. *Cost of bringing the technologies to the market.* This includes annual R&D cost, the cost of technology extension/dissemination, and any other associated market-related costs.
7. *Yield change.* The difference in IR cowpea and NUE rice yields relative to the conventional variety ones. This estimate answers the following question: assuming R&D and regulatory success, what will be the percentage change in the yield (compared with the conventional variety) if farmers adopt the IR cowpea and NUE rice varieties? If changes in yields are anticipated—as the case is for the technologies evaluated here—then this difference will be positive.
8. *Cost change.* The difference in IR cowpea and NUE rice production cost relative to the conventional variety. Although not all technologies may involve changes in production costs, the IR and NUE technologies do. Similar to (7) above, this answers the following question: what is the anticipated difference in production cost per ha, ceteris paribus, if the technologies are successful and adopted? This value could be positive or negative, depending of each input.

The parameters in (7) and (8) are combined to produce the technology-induced supply shift described in section 4. This section will describe how the values of some of the parameters have been derived, as well the accompanying assumptions.

Two main categories of costs—R&D and regulatory—are involved in bringing the GM technology to the market. There are other costs incurred by companies that have developed GM technologies in their efforts to bring their products to the market. It is likely that one of the costliest one is the investment in public relations (PR) efforts, investments that are particularly high for GM technologies given the controversial public opinions about these technologies. Although there is no data to draw on to be able to estimate these costs, this report recognizes that this is an important issue. However, further research is required beyond the scope of this report to address the issue.

Regarding the R&D costs, it would be right to argue that those should not be included in the assessment since from the financial point of view, the technologies under consideration have been externally funded and require minimum investment from the GoG. Nevertheless, what the ESM measures is the economic welfare to society, and for that reason the costs of R&D need to be included, particularly if these assessments are to be compared vis-à-vis other investment opportunities. Because the authors were not aware of any in-country estimates of these R&D costs, this report relies on literature to estimate these costs. It is important to remember that these technologies are developed by not-for-profit institutions for developing countries. Schiek et al. (2016) estimated that the cost required for two not-for-profit institutions to develop a comparable technology (i.e., late blight resistant potatoes) for a developing country was US$1.6 million over eight years for one institution and US$1.4 million over nine years for the other. The share of regulatory compliance in the total cost was estimated to be between 16–36 percent. According to Falck-Zepeda et al. (2012) the cost of regulatory compliance alone in developing countries could range from US$100,000 to US$1.7 million.

Given these figures, the authors use US$2.6 million as the total cost of R&D and regulatory compliance, distributed over the R&D time lag. About a third of this cost is attributed to regulatory compliance. About 10 percent of the regulatory cost is set aside for additional government regulation after release. Although regulatory compliance costs are fixed across the commodity production regions, R&D costs are distributed across the regions based on a crop's relative importance in a region, as measured by the region's share in national output.

IR cowpea is at a more advanced stage in the regulatory process than NUE rice. The scientists and other experts (including the National Biosafety Authority) estimated that the IR cowpea expected release date is 2019–2020, or between five and six years from the base year. Nigeria, it should be noted, is planning to release the IR cowpea in 2018. NUE rice likely will be released later, and the scientists estimated 2020–2022 as possible release dates, or six to eight years from the base period.

The scientists interviewed concurred that there is 100 percent probability of R&D success, because the confined field trials had been successful for both the IR cowpea and NUE rice.[7] The scientists estimated the probability of regulatory success to be 85 percent for the IR cowpea and 80 percent for NUE rice. Therefore, the estimated probability that the technology would reach the market is 85 percent and 80 percent for the IR cowpea and NUE rice, respectively.

When scientists and other experts were asked to estimate potential adoption rates of the biotechnologies, they stated while adoption rates of the GM crops could be higher than that for existing improved seeds, public sentiments about GMOs in Ghana suggest that farmers are more likely to adopt a "wait-and-see" attitude toward the GM seeds than they would toward a non-GM technology. The anticipated adoption rates are also informed by the varieties into which the transgenic gene has been introgressed. Further information on these issues and the rest of the assumptions for each crop are discussed below.

Table 4 presents a summary of the main assumptions. This table includes the exchange rate, although all estimations were done in Ghanaian cedi (₵). The results presented here are in U.S. dollars using an exchange rate of 4.41₵/US$1.

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[7] Although the initial project also examined the WUE and ST traits, the scientists were not confident of success with respect to these traits because of funding limitations for carrying out in-country trials. They therefore put the probability of R&D success for NEWEST rice at 50 percent.

Table 4 Baseline key parameters for the ex ante ESM

		Crop		
Parameter	**Unit**	**Cowpea**	**Rice**	**Source/Note**
Base year	Year	2014	2014	Authors
Simulation period	Years	30	30	Authors
Real discount rate	Percent	10	10	Literature
Exchange rate	GH₵/US$	4.41	4.41	Bank of Ghana
Regions	Number	5		Authors', based on secondary data
Elasticity of supply	Neutral	0.24	0.16	IMPACT
Elasticity of demand	Neutral	−0.21	−0.29	IMPACT
Exogenous supply growth rate	Percent	0.09–4.71	2.16–5.40	Varies by region
Exogenous demand growth rate	Percent	2.01–4.22	2.52–4.88	Varies by region
R&D and regulatory time lag	Years	6	85	Scientists and policymakers
Probability R&D success	Percent	100	100	Survey of expert opinion
Probability regulatory success	Percent	85	80	Scientists and policymakers
Probability R&D and regulatory success	Percent	85	80	Calculated from the above
Maximum adoption rate	Percent	20–70	5–70	Survey of expert opinion & data
Adoption lag	Years	5	5	Survey of expert opinion
Year at maximum adoption rate	Years	10	10	Survey of expert opinion
Years to abandon	Years	9	7	Based on time horizon
Probability of *Maruca* attack	Percent	80	N/A	Survey of expert opinion

Source: Authors' elaboration, using on experts' opinions.
Note: N/A = not applicable

5.1.1. Cowpea

Adoption. There is a general paucity of literature documenting adoption rates for improved cowpea varieties. Asante et al. (2017) found that three years after introducing a new cowpea variety (dual-purpose cowpea), about 41 percent of farmers in the forest-savannah transitional zone had adopted it. The authors, however, found that potential adoption rates were 83 percent if all farmers in their sample had knowledge of and access to the variety. As indicated in section 2, the *Maruca*-resistant gene was introduced into the Songotra variety, which is produced mainly in the Northern Region and to a less extent in the Upper West Region. The Songotra adoption rate was estimated to be about 10 percent according to the Diffusion and Impact of Improved Varieties in Africa (DIIVA) project (https://www.asti.cgiar.org/diiva). Most Songotra is grown in the Northern Region, about 18–20 percent of cultivated area. It is used in other cowpea-growing areas of the north to a much less extent. Scientists and industry experts' "best guess" estimate for IR cowpea maximum adoption rate if introgressed into only Songotra ranged from 10 to 20 percent. There are plans, however, to introduce the *Maruca*-resistance gene into other cowpea varieties. If this is done successfully, then the industry experts give the conjectured maximum adoption rate at 70 percent. Although this figure might seem too optimistic on the bases of survey data on improved cowpea seed adoption, which suggests a maximum adoption rate of 46 percent, the DIIVA project's estimate of improved cowpea adoption in Ghana is even higher at 81 percent.[8]

Scientists and industry experts estimate an adoption lag of five years because of their concern (based on current public perception) that it may take slightly longer than normal for adoption to peak after release. The 30-year simulation period assumes that the maximum adoption will be at year 10 after release, continue at its peak for 11 additional years, followed by 9 years of dis-adoption.

Yield change. The scientists estimated the anticipated yield increase attributable to the IR cowpea based on their results of field trials. With low pest pressure, the yield advantage estimated from field trials is 13.3 percent. With high pest pressure, this goes up to about 67.6 percent. With 80 percent probability of high *Maruca* pressure and 20 percent probability of low pressure, the overall average yield change is estimated at 57 percent. However, scientists know from their experience with other varieties that the average yield gains could be lower on farmer-managed farms. They therefore adjusted the field trial yield changes down to 5 percent under low *Maruca* pressure and 30 percent under high pressure. Using the probabilities attached to the low and high pressure gives an estimated mean yield change of 25 percent. This analysis uses a range of values between 5 and 30 percent.

Cost change. Partial budget analysis was employed to determine the incremental effect (in terms of cost) of the proposed technology change, comparing the cost implications (to the farmer) for adopting the new technology compared with the status quo. The partial budgets are based on expert opinion from farmers, scientists, and industry experts. Appendix Table A2 presents the estimated partial budget comparing the IR and conventional cowpea varieties for the "baseline" scenario. There are two sources of production expenditure differences between the conventional and IR varieties in the baseline scenario: (a) difference in seed cost and (b) difference in number of sprays required. On (a), the scientists and industry experts estimated

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[8] The 46 percent maximum adoption rate is based on farmers' reported use of purchased seeds from the GLSS.

that the price of the IR seed could attract a maximum of 50 percent premium over the conventional seed (i.e., Songotra). For (b), initial discussions suggested a conservative figure of one spray saved, which later was updated to three. The field trials suggest that whereas a maximum of two insecticide sprays are required to combat secondary pests for the IR variety, the conventional variety requires five. An alternative scenario with the same outcome is no spray against *Maruca* for the IR variety and three insecticide sprays for the conventional variety, as the literature implies (Oyewale and Bamaiyi, 2013; Abudulai et al., 2017). Either way, farmers could have a maximum of three insecticide spray savings.

Some farmers spray up to five times, but an average of three sprays is more typical. Because the IR cowpea also requires some spraying against secondary pests, two insecticide spray savings should be assumed. The savings of this reduction in sprayings include not only the cost of purchasing the insecticide but also the labor cost of spraying—not to mention the potential health and environmental cost savings.

The experts estimated that IR seed cost premium could run between 0 and 50 percent. Even though seed sale prices will benefit from a royalty-free license, it is likely that the market for IR seed will command a premium over other preferred varieties. A cost premium of up to 50 percent leads to 7.7 percent higher proportionate seed cost share of total production cost. However, the insecticide saving yields 0.55 and 11.8 percent lower proportionate cost share from the saved costs of insecticides and spraying labor, respectively. The proportionate cost change attributed to the technology is therefore −4.7 percent. Thus, the adoption of the IR cowpea could lead to a 4.7 percent proportionate cost reduction for the base scenario. The results and discussion section of the paper examines other scenarios.

5.1.2. Rice

Adoption. Assumptions for the expected adoption rates of a NUE rice variety are based on expert opinions from scientists, farmers, and industry experts. These sources were complemented with survey data on improved rice seed adoption and information from the literature. Ragasa et al. (2013) reported 58 percent adoption rate for modern rice varieties for Ghana, although only 34 percent of these varieties were from certified sources.[9] However,

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[9] Adoption was measured as the share of total rice area cultivated to modern varieties.

modern variety adoption differs by rice ecology; that is whether the rice is farmed on irrigated land, lowland, or upland. For example, lowland and upland adoption rates were 48 percent and 61 percent, respectively, from the Ragasa et al. (2013) study. The study also reported that modern rice variety adoption rates are lower in the Northern Savannah zone compared with the rest of the country.

As indicated in section 2.2, the NUE trait is being introduced into the NERICA4 rice variety, which is grown in lowland rice ecologies. Although there is no nationally representative survey on adoption rate for this variety, figures from Ragasa et al. (2013) suggest NERICA adoption rate of about 2.3 percent. This low rate of adoption is also because this is an upland variety of rice and, as shown earlier, only 12 percent of total rice cultivated area in Ghana is upland rice.[10] In spite of these constraints, scientists estimated a maximum adoption rate of 5 percent for NUE rice. This figure has been adjusted using zonal variations in adoption rates from Ragasa et al. (2013) and nationally representative survey data for improved rice variety adoption.[11] The maximum country average adoption rate remains at 5 percent, with some variation across the rice production regions.

The consulted scientists expect that the NUE trait will be introduced into other rice varieties in the near future. If this process is successful, industry experts feel that the maximum adoption rates could reach 70 percent. However, given the historically lower adoption rates for modern rice varieties—58 percent, as reported by (Ragasa et al., 2013) and the DIIVA project—this report uses a less optimistic maximum adoption rate of 60 percent if the gene is introgressed into other varieties.

Scientists and industry experts estimate an adoption lag of five years for the same reason given for the lag in adoption for the IR cowpea. Public perception could influence the lag, but judging from adoption in other countries, the adoption may spread more quickly once the early adopters show positive outcomes. The number of years at maximum adoption rate was estimated to be 10 years, according to the scientists. The rice sector has a “fast varietal

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[10] A reason for the NUE variety being introgressed into an upland variety, although lowland rice is more popular, is that nitrogen deficiency is more acute in upland areas (Saito et al., 2018; AATF, n.d).

[11] Based on information from the GLSS sixth round (GLSS 6), assuming that purchased seeds are likely to be modern varieties.

turnover" (Ragasa *et al.*, 2013, p. 14), estimated at about six years. Assuming dis-adoption, it could take a minimum of six years for the technology to be completely abandoned, and therefore it may take between six and nine years for complete dis-adoption. The underlying assumptions described here are summarized in Table 5.

Table 5 IR cowpea and NUE rice: Anticipated adoption rates

	Cowpea		Rice	
	If Songotra only	**If other varieties**	**If NERICA only**	**If other varieties**
Northern	32.00	82.00	4.56	48.00
Upper East	10.00	65.00	4.40	44.00
Upper West	18.00	60.00	N/A	N/A
Brong Ahafo	6.00	75.00	N/A	N/A
Volta	N/A		5.51	76.00
Other	4.00	80.00	5.51	75.00
Non-weighted Average	15.00	70.00	5.00	60.00

Source: Authors' elaboration based on experts' opinions.
Note: N/A = not applicable

Yield change. Assumptions about yield change are based on scientists' opinions, the literature, and survey data. Estimating a rice yield function using nationally representative survey data gives a 21 percent average yield difference between farmers who used improved seed versus those who did not.[12] The scientists' estimate of yield change was 10–20 percent, which is lower than the results obtained from field trials (14–25 percent yield advantage depending on fertilizer use). The highest yield advantage was realized with the least amount of fertilizer applied, simply because the GM crop is developed to use nitrogen more efficiently under limiting conditions (Han et al., 2015). Selvaraj et al. (2017) provides results under different nitrogen regimes, including no nitrogen fertilization. This report uses a range of values between 10 to 20 percent.

Cost change. Adopting the technology could produce two sources of cost change: (1) seed cost and (2) change in cost due to change in fertilizer use. For the first, the scientists and industry experts estimated that NUE seed could cost 0–50 percent more, compared with the conventional variety, depending if the seed will command or not a premium. These opinions

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[12] This estimate is based on the regression model: $logRiceyield = \alpha + \delta(improvedseed) + \beta X + \varepsilon$, where δ is the main parameter of interest. The model was fitted on GLSS 6 data accounting for the complex survey nature of the survey sample.

are based on the release history of other improved varieties, as well as policies aimed at moderating the cost of improved seeds to farmers. The second source of cost change is kept as zero because there are no trials comparing yield outcomes for fertilizer use on the conventional variety and no fertilizer use for the NUE variety, for example. Scientists believe that assuming either no fertilizer use or the same level of use for both conventional and the NUE variety captures the essence of the technology. Appendix Table A2 displays the partial budget comparing production cost for the conventional and NUE rice varieties, showing that a 50 percent cost differential between the NUE and the conventional seed would lead to a 4.61 percent difference in the share of total production cost attributable to the cost of seed.

6. RESULTS AND DISCUSSION

This section presents an estimation of the economic benefits of IR cowpea and NUE rice. These benefits were based on the ESM using DREAM, as well as on the secondary data collected and the different assumptions described below. This review also provides sensitivity analysis using DREAM.

Table 6 and Table 7 summarize the underlying assumptions for the construction of the scenarios for the ex ante DREAM simulations for IR cowpea and NUE rice. Each scenario is derived from a combination of expected changes in yield and cost, and adoption rates. The “optimistic” scenarios are labelled as such because they are derived from highest expected decrease in cost of production, highest expected yield increase, and highest expected adoption rates. The opposite holds for the “pessimistic” scenarios. Combining these parameters gives eight scenarios for each of the crops under analysis. Detailed results for each of these scenarios are presented in Appendix Table A4through A19. The scenarios assumptions are summarized in Table 6 and Table 7 and are ranked from 1 to 8, according to the estimated net present value (NPV) benefits. Scenario 1, with the lowest estimate benefits, is labeled “pessimistic”; Scenario 8, with the highest estimated benefits, is labeled “optimistic.”

Table 6 IR cowpea: DREAM scenarios description and ranking

Change in cost of production		**Increased yields**			
		Low: 5%		High: 30%	
		Maximum Adoption (*)		Maximum Adoption (*)	
		15%	70%	15%	70%
−10%	Lower insecticide use No increase in seed cost	**Scenario 2** −10%, 5%, 15%	**Scenario 6** −10%, 5%, 70%	**Scenario 3** −10%, 30%, 15%	**Scenario 8, "Optimistic"** −10%, 30%, 70%
−4.7%	Lower insecticide use Higher seed cost	**Scenario 1, "Pessimistic"** −4.7%, 5%, 15%	**Scenario 4** −4.7%, 5%, 70%	**Scenario 5** −4.7%, 30%, 15%	**Scenario 7** −4.7%, 30%, 70%

Source: Authors' elaboration based on experts' opinions. Note: Scenarios are ranked from 1 (Pessimistic) to 8 (Optimistic), according to the estimated DREAM NPV benefits. Maximum adoption rates vary by region

Table 7 NUE rice: DREAM scenarios description and ranking

Change in cost of production		**Increased yields**			
		Low: 10%		High: 20%	
		Maximum Adoption (*)		Maximum Adoption (*)	
		5%	60%	5%	60%
0%	No change in nitrogen use No increase in seed cost	**Scenario 2** 0%, 10%, 5%	**Scenario 6** 0%, 10%, 60%	**Scenario 4** 0%, 20%, 5%	**Scenario 8, "Optimistic"** 0%, 20%, 60%
4.4%	No change in nitrogen use Higher seed cost	**Scenario 1, "Pessimistic"** 4.4%, 10%, 5%	**Scenario 5** 4.4%, 10%, 60%	**Scenario 3** 4.4%, 20%, 5%	**Scenario 7** 4.4%, 20%, 60%

Source: Authors' elaboration based on experts' opinions. Note: Scenarios are ranked from 1 (Pessimistic) to 8 (Optimistic), according to the estimated DREAM NPV benefits

In addition to these eight scenarios, this section considers the effects of a five-year regulatory delay for the optimistic and pessimistic scenarios.

Tables B22, B23, B25 and B26 in the Appendix present detailed results for these two scenarios for both crops.

6.1 Potential welfare effects of IR cowpea adoption

The estimated NPV of adopting the *Maruca*-resistant cowpea (IR cowpea) ranges from US$5.55 million for the "pessimistic" scenario, as described above, to US$125.36 million for the "optimistic" one, with an internal rate of return (IRR) from 24.8 to 71.8 percent for the estimated US$2.11 million investment in developing and commercializing the IR technology. (Tables A4 to A19 in the Appendix present detailed results for these scenarios as well as others described and ranked in Table 6.)

Aside from savings from spraying fewer times or not spraying at all, the lowest-bound "pessimistic" estimate assumes that (a) the IR cowpea seed will attract a 50 percent cost premium; (b) there is low *Maruca* pressure, so that the benefit from adoption in terms of yield change is only 5 percent; and (c) the *Maruca*-resistance trait is introgressed into only the Songotra cowpea variety, in which case the maximum adoption rate (in terms of the share of total cowpea cultivated area under the IR cowpea) is only 15 percent. The highest estimate, labeled optimistic, assumes that (a) the IR cowpea seed attracts no cost premium; (b) there is high pressure from *Maruca*, translating to 30 percent yield increase for adopters compared with nonadopters; and (c) aside from Songotra, the *Maruca*-resistance gene is introduced into other cowpea varieties, planted across Ghana.

Table 8, shows the regionally disaggregated and total NPV for all eight scenarios described above. Note the estimated potential negative NPV for the Upper East and Upper West regions for the pessimistic scenario. For these regions, the value of benefits is less than the costs (i.e., low *Maruca* pressure and low adoption rates). Although these are the only cases of potential net losses from regional investments, in other cases, the estimated NPV is positive but there are producer losses that are offset only by the corresponding consumer benefits (Appendix Tables A4–A19). This instance occurs mainly when there are only few producers relative to consumers and yet adoption rates are very low. This is the case for Brong Ahafo, Upper East and "Other regions" for all scenarios with the lowest expected adoption rate. These regions may not see a producer benefit if the *Maruca*-resistance trait is not introgressed into other cowpea varieties.

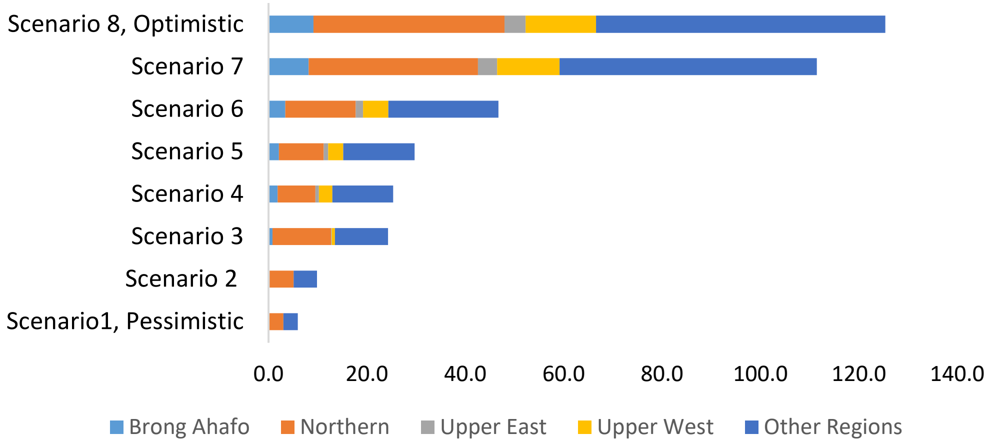
Table 8 IR cowpea: Estimated benefits, NPV, US$ millions

Scenario	**Regions** **Brong Ahafo**	**Northern**	**Upper East**	**Upper West**	**Other Regions**	**Total**
Scenario1, Pessimistic	0.09	2.90	−0.12	−0.30	2.98	5.55
Scenario 2	0.24	4.89	−0.07	−0.11	4.69	9.63
Scenario 3	0.79	11.92	0.13	0.65	10.79	24.27
Scenario 4	1.82	7.70	0.74	2.69	12.40	25.35
Scenario 5	2.14	9.06	0.92	3.09	14.51	29.72
Scenario 6	3.39	14.33	1.53	5.09	22.37	46.70
Scenario 7	8.14	34.46	3.85	12.69	52.33	111.47
Scenario 8, Optimistic	9.16	38.78	4.35	14.31	58.75	125.36

Source: Authors’ estimations using DREAM

Figure 2 plots the regional total estimated benefits detailed in Table 8 , showing the regionally disaggregated and total NPV for all eight scenarios. The graph shows that the net benefit of adopting the IR cowpea technology is highest for “Other regions” (i.e., regions that are net consumers of cowpea) in six of the eight scenarios; in the other two cases, the highest net benefits accrue to the Northern region—the highest cowpea-producing region, where Songotra is most common. An average of US$20.80 million is estimated as potential benefit across all “Other regions” scenarios compared with US$38.78 million for the Northern region, with the lowest average NPV (US$2.88 million) being for the Brong Ahafo region, which produced only 4 percent of total cowpea output.

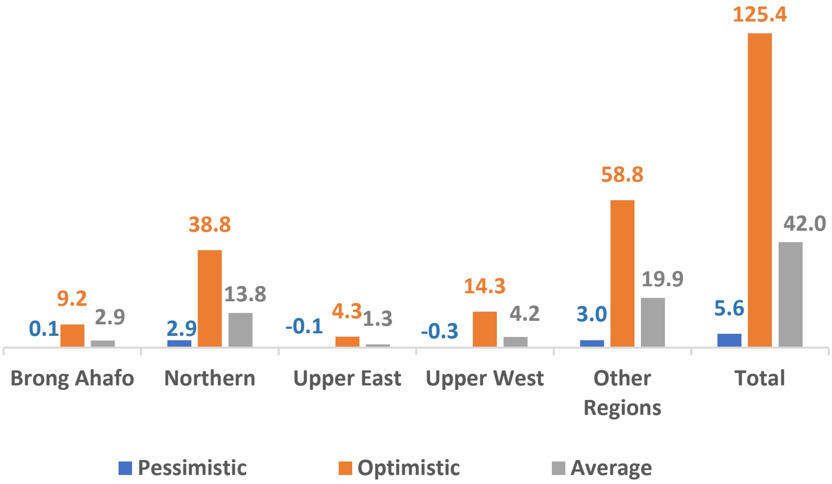
Figure 2 IR cowpea: NPV by region and across all scenarios, US$ millions



Source: Authors’ estimations using DREAM

Figure 3 shows the potential net benefits to producers and consumers for the pessimistic and optimistic scenarios, as well for the "average" for all eight scenarios detailed in Table 8. On average, consumers receive a higher share of the benefits—about 58 percent, or US$26.71 million, compared with US$19.59 million for producers. The higher share of net benefits to consumers is irrespective of the scenario. For the two major producing regions (the Northern and Upper West regions), producers have the highest share of the net benefits (84 and 80 percent for the Northern and Upper West regions, respectively), as one would expect.

Figure 3 IR cowpea: Regional NPV benefits, optimistic and pessimistic scenarios and overall average, US$ millions



Source: Authors' estimations using DREAM

Presenting all these different and diverging scenarios shows how sensitive these estimates are to the different assumptions about the projected changes caused by the new technology, particularly with regard to yield and cost change, and the rate of adoption. A more relevant question is which of these scenarios is most likely to happen under current conditions. The average scenario, presented in Figure 3, is only a standard to compare different scenarios; it cannot and should not be taken as the most likely. Rather than referring to an average, a more relevant question is which of all these scenarios is the most plausible. The answer likely lies between the two extremes of the "pessimistic" and "optimistic" scenarios.

A relevant scenario to consider is one where the trait is not introgressed into preferred varieties, and farmers are then slow to adopt it. In fact, the 15 percent adoption rate is most likely at present, as the *Maruca*-resistance trait has not yet been introgressed into other varieties apart from Songotra. This scenario is called "business as usual" here—it is not a probabilistic calculation, but rather based in the current situation where there are not yet established plans to introgressed these trait into preferred varieties or a defined business plan to effectively deliver varieties to farmers and create the conditions to enable higher adoption rates. In addition to lower adoption rates, the “business as usual” scenario also assumes that the decrease in production cost likely will be between 4.7 and 10 percent, rather than either one or the other. The uncertainty associated with the cost change could come mainly from the price of the GM seed. This higher seed price is likely to happen despite the royalty free license associated with the development of these new varieties

Although the cost of GM seed in developing countries is lower than it is in the developed world (Sadashivappa and Qaim, 2009), GM seeds also have been commanding higher prices worldwide, as farmers are willing to pay more for the potential benefits of these technologies. For this reason, ex ante studies in Norton and Hautea (2009) offer a wide variety of estimates in the expected increased cost of GM seeds in Indonesia and the Philippines, that go from 0 to up to 100 percent difference relative to conventional seeds . Meta-analysis from Finger *et al.* (2011) confirms that GM seed prices in India, China, and South Africa were 233, 28, and 96 percent higher, respectively, than conventional varieties.

Given lessons from fertilizer and other input subsidies (Banful, 2011), farmers adopting the IR cowpea likely would pay a cost premium even with a policy instrument that does not allow a price differential between IR and conventional seeds. For these reasons, a 25 percent price difference is more likely. Scientists have indicated that the probability of high *Maruca* pressure is around 75 percent, meaning that high pressure is most likely. Applying the probabilities attached to the low and high pest pressure gives a most likely yield change of about 23.75 percent from IR cowpeas. Also, rather than using the “optimistic” 70 percent adoption rate, the “business as usual” scenario is run with a 15 percent adoption rate, which is more likely given that only a few cowpea-production regions in Ghana prefer the Songotra variety.

Updating the parameters with the “business as usual” assumptions described above gives 7.26 percent proportionate production cost decrease (rather than 4.70 or 10 percent) and 23.75 percent yield increase.[13] Together with the 15 percent adoption rate (average across all

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[13] Maintaining the 15 percent adoption rate (averaged across all regions).

regions), the NPV of adoption is estimated to be US$21.87 million, with an IRR of 40.9 percent if the technology is available to farmers by 2019. Table 9 shows the total and regionally disaggregated net benefits to producers and consumers using the updated "business as usual" anticipated parameters, along the pessimistic and optimistic scenarios. As with the optimistic and pessimistic scenarios, the "business as usual" scenario also shows that that a larger share (58%) of the potential benefit would be accrue to cowpea consumers. The lowest estimated total NPV is US$5.55 million, with an IRR of 24.8 percent and a benefit-cost ratio (BCR) of 3.6. This means that every dollar invested in development and commercializing the IR technology can earn a minimum US$3.6.

Table 9 IR cowpea: Pessimistic, optimistic, and "business as usual" scenarios

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producer Benefits, Present Value (PV), US$ millions						
Pessimistic	−0.12	3.25	−0.05	0.25	−0.14	3.19
Business as usual	−0.32	8.67	−0.12	0.70	−0.35	8.58
Optimistic	2.75	31.88	2.18	13.2	4.12	54.14
Consumer Benefits, PV, US$ millions						
Pessimistic	0.4	0.47	0.15	0.11	3.35	4.47
Business as usual	1.07	1.27	0.38	0.28	8.99	11.99
Optimistic	6.61	7.72	2.39	1.76	54.85	73.33
Total Benefits, PV, US$ millions						
Pessimistic	0.28	3.72	0.1	0.36	3.21	7.66
Business as usual	0.76	9.94	0.26	0.98	8.64	20.58
Optimistic	9.36	39.6	4.57	14.97	58.98	127.47
NPV, US$ millions						
Pessimistic	0.09	2.9	−0.12	−0.30	2.98	5.55
Business as usual	0.58	9.19	0.05	0.38	8.43	18.64
Optimistic	9.16	38.78	4.35	14.31	58.75	125.36
Benefit/Cost, Ratio (BCR)						
Pessimistic	1.5	4.6	0.4	0.5	14.5	3.6
Business as usual	4.3	13.3	1.3	1.6	42.5	10.6
Optimistic	48.4	48.6	20.5	22.8	266.6	60.5
IRR, %						
Pessimistic	14.4	27.5	3.8	5.7	44.0	24.8
Business as usual	24.7	38.4	12.8	14.9	54.2	35.7
Optimistic	66.6	66.8	51.6	50.8	106.9	71.8

Source: Authors' estimations using DREAM

All the scenarios described above assume that the IR cowpea will be released in 2019. One of the critical factors analyzed in the literature is the effect of regulatory delays on the potential benefits of technology release (Falck Zepeda et al., 2012) The authors demonstrate that the one of the most critical factors affecting the estimated benefits are time delays in the commercialization of these crops. This study’s estimates confirm these results. Table 10 compares the results in the estimated benefits for the optimistic, “business as usual,” and pessimistic scenarios, and show that the calculated total NPV benefits are cut by a minimum of 29 percent for the optimistic scenario to a maximum of 39 percent for the pessimistic scenario. The regional distribution of losses varies, with the Upper West losing the least and Brong Ahafo the most.

Table 10 IR cowpea: Cost of a five-year regulatory delay

	Regions					Total
	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	
NPV, US$ millions – no delay						
Pessimistic	0.09	2.90	−0.12	−0.30	2.98	5.55
Business as usual	1.29	4.26	0.62	3.26	9.32	18.75
Optimistic	9.16	38.78	4.35	14.31	58.75	125.36
NPV, US$ millions – five-year regulatory delay						
Pessimistic	0.01	1.81	−0.16	−0.38	2.10	3.37
Business as usual	0.86	2.78	0.32	2.30	6.61	12.87
Optimistic	6.42	27.26	2.77	10.78	41.68	88.90
Cost of five-year regulatory delay, percentage NPV reduction						
Pessimistic	92%	38%	30%	27%	30%	39%
Business as usual	34%	35%	47%	29%	29%	31%
Optimistic	30%	30%	36%	25%	29%	29%

Source: Authors’ estimations using DREAM

6.2 Potential welfare effects of NUE rice adoption

Investing in the NUE rice technology is estimated to yield potentially positive NPVs for all rice producing and consuming regions under the assumptions described in section 5.3 and summarized in Table 7 above. The estimates, summarized in Table 11, show that the lowest potential NPVs range from US$0.25 million for the Upper East region to US$0.81 million for the Volta region with corresponding IRRs of 15.1 percent and 18.7 percent, respectively (Table A20.) The lowest estimated total NPV is US$1.85 million, with an IRR of 16.6 percent and a benefit-cost ratio (BCR) of 21.95. This means that every dollar invested in development and commercializing the NUE technology can earn approximately US$21.95. The IRR estimate, however, means that the investment may not be worthwhile if the discount rate exceeds 16.6 percent.

Scenario1 is based on the most pessimistic estimates, where (a) adopting the technology leads to a 4.42 percent proportionate increase in production cost caused by the assumed 50 percent seed cost for premium NUE adopters; (b) NUE is lowest and thus leads to only a 10 percent yield premium of adoption; and (c) the NUE trait is introgressed only into NERICA4, which gives the lowest maximum adoption rate of only 5 percent.

Table 11 NUE rice: Potential benefits, NPV, US$ millions

	Regions				
Scenario	Northern	Upper East	Volta	Other Regions	Total
Scenario1, Pessimistic	0.53	0.25	0.81	0.26	1.85
Scenario 2	1.23	0.70	1.73	0.73	4.39
Scenario 3	2.34	1.40	3.17	1.48	8.39
Scenario 4	2.98	1.80	4.01	1.92	10.72
Scenario 5	10.42	6.20	18.35	9.20	44.17
Scenario 6	17.80	10.65	31.11	15.71	75.27
Scenario 7	29.43	17.66	51.26	25.99	124.34
Scenario 8, Optimistic	36.21	21.75	63.04	32.00	153.01

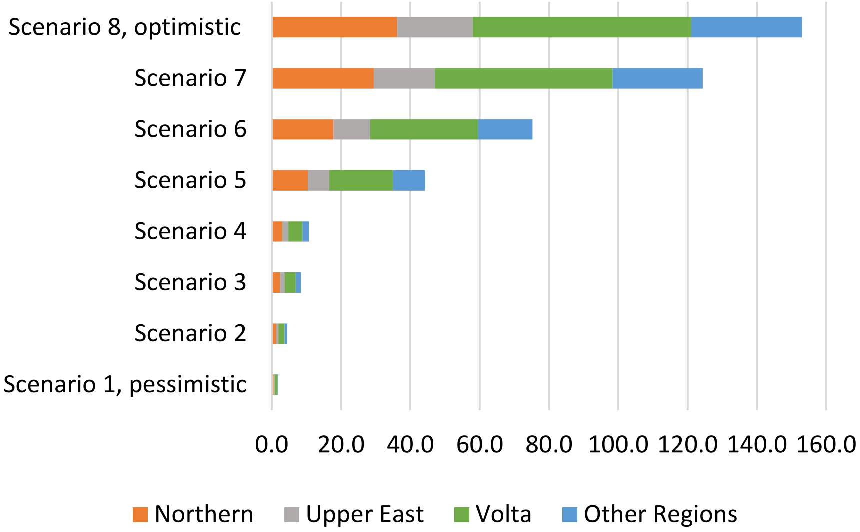
Source: Authors' estimations using DREAM

On the opposite end is Scenario 8, with the most favorable conditions, meaning that (a) policymakers ensure that there is no price difference between the conventional and NUE seed, (b) there is optimum efficiency in nitrogen uptake, and (c) the NUE trait is introgressed into other, more popular rice varieties and thus raise adoption rates from 5 to 60 percent. This most optimistic scenario gives estimated potential NPVs from US$21.75 million for the Upper East region (the smallest rice producing region) to US$63.04 million for the Volta region (the biggest rice producing region). Across all regions, the total potential NPV of adoption is estimated to be US$153.01 million, with an IRR of 63.8 (Table A19).

The estimated net benefit in this optimistic scenario would be 51 percent and 56 percent of the average import value of rice between 2013 and 2015 (US$299.57 millions) and for 2016, respectively, according to MoFA (2016) and the Observatory of Economic Complexity (https://atlas.media.mit.edu/en/profile/country/gha/). The BCR value suggests that a dollar invested in developing and commercializing the NUE technology under the most optimistic scenario assumptions may yield up to US$80.11. With the estimated IRR, the investment may be worthwhile even with a discount rate of approximately 63 percent.

Figure 4 displays the distribution of potential NPV benefits for all eight scenarios for each region. These potential benefits are relatively small from scenarios 1 through 4, and then quadruple between scenarios 4 and 5 and 8, which is when adoption rates jump from 5 percent to 60 percent, as shown in Table 7 above. Adoption rates, therefore, are the most critical variable in these estimations of potential technology-based gains. To realize these gains, the NUE trait would need to be introgressed into other rice varieties. Comparing results presented in Figure 4 with rice regional production from Table 3, shows that production is correlated with the region's share of total rice production : the Volta region has the highest potential benefits, irrespective of scenario, while the Upper East region has the lowest ones.

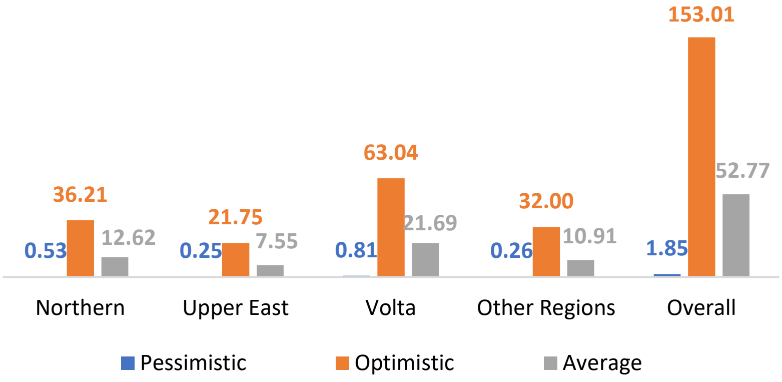
Figure 4 NUE rice: NPV across various scenarios, US$ millions



Source: Authors' estimations using DREAM

Figure 5 presents the NPV benefits from the pessimistic (Scenario 1) and the optimistic (Scenario 8) scenarios, as well as the NPV benefits averaged across all scenarios. On average, the estimated net benefit of adoption ranges from US$7.55 million for the Upper East region to US$21.69 million for the Volta region; the countrywide average is US$52.77 million.

Figure 5 NUE rice: Regional NPV benefits, optimistic and pessimistic scenarios and overall average, US$ millions



Source: Authors' estimations using DREAM

As with the cowpea analysis, a "business as usual" scenario identifies which of the eight NUE rice technology scenarios could be considered the most likely one, if no set plans are made to introgressed these trait into other varieties or to define and implement a business plan to facilitate the availability of the NUE seeds to all farmers. This scenario will have to fall somewhere between the pessimistic scenario's total NPV benefit of US$1.85 million and IRR of 16.6 percent and the optimistic scenario's NPV benefits of US$153.01 million and IRR of 63.8 percent. As before, the answer most likely lies somewhere between these two extreme scenarios. Much as with the IR cowpea, a 25 percent cost premium for the NUE seed is probably more likely than a 50 percent one. Also, the "business as usual" scenario incorporates a 10 percent yield change because a new GM technology's yield performance is often lower when used by farmers than in its field trials (MoFA, 2016). Although the maximum adoption rate of 5 percent (averaged over all regions) seems too low, it makes sense to work with it as the "business as usual" scenario because efforts to introgress the NUE trait into other rice varieties has not yet been considered.

Table 12 summarizes the assumptions for the "business as usual" scenario, compared with the optimistic and pessimistic ones. It is based on (a) a proportionate production cost increase of 2.27 percent, instead of 4.42 percent under the pessimistic scenario; (b) a 10 percent yield increase; and (c) a 5 percent maximum adoption rate.

Table 12 NUE rice: Pessimistic, optimistic, and "business as usual" scenarios

	Cost change	Yield change	Adoption rate
Scenario 1, Pessimistic	+4.42	10%	5%
Business as usual	+2.27	10%	5%
Scenario 8, Optimistic	0	20%	60%

Source: Authors' estimations, based on experts' opinions

Using these assumptions, Table 13 summarizes the NPV of developing and commercializing NUE rice under "business as usual" assumptions compared with the pessimistic and optimistic scenarios. The "business as usual" scenario is estimated to be US$3.08 million, with an IRR of 19.4 percent, if the seeds become available to farmers by 2020. Not surprisingly, this scenario is closer to the pessimistic one, because the critical variable (adoption rate) is set to 5 percent. This scenario highlights the importance of having NUE varieties that can be used in the main rice-production areas.

Table 13 NUE rice: Pessimistic, optimistic, and "business as usual" scenarios

	Northern	Upper East	Volta	Other Regions	National
Producers' Benefits, PV, US$ millions					
Pessimistic	1.04	0.66	1.36	0.67	3.73
Business as usual	1.51	0.99	1.64	0.81	4.95
Optimistic	36.54	22.1	63.46	30.88	152.97
Consumers' Benefits, PV, US$ millions					
Pessimistic	0.00	0.00	0.00	0.04	0.05
Business as usual	0.01	0.00	0.00	0.05	0.06
Optimistic	0.20	0.06	0.14	1.58	1.97
Total Benefits, PV, US$ millions					
Pessimistic	1.05	0.66	1.36	0.71	3.78
Business as usual	1.51	1.00	1.65	0.86	5.01
Optimistic	36.73	22.16	63.6	32.46	154.95
NPV, US$ millions					
Pessimistic	0.53	0.25	0.81	0.26	1.85
Business as usual	0.99	0.59	1.09	0.41	3.08
Optimistic	36.21	21.75	63.04	32	153.01
BCR					
Pessimistic	2.0	1.6	2.5	1.6	2.0
Business as usual	2.9	2.5	3.0	1.9	2.6
Optimistic	70.6	54.8	114.6	71.5	80.1
IRR, percentage					
Pessimistic	16.9	15.1	18.7	14.8	16.6
Business as usual	20.5	19.0	20.6	16.6	19.4
Optimistic	61.6	58.6	69.0	63.6	63.8

Source: Authors' estimations using DREAM

Table 13 also shows the distribution of benefits among producers and consumers for all three scenarios. Unlike the IR cowpea technology, almost all potential net benefits from developing and commercializing NUE rice technology are projected to accrue to producers for the three scenarios in this table. The consumer share of these benefits is low because of the large volumes of rice imports. Producers gain by capturing some of the gains that hitherto would have gone to producers in importing countries.

At the national level, for the "business as usual" scenario only US$0.06 million—1.3 percent of the potential total present value of adopting the NUE technology—is projected as consumer benefits, and the rest (US$4.95 million or 98.7 percent of the total) is potential producer benefits. The largest share of potential consumer benefits (about 5%) is estimated to accrue in "Other regions"—NPV of US$0.05 million to consumers compared with US$0.81 million to producers in the same region.

Regulatory delays can drastically reduce these NPV benefits estimates for all projected scenarios, as summarized in Table 14. For the optimistic scenario, for example, society would pay a hefty penalty of US$42.85 million if regulatory delays prevent the GM seeds from reaching farmers until 2025. The largest proportional penalty for regulatory delay is borne by those in "Other regions," while the lowest penalty is for those in the Volta region. "Other regions" collectively are the largest net importer of rice, and therefore a delay in these areas would erode a larger proportion of consumer benefits.

Table 14 NUE rice: Cost of a five-year regulatory delay

	Regions				
	Northern	Upper East	Volta	Other Regions	Total
NPV, US$ millions					
No regulatory delay					
Pessimistic	0.53	0.25	0.81	0.26	1.85
Business as usual	0.99	0.59	1.09	0.41	3.08
Optimistic	36.21	21.75	63.04	32.00	153.01
Five-year regulatory delay					
Pessimistic	0.25	0.05	0.48	0.02	0.80
Business as usual	0.59	0.28	0.69	0.12	1.69
Optimistic	26.54	14.91	47.67	21.13	110.25
Cost of five-year regulatory delay, percentage NPV reduction					
Pessimistic	53%	80%	41%	93%	57%
Business as usual	40%	52%	36%	71%	45%
Optimistic	27%	31%	24%	34%	28%

Source: Authors' estimations using DREAM.

6.3 Gender differences in potential welfare effects

The analysis of potential gender differentiated welfare effects of the estimations presented in this report for NUE rice and IR cowpea would require the existence of regional sex disaggregated data related to technology adoption rates, yields, prices, insecticide use and overall cost of production. Given that such information is not readily available, the estimations presented below are based on data gathered from GLSS and secondary sources. No attempt has been made to do a regional disaggregation given the limited available data. The estimations are based on three gender-differentiated indicators: adoption rates, production and consumption for each of the two crops.

Peterman et al. (2014) literature review on gender differences in agricultural technology adoption shows that adoption tends to be lower among female farmers than among male farmers. Evidence also suggests that women's access to productive resources is lower than men's (Quisumbing, 1996; Udry, 1996; Doss and Morris, 2001; Doss, 2002). With this background, one could conjecture that the benefits of the IR cowpea and NUE rice technologies are not gender neutral.

The main sources of such gender gaps are differences in how men and women participate in production and consumption at the household level. Census data and GLSS survey data is used to estimate female share of production and consumption.[14] Using household headship as the gender dichotomy for production differences would highly underestimate female farmer production shares for at least two reasons. First, our analysis of the GLSS 6 survey shows that only 11 percent of beans producing farm households are female-headed, and they produce only 5 percent of total beans output. Second, female contribution to production in male-headed households is expected to be greater than male contribution to production in female-headed households (Doss and Morris, 2001; Hill and Vigneri, 2014). To mitigate the potential underestimation of female farmers' production in male-headed households this study allocates a proportion of production in male-headed households to females based on the share of female adults in total adult equivalent household labor. While the ratio of female to male adults

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[14] These estimates come from round 6 of GLSS (GLSS 6) and the 2010 census data.

working on the farm in male-headed households is close to one (0.98), the ratio of male to female adults in female-headed households is only 0.45.

Estimates for female share of consumption are drawn from gender-disaggregated adult equivalent energy requirements (FAO, 2001). Female shares of production for the two crops are 33.5and 33.2 percent for cowpea and rice, respectively. In terms of food consumption, based on FAO estimates, 1 male equivalent adult is equal to 0.79 female equivalent adults (FAO, 2001). Although the overall female population share is higher, about 51.2 percent (Ghana Statistical Service, 2012), female share of cowpea and rice consumption is estimated to be 42.9 percent of total demand for the two commodities due to females' lower energy requirement, on average.

Another source of gender heterogeneity is the possible differences in adoption rates between female and male farmers. As mentioned above, agricultural technology adoption rates tend to be gendered, with female farmers' adoption rates being lower than male ones. Therefore, this study applies a gender differential in adoption rates based on gender differences in improved seed adoption from the nationally representative surveys. From the GLSS 6, for example, the use of purchased beans seeds was 18.5 percent for female-headed households but was 10 points higher for male-headed households.

Table 15 summarizes the differential production, consumption, and adoption rates for men and women. The estimated differential rate of adoption among male and female farmers was constructed using purchased seed adoption rates from the latest GLSS survey (GLSS 6).

Table 15 Gender differences in the key parameters used in the ESM estimates

	Female	Male
Cowpea, production share	33.5%	66.5%
Rice, production share	33.2%	66.8%
Rice and cowpea, consumption share	42.9%	57.1%
Maximum adoption rate if IR gene introgressed into Songotra cowpea variety only	12.6%	16.8%
Maximum adoption rate if IR-resistance introgressed into other cowpea varieties	67.4%	77.4%
Maximum adoption rate if NUE gene introgressed into NERICA4 rice variety only	4.9%	5.2%
Maximum adoption rate if NUE gene introgressed into other rice varieties	56.8%	63.8%

Source: Authors' calculations from secondary data

Gender-specific estimates of potential net benefits of adopting IR cowpea and NUE rice are given for the pessimistic, optimistic, and "business as usual" scenarios, as well as results for a five-year regulatory delay. Because information on the underlying gender assumptions is available only at the national level, estimates have not been disaggregated by region. Detailed results are presented in Appendix Table C28 to C35.

6.3.1 Sex-disaggregated results for IR cowpea

Table 16 summarizes gender-specific estimates for IR cowpea from the ESM. Detailed results can be found in the tables in Appendix C. The estimated potential NPV of adopting IR cowpea is US$0.819 million for female farmers and US$1.289 million for male farmers under the “business as usual” scenario with no regulatory delays; the corresponding IRRs are 37.5 percent and 40.1 percent. With a five-year delay, these potential net benefits drop by 35 percent for females, slightly more than the corresponding 33.8 percent for males. This is partly because the delay tends to erode potential consumer benefits slightly more than it does potential producer benefits, yet female share of consumer surplus is higher than their share of producer surplus.[15]

Table 16 IR cowpea: Summary of sex-disaggregated potential benefits

Scenario		**Producer Benefit**	**Consumer Benefit**	**Total Benefits**	**Research Costs**	**NPV**	**IRR**
				US$ millions			%)
Pessimistic	Female	0.569	1.527	2.096	0.819	1.276	20.5
	Male	2.539	2.031	4.571	1.289	3.281	24.4
Optimistic	Female	14.589	29.528	44.117	0.819	43.297	69.4
	Male	45.533	39.290	84.823	1.289	83.534	73.8
Business as usual	Female	1.937	4.733	6.670	0.819	5.851	35.7
	Male	7.703	6.298	14.001	1.289	12.712	40.1
Business as usual w/five-year regulatory delay							
	Female	1.345	3.278	4.622	0.819	3.803	23.3
	Male	5.332	4.361	9.693	1.289	8.404	25.8

Source: Authors’ estimations using DREAM.

Under the most optimistic scenario, the potential NPVs increase by a factor of 33.9 for female farmers and 25.5 for male farmers, and the IRRs also increase by approximately 49 percentage points for both men and women. These large increases are driven chiefly by adoption rates, though the cost and yield changes play a role. Under the “business as usual” scenario, however, the estimated potential NPV of adoption is US$5.85 million for female

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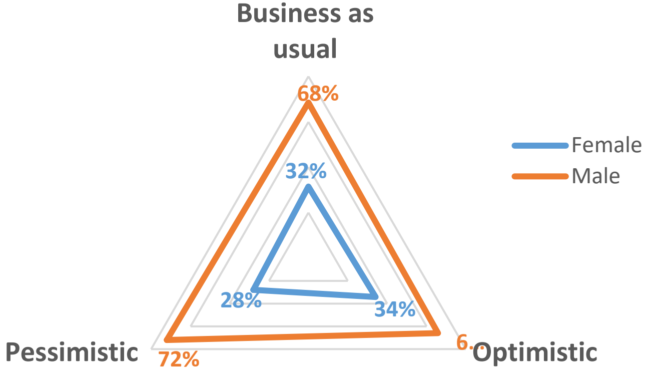
[15] Female producers constitute a smaller share of total producers compared with consumers.

farmers and US$12.71 million for male farmers, with IRRs of 35.7 percent and 40.1 percent, respectively.

The “business as usual” NPV benefits estimates show a 4.6 and 3.9 factor increase over the pessimistic estimates for female and male farmers, respectively. The gender gap reduces as the key parameters (cost change, yield change, and adoption rates) become more favorable for all farmers. Figure 6 shows female shares of potential NPVs under the three scenarios, with the highest share realized under the optimistic scenario. Female shares of potential producer benefits are lower than the overall female shares of the benefits, given that female share of production is lower and female farmers have lower adoption rates, which affects potential producer benefits but not consumer benefits. Figure 6 illustrates the sex-disaggregated shares of the NPV estimated benefits for IR cowpea.

Figure 6 IR cowpea: Sex-disaggregated NPV under different scenarios, percentage share



Source: Authors’ elaboration based on DREAM.

6.3.2 Sex-disaggregated results for NUE rice

Table 17 summarizes the sex-disaggregated result for NUE rice for the optimistic, pessimistic and “business as usual” scenario, as well as the effect of a 5-year delay for the latter scenario.

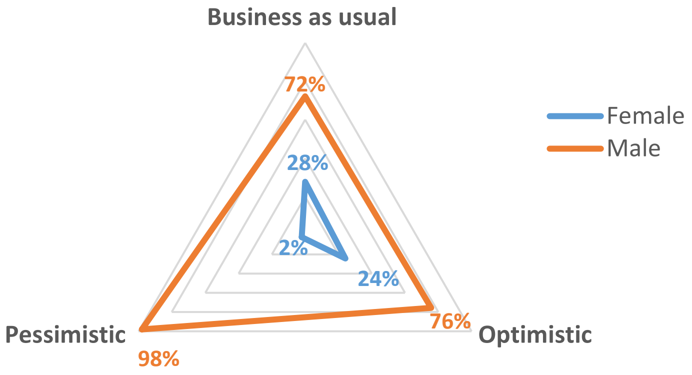
In the most optimistic scenario—where (a) the NUE trait is introduced into other rice varieties and anticipated adoption rates increase, (b) yield change on farmer fields reaches levels similar to those in field trials, and (c) there is no cost premium on GM seeds—then the potential net gains from the investments in the technology would increase by a large factor for all farmers, although at a higher proportional rate for females farmers compared to males and in particular relative to the pessimistic scenario. Figure 7 illustrates the sex-disaggregated shares of the NPV estimated benefits for NUE rice.

Table 17 NUE rice**:** Summary of sex-disaggregated potential benefits

Scenario	Producer Benefit	Consumer Benefit	Total Benefits	Research Costs	NPV	IRR
	US$ millions					%
Pessimistic						
Female	0.774	0.020	0.794	0.747	0.046	11.3
Male	3.423	0.026	3.449	1.187	2.262	20.6
Optimistic						
Female	38.812	0.748	39.560	0.747	38.813	57.6
Male	121.446	0.998	122.444	1.187	121.257	68.5
Business as usual						
Female	1.577	0.023	1.600	0.747	0.852	17.6
Male	3.374	0.031	3.405	1.187	2.218	20.5
Business as usual w/5-yr reg. delay						
Female	1.120	0.017	1.137	0.747	0.390	13.2
Male	2.397	0.022	2.419	1.187	1.232	15.2

Source: Authors' estimations using DREAM.

Figure 7 NUE rice: Sex-disaggregated NPV under different scenarios, percentage share



Source: Authors' elaboration based on DREAM.

7. SENSITIVITY ANALYSIS

The following sensitivity analysis reports variations in the results over the eight scenarios. It varies some of the previously fixed parameters, as well as figures for production cost, yield change, adoption rates, and regulatory timelines. These previously fixed parameters include discount rates, supply and demand elasticities, production and consumption growth rates, R&D

and regulatory costs, and gender-related adoption rates. In the interest of brevity, this analysis has been based on the “business as usual” scenario.

7.1 Discount rate

The 10 percent discount rate applied to all scenarios may seem too high based on calculated real discount rates from financial market data. This analysis therefore looks at the impact caused by a 5 percent discount rate, which is not only consistent with suggestions in the literature (Alston et al., 1995) but also similar to recent real interest rates on domestic public debt for Ghana (IMF, 2016). The present value of potential future cash flows of developing and commercializing the technologies are expected to increase as the opportunity cost of investment capital decreases, as seen in Table 18 . A fifty percent decrease in the discount rate (from 10% to 5%) is estimated to increase potential present value of net benefits by 122 and 203 percent for IR cowpea and NUE rice, respectively.

Table 18 IR cowpea and NUE rice: Change in benefits NPV under varying parameter assumptions

	IR Cowpea		NUE Rice	
Scenario	Benefits NPV “business as usual” *US$ millions*	Change relative to base model *percent*	Benefits NPV “business as usual” *US$ millions*	Change relative to base model *percent*
Base model	22.51		3.05	
Discount rate:				
5 percentage point reduction	50.00	122.2	9.23	203.0
Elasticity of supply:				
50 percent increase	22.61	0.46	3.05	0.10
50 percent decrease	22.33	−0.79	3.04	−0.13
Elasticity of demand:				
50 percent increase	22.43	−0.35	3.04	−0.07
50 percent decrease	22.62	0.49	3.05	0.13
Exogenous growth, supply:				
50 percent increase	24.83	10.3	5.05	66.0
50 percent decrease	20.27	−9.92	1.66	−45.6
Exogenous growth, demand:				
50 percent increase	26.60	18.2	3.07	0.95
50 percent decrease	18.92	−15.9	3.03	−0.65
R&D and regulatory costs				
50 percent increase	21.47	−4.61	2.09	−31.3
Base model: female	5.85		0.85	
Base model: male	12.71		2.22	
No gender gaps in adoption: female	7.87	34.5	0.95	11.4
No gender gaps in adoption: male	12.58	−1.02	2.22	0.02

Source: Authors’ estimations using DREAM

7.2 Elasticities

Increasing or decreasing the supply and demand elasticities by 50 percent does not affect the PV of net benefits of adopting both technologies, as illustrated in Table 18. This is an expected result, since changing the values of the elasticity of supply and demand affect mainly the distribution of benefits among producers and consumers. In addition., since these elasticities are low for both cowpea and rice (Table 4), even a 50 percent rise still result in inelastic elasticities

7.3 Production and consumption growth rates

By contrast, a 50 percent increase or decrease in the growth rate of exogenous supply has a meaningful impact on the PV of potential net benefits of adopting the technologies, particularly for rice (for which there is a large deficit). For example, a 50 percent increase in exogenous supply growth (i.e., 2.39% to 3.59% for cowpea; 3.87% to 5.81% for rice) is estimated to increase the PV of potential net benefits of adopting the technologies by 10.3 and 66.0 percent for cowpea and rice, respectively, ceteris paribus. The same percentage decrease in supply growth works the opposite direction, although for rice, the estimated decrease in potential NPV caused by the decrease in exogenous supply growth is much lower (by approximately 20 percentage points) than the potential NPV increase associated with an increase in supply growth. This result stems from the model's "openness" to rice from Asian markets. For the same reason, an exogenous increase or decrease in demand growth has no meaningful impact on the PV of potential net benefit of adopting NUE rice, but it has a meaningful impact on the PV of potential net benefit of IR cowpea adoption (Table 11).

7.4 R&D and regulatory costs

Increased R&D and regulatory costs erode the present value of potential net benefits of adopting both technologies, more so for NUE rice than for IR cowpea. Supposing that R&D and regulatory costs go up by 50 percent, the potential gains of adopting IR cowpea would decrease by an estimated 4.6 percent, and that of NUE rice would decrease by as much as 31.3 percent. This is because the "business as usual" base scenario assumes that the NUE technology is introgressed into only NERICA4, yielding very low adoption rates, but the R&D cost component is fixed. If R&D costs go up and the NUE trait is not introgressed into other rice varieties, then the potential net returns for developing and commercializing the technology would be minimal.

8. GAPS, LIMITATIONS, AND OPPORTUNITIES

The estimations in this report focus on the potential national and regional benefits that consumers and producers of cowpea and rice in Ghana could reap from the introduction, adoption, and diffusion of specific GM technologies. The estimations are based on secondary data collected locally and on different scenarios about the potential impacts of these technologies on yields and production costs, as well as estimations regarding adoption rates. Given that these assumptions are not and cannot be set to a unique value, increasing or decreasing the values of these different estimates changes the potential national or regional benefits. The "business as usual" scenario shows the importance of making policy decisions that could increase estimated benefits toward the more "optimistic" scenario.

Although these estimations are a step toward valuing the benefits and cost of GM technologies, there are questions that this report has not answered and that might be of interest to decisionmakers. These questions include the possible impact of these benefits on poverty alleviation, nutrition, employment, and overall food security. To accurately make such estimations, researchers would need to collect primary data, develop more sophisticated research methods, and secure greater time and resource investments beyond the scope and objective of this project, particularly related to the rapid results expected from the analysis.

The main objective of this project was to locally generate estimates about the benefits of two nationally selected technologies in a limited timeframe to better suit the demands of policymakers and decisionmakers. This objective was met using the methods and tools described in this report. The locally led process has opened an opportunity to locally generate such type of estimates not only for GM technologies, but also for other technologies, a process that can help guide and prioritize public investment decisions.

9. CONCLUSIONS AND RECOMMENDATIONS

The analysis shows that the estimated potential benefits for IR cowpea and NUE rice technologies to producers and consumers in Ghana can be substantial. The range of net benefits estimated are wide and go from US$5.5 million to US$125.3 million for IR cowpea, and from US$1.9 million to US$153 million for NUE rice. These ranges are based on different assumptions, regarding the effect of these technologies on farm cost of production and yields and the estimated adoption rates. The lower bound reflects the most pessimist assumptions of each of these variables and the upper bound the most optimistic ones.

Eight possible scenarios are evaluated for IR cowpea and NUE rice, according to different values for the projected change in crop yield and cost, as well as expected adoption rates. The analysis shows that of these three variables, the most critical one is the expected adoption rate, which in turn would be affected by the availability of these technologies in farmers' preferred varieties. The lowest estimated NPV benefits of all eight estimated scenarios are those where the adoption rate is the lowest, both for IR rice and NUE rice. The opposite is true for the most optimistic scenarios. Efforts directed towards achieving the most optimistic assumptions regarding adoption rates have already started but having a financial plan to guarantee its implementation is crucial to be able to realize the projected higher benefits.

The gains at the farm level of IR cowpea are derived mainly from a reduction in the number of insecticide applications and the associated labor cost from spraying, which are estimated to decrease the cost of production by almost 10 percent. One cost that could increase would be that of the GM seed. Some experts estimate that even if the seed is commercialized under the royalty free agreement, it is possible that the production cost of the new seed might be higher. If this is the case, given that there are no effective price ceilings, the seed would need to be commercialized with a price premium, as compared to other commercialized varieties. The estimates show, that even if the GM seed carries a market premium of up to 50 percent, the cost of production will still be reduced by 4.7 percent. The net farm gains will then depend on the extend of *Maruca* and the effective control of the IR variety, which in turn will influence farm yields. Estimations about *Maruca* damage are as high as 80 percent, with variability over region and over time. The different scenarios estimated for IR cowpea contemplate this variability, with increase in yield of 5 to up to 30 percent, according to the underlying assumption regarding *Maruca* pressure.

The estimated farmer gains for NUE rice do not come from the reduction in costs, as experts do not estimate that there will be a reduction of nitrogen use. Since the use of fertilizers for smallholder rice production is very limited in Ghana, producer gains derived from the use of NUE rice come from the more efficient use of nitrogen. Experts estimate that such use-efficiency could have 10-20 percent increase in rice yields. As in cowpea, the study also contemplates the possible increase in the GM seed prices, which in the case of NUE rice could translate into a net increase of farm cost of production of up to 4.4 percent. Of course, no such increase will be in place if the seed cost of production and distribution is like that of other commercialized seeds.

An interesting result of this evaluation are the regionally disaggregated estimations. For cowpea, results are estimated for 5 regions: Brong Ahorfo, Northern, Upper East, Upper West and ‘Other Regions.’ Overall, benefits of IR cowpea are higher in the Northern area, the current highest cowpea-producing region, and in regions that are net consumers of cowpea, grouped under ‘Other regions.’ Under the assumption that the IR trait becomes available in popular varieties common in the other producing regions, the benefits of the technology expand to the Upper West and Brong Ahafo producing regions.

The regions of interest in the case of rice are Northern, Upper East, Volta and ‘Other Regions’. Benefits to producers under the most pessimistic assumptions are concentrated mainly in the Volta region, where the upland variety NERICA4 is most popular. Under the assumption that the NUE technology will be successfully introgressed into popular lowland varieties common in the other producing regions, the benefits will be realized in the other producing regions, although under all 8 scenarios analyzed the Volta region is where the greatest proportion of benefits will accrue. The distribution of benefits between consumers and producers is heavily weighted towards the latter, given that rice imports are currently relatively high in Ghana. Producers in the country will be capturing the benefits that would have gone to producers from the rest of the world under non-adoption conditions.

Aside from the eight scenarios analyzed, this report shows the effects of regulatory delays in the estimated benefits. Specifically, the analysis shows that if there is a five-year regulatory delay, the estimated net benefits will be reduced from 29 to 39 percent for IR cowpea and from 28 to up to 57 percent for NUE rice. The regions that will be most affected with the regulatory delay of IR cowpea is Brong Ahafo, with reduction in net benefits from 30 to up to 90 percent, depending on the scenario analyzed. In the case of rice, the major losers will be in ‘Other

Regions' where the largest proportion of consumers are therefore a larger proportion of consumer benefits will be eroded by a delay

Additional to the 8 scenarios analyzed, based on different assumptions related to cost, yield, and adoption rate, the report also presents a sensitivity analysis for other underlying assumptions, including discount rate, elasticities, production and consumption growth rates, and R&D regulatory rates. Of all these assumptions, the analysis shows that in the calculation of the net benefits the most sensitive variables are the discount rate, for both IR cowpea and NUE rice, and the exogenous demand growth rate, for IR cowpea, and the exogenous supply growth rate for NUE rice. This difference for cowpea and rice aligns with the regional analysis for IR cowpea, where the major beneficiaries are the producers and for NUE rice where the most important beneficiaries are the consumers.

This finding highlights the importance of having a functional biosafety system that can efficiently overview the regulatory process. 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 polices 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 that may be ill defined and thus lengthen 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 additional time the process. Policies related to product liability and punitive considerations should be considered commensurate with risk. Strict liability, as opposed to fault-based liability systems, are not consistent with the historical track record of safety with respect to these new products and can overly burden the regulatory system, while disincentivizing product developers. In addition, capacity and confidence of regulators is also important to insure consistency in how regulatory policies and processes are applied and to insure predictability in the application of regulatory laws and norms. 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 longevity in the market place. 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, 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.

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. Investments in effective extension practices and seed delivery might be one such policy that could merit the attention of decision makers.

APPENDIX A

Table A1 Cowpea**:** Partial budget estimates for conventional and IR cowpea production

	Conventional				IR			
Input/Activity	Qty.	Unit	Unit Price (GHC)	Total (GHC)	Qty.	Unit	Unit Price (GHC)	Total (GHC)
Rental cost of land	1.0	hectare	247.00	247.00	1.0	hectare	247.00	247.00
Land preparation	1.0	hectare	161.00	161.00	1.0	hectare	161.00	161.00
Seeds	28.0	kg/ha	6.67	186.76	28.0	kg/ha	6.67	186.76
Planting	1.0	hectare	247.00	247.00	1.0	hectare	247.00	247.00
Weed control	1.0	hectare	247.00	247.00	1.0	hectare	247.00	247.00
Insecticide	2.4	L/ha	5.25	12.60	0.8	L/ha	5.25	4.20
Labor cost for spraying	3.0	sprays	90.00	270.00	1.0	sprays	90.00	90.00
Harvesting	1.0	hectare	100.00	100.00	1.0	hectare	100.00	100.00
Total				**1,471.36**				**1,282.96**

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

Table A2 Rice: Partial budget estimates for conventional and NUE rice production

	Conventional				**NUE**			
Input/Activity	Qty.	Unit	Unit Price (GHC)	Total (GHC)	Qty.	Unit	Unit Price (GHC)	Total (GHC)
Land	1	hectare	247.00	247.00	1	hectare	247.00	247.00
NPK	240	kg/ha	1.15	276.00	240	kg/ha	1.15	276.00
Urea	120	kg/ha	0.95	114.00	120	kg/ha	0.95	114.00
Weedicide	25	L/ha	15.00	375.00	25	L/ha	15.00	375.00
Spraying	3	spray	50.00	150.00	3	spray	50.00	150.00
Seeds	35	kg/ha	5.51	192.79	35	kg/ha	8.26	289.19
Labor for planting	1	hectare	112.50	112.50	1	hectare	112.50	112.50
Bird scaring	14	days	10.00	140.00	14	days	10.00	140.00
Feeding	10	workers	25.00	250.00	10	workers	25.00	250.00
Total				**1,857.29**				**1,953.69**

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

Table A3 Scenarios summary, main changes due to technology adoption, percentage

	Cowpea			Rice		
Scenarios	Cost change	Yield change	Adoption rate	Cost change	Yield change	Adoption rate
Scenario 1, Pessimistic	-4.70	5.00	15.00	4.42	10.00	5.00
Scenario 2	-10.00	5.00	15.00	0.00	10.00	5.00
Scenario 3	-10.00	30.00	15.00	4.42	20.00	5.00
Scenario 4	-4.70	5.00	15.00	0.00	20.00	5.00
Scenario 5	-4.70	5.00	70.00	4.42	10.00	60.00
Scenario 6	-10.00	5.00	70.00	0.00	10.00	60.00
Scenario 7	-4.70	30.00	70.00	4.42	20.00	60.00
Scenario 8, Optimistic	-10.00	30.00	70.00	0.00	20.00	60.00
Most likely Scenario	-7.26	23.75	25.00	2.27	10.00	5.00

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

Table A4 IR cowpea: Scenario 1 - Pessimistic

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	-0.12	3.25	-0.05	0.25	-0.14	3.19
Consumers' Benefits, PV, US$ mill.	0.4	0.47	0.15	0.11	3.35	4.47
Total Benefits, PV, US$ mill.	0.28	3.72	0.1	0.36	3.21	7.66
Cost of Research, US$ mill.	0.19	0.81	0.22	0.66	0.22	2.11
Net present value (NPV), US$ mill.	0.09	2.9	-0.12	-0.3	2.98	5.55
Benefit/Cost, Ratio	1.5	4.6	0.4	0.5	14.5	3.6
Internal Rate of Return (IRR), percentage	14.4	27.5	3.8	5.7	44.0	24.8

Source: Authors' estimation using DREAM

Table A5 IR cowpea: Scenario 2

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	-0.18	4.98	-0.07	0.38	-0.22	4.89
Consumers' Benefits, PV, US$ mill.	0.62	0.72	0.22	0.16	5.13	6.85
Total Benefits, PV, US$ mill.	0.43	5.7	0.15	0.55	4.91	11.74
Cost of Research, US$ mill.	0.19	0.81	0.22	0.66	0.22	2.11
Net present value (NPV), US$ mill.	0.24	4.89	-0.07	-0.11	4.69	9.63
Benefit/Cost, Ratio	2.2	7.0	0.7	0.8	22.2	5.6
Internal Rate of Return (IRR), percentage	18.9	33.3	7.3	9.2	51.3	30.4

Source: Authors' estimation using DREAM

Table A6 IR cowpea: Scenario 3

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	-0.4	11.05	-0.15	0.89	-0.45	10.93
Consumers' Benefits, PV, US$ mill.	1.37	1.61	0.48	0.36	11.45	15.27
Total Benefits, PV, US$ mill.	0.96	12.66	0.33	1.25	11	26.2
Cost of Research, US$ mill.	0.18	0.75	0.2	0.6	0.2	1.93
Net present value (NPV), US$ mill.	0.79	11.92	0.13	0.65	10.79	24.27
Benefit/Cost, Ratio	5.4	17.0	1.6	2.1	54.2	13.6
Internal Rate of Return (IRR), percentage	27.3	41.6	15.0	17.1	57.9	38.8

Source: Authors' estimation using DREAM

Table A7 IR cowpea: Scenario 4

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	0.59	6.78	0.45	2.92	0.83	11.58
Consumers' Benefits, PV, US$ mill.	1.41	1.66	0.5	0.37	11.77	15.7
Total Benefits, PV, US$ mill.	1.99	8.44	0.95	3.29	12.6	27.28
Cost of Research, US$ mill.	0.18	0.75	0.2	0.6	0.2	1.93
Net present value (NPV), US$ mill.	1.82	7.7	0.74	2.69	12.4	25.35
Benefit/Cost, Ratio	11.2	11.3	4.6	5.5	62.1	14.1
Internal Rate of Return (IRR), percentage	36.1	36.2	26.1	27.0	60.4	39.3

Source: Authors' estimation using DREAM

Table A8 IR cowpea: Scenario 5

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	0.69	7.94	0.55	3.31	1.03	13.51
Consumers' Benefits, PV, US$ mill.	1.65	1.93	0.6	0.44	13.71	18.32
Total Benefits, PV, US$ mill.	2.33	9.87	1.14	3.75	14.73	31.83
Cost of Research, US$ mill.	0.19	0.81	0.22	0.66	0.22	2.11
Net present value (NPV), US$ mill.	2.14	9.06	0.92	3.09	14.51	29.72
Benefit/Cost, Ratio	12.1	12.1	5.1	5.7	66.6	15.1
Internal Rate of Return (IRR), percentage	41.4	41.6	29.6	29.7	73.3	45.5

Source: Authors' estimation using DREAM

Table A9 IR cowpea: Scenario 6

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	1.05	12.19	0.84	5.07	1.57	20.72
Consumers' Benefits, PV, US$ mill.	2.53	2.95	0.91	0.67	21.02	28.09
Total Benefits, PV, US$ mill.	3.58	15.14	1.75	5.75	22.59	48.81
Cost of Research, US$ mill.	0.19	0.81	0.22	0.66	0.22	2.11
Net present value (NPV), US$ mill.	3.39	14.33	1.53	5.09	22.37	46.7
Benefit/Cost, Ratio	18.5	18.6	7.9	8.8	102.1	23.2
Internal Rate of Return (IRR), percentage	48.5	48.7	35.7	35.6	82.9	52.9

Source: Authors' estimation using DREAM

Table A10 IR cowpea: Scenario 7

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	2.45	28.4	1.95	11.77	3.67	48.24
Consumers' Benefits, PV, US$ mill.	5.89	6.88	2.13	1.57	48.88	65.35
Total Benefits, PV, US$ mill.	8.34	35.27	4.07	13.34	52.55	113.58
Cost of Research, US$ mill.	0.19	0.81	0.22	0.66	0.22	2.11
Net present value (NPV), US$ mill.	8.14	34.46	3.85	12.69	52.33	111.47
Benefit/Cost, Ratio	43.1	43.3	18.3	20.3	237.6	53.9
Internal Rate of Return (IRR), percentage	64.3	64.5	49.5	48.9	103.8	69.4

Source: Authors' estimation using DREAM

Table A11 IR cowpea: Scenario 8, Optimistic

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	2.75	31.88	2.18	13.2	4.12	54.14
Consumers' Benefits, PV, US$ mill.	6.61	7.72	2.39	1.76	54.85	73.33
Total Benefits, PV, US$ mill.	9.36	39.6	4.57	14.97	58.98	127.47
Cost of Research, US$ mill.	0.19	0.81	0.22	0.66	0.22	2.11
Net present value (NPV), US$ mill.	9.16	38.78	4.35	14.31	58.75	125.36
Benefit/Cost, Ratio	48.4	48.6	20.5	22.8	266.6	60.5
Internal Rate of Return (IRR), percentage	66.6	66.8	51.6	50.8	106.9	71.8

Source: Authors' estimation using DREAM

Table A12 NUE rice: Scenario 1 - Pessimistic

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	1.04	0.66	1.36	0.67	3.73
Consumers' Benefits, PV, US$ mill.	0	0	0	0.04	0.05
Total Benefits, PV, US$ mill.	1.05	0.66	1.36	0.71	3.78
Cost of Research, US$ mill.	0.52	0.4	0.55	0.45	1.93
Net present value (NPV), US$ mill.	0.53	0.25	0.81	0.26	1.85
Benefit/Cost, Ratio	2.0	1.6	2.5	1.6	2.0
Internal Rate of Return (IRR), percentage	16.9	15.1	18.7	14.8	16.6

Source: Authors' estimation using DREAM

Table A13 NUE rice: Scenario 2

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	1.74	1.1	2.28	1.12	6.24
Consumers' Benefits, PV, US$ mill.	0.01	0	0.01	0.06	0.08
Total Benefits, PV, US$ mill.	1.75	1.1	2.28	1.19	6.32
Cost of Research, US$ mill.	0.52	0.4	0.55	0.45	1.93
Net present value (NPV), US$ mill.	1.23	0.7	1.73	0.73	4.39
Benefit/Cost, Ratio	3.4	2.7	4.1	2.6	3.3
Internal Rate of Return (IRR), percentage	22.0	20.1	23.9	19.8	21.7

Source: Authors' estimation using DREAM

Table A14 NUE rice: Scenario 3

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	2.85	1.8	3.72	1.83	10.19
Consumers' Benefits, PV, US$ mill.	0.01	0	0.01	0.1	0.13
Total Benefits, PV, US$ mill.	2.86	1.8	3.73	1.94	10.32
Cost of Research, US$ mill.	0.52	0.4	0.55	0.45	1.93
Net present value (NPV), US$ mill.	2.34	1.4	3.17	1.48	8.39
Benefit/Cost, Ratio	5.5	4.5	6.7	4.3	5.3
Internal Rate of Return (IRR), percentage	27.2	25.2	29.2	25.0	26.9

Source: Authors' estimation using DREAM

Table A15 NUE rice: Scenario 4

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	3.49	2.2	4.56	2.25	12.49
Consumers' Benefits, PV, US$ mill.	0.02	0	0.01	0.13	0.16
Total Benefits, PV, US$ mill.	3.5	2.21	4.57	2.37	12.65
Cost of Research, US$ mill.	0.52	0.4	0.55	0.45	1.93
Net present value (NPV), US$ mill.	2.98	1.8	4.01	1.92	10.72
Benefit/Cost, Ratio	6.7	5.5	8.2	5.2	6.5
Internal Rate of Return (IRR), percentage	29.5	27.5	31.6	27.3	29.2

Source: Authors' estimation using DREAM

Table A16 NUE rice: Scenario 5

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	10.88	6.58	18.87	9.18	45.51
Consumers' Benefits, PV, US$ mill.	0.06	0.02	0.04	0.47	0.59
Total Benefits, PV, US$ mill.	10.94	6.6	18.91	9.65	46.1
Cost of Research, US$ mill.	0.52	0.4	0.55	0.45	1.93
Net present value (NPV), US$ mill.	10.42	6.2	18.35	9.2	44.17
Benefit/Cost, Ratio	21.0	16.3	34.1	21.3	23.8
Internal Rate of Return (IRR), percentage	43.7	41.0	50.1	45.1	45.5

Source: Authors' estimation using DREAM

Table A17 NUE rice: Scenario 6

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	18.22	11.02	31.6	15.37	76.22
Consumers' Benefits, PV, US$ mill.	0.1	0.03	0.07	0.79	0.99
Total Benefits, PV, US$ mill.	18.32	11.05	31.67	16.16	77.2
Cost of Research, US$ mill.	0.52	0.4	0.55	0.45	1.93
Net present value (NPV), US$ mill.	17.8	10.65	31.11	15.71	75.27
Benefit/Cost, Ratio	35.2	27.3	57.1	35.6	39.9
Internal Rate of Return (IRR), percentage	51.0	48.2	57.7	52.6	53.0

Source: Authors' estimation using DREAM

Table A18 NUE rice: Scenario 7

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	29.79	18.02	51.7	25.16	124.66
Consumers' Benefits, PV, US$ mill.	0.16	0.05	0.11	1.29	1.61
Total Benefits, PV, US$ mill.	29.95	18.07	51.82	26.45	126.27
Cost of Research, US$ mill.	0.52	0.4	0.55	0.45	1.93
Net present value (NPV), US$ mill.	29.43	17.66	51.26	25.99	124.34
Benefit/Cost, Ratio	57.5	44.6	93.4	58.2	65.3
Internal Rate of Return (IRR), percentage	58.4	55.4	65.6	60.2	60.5

Source: Authors' estimation using DREAM

Table A19 NUE rice: Scenario 8, Optimistic

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	36.54	22.10	63.46	30.88	152.97
Consumers' Benefits, PV, US$ mill.	0.2	0.06	0.14	1.58	1.97
Total Benefits, PV, US$ mill.	36.73	22.16	63.6	32.46	154.95
Cost of Research, US$ mill.	0.52	0.4	0.55	0.45	1.93
Net present value (NPV), US$ mill.	36.21	21.75	63.04	32	153.01
Benefit/Cost, Ratio	70.6	54.8	114.6	71.5	80.1
Internal Rate of Return (IRR), percentage	61.6	58.6	69.0	63.6	63.8

Source: Authors' estimation using DREAM

Table A20 IR cowpea: “Business as usual” scenario

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers’ Benefits, Present value (PV), US$ mill.	0.41	3.81	0.45	3.63	0.55	8.84
Consumers’ Benefits, PV, US$ mill.	1.08	1.26	0.39	0.29	8.99	12.02
Total Benefits, PV, US$ mill.	1.49	5.08	0.84	3.91	9.54	20.86
Cost of Research, US$ mill.	0.19	0.81	0.22	0.66	0.22	2.11
Net present value (NPV), US$ mill.	1.29	4.26	0.62	3.26	9.32	18.75
Benefit/Cost, Ratio	7.7	6.2	3.8	6.0	43.1	9.9
Internal Rate of Return (IRR), percentage	34.5	31.6	25.5	30.4	64.1	38.2

Source: Authors’ estimation using DREAM

Table A21 NUE rice: “Business as usual” scenario

	Northern	Upper East	Volta	Other Regions	Total
Producers’ Benefits, Present value (PV), US$ mill.	1.51	0.99	1.64	0.81	4.95
Consumers’ Benefits, PV, US$ mill.	0.01	0.00	0.00	0.05	0.06
Total Benefits, PV, US$ mill.	1.51	1.00	1.65	0.86	5.01
Cost of Research, US$ mill.	0.52	0.40	0.55	0.45	1.93
Net present value (NPV), US$ mill.	0.99	0.59	1.09	0.41	3.08
Benefit/Cost, Ratio	2.9	2.5	3.0	1.9	2.6
Internal Rate of Return (IRR), percentage	20.5	19.0	20.6	16.6	19.4

Source: Authors’ estimation using DREAM

APPENDIX B

Table B22 IR cowpea: Pessimistic Scenario with a 5-year regulatory delay

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers’ Benefits, Present value (PV), US$ mill.	-0.083	2.281	-0.029	0.204	-0.085	2.288
Consumers’ Benefits, PV, US$ mill.	0.284	0.340	0.095	0.073	2.402	3.193
Total Benefits, PV, US$ mill.	0.200	2.621	0.066	0.277	2.317	5.481
Cost of Research, US$ mill.	0.193	0.815	0.223	0.657	0.221	2.109
Net present value (NPV), US$ mill.	0.007	1.806	-0.156	-0.380	2.096	3.373
Benefit/Cost, Ratio	1.03	3.21	0.29	0.42	10.47	2.59
Internal Rate of Return (IRR), percentage	10.8	18.9	3.1	5.3	28.4	17.2

Source: Authors’ estimation using DREAM

Table B23 IR cowpea: Optimistic Scenario with a 5-year regulatory delay

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers’ Benefits, Present value (PV), US$ mill.	1.957	22.488	1.427	10.242	2.543	38.658
Consumers’ Benefits, PV, US$ mill.	4.653	5.585	1.566	1.192	39.358	52.354
Total Benefits, PV, US$ mill.	6.611	28.073	2.993	11.434	41.901	91.012
Cost of Research, US$ mill.	0.193	0.815	0.223	0.657	0.221	2.109
Net present value (NPV), US$ mill.	6.417	27.259	2.770	10.777	41.680	88.903
Benefit/Cost, Ratio	34.19	34.46	13.42	17.4	189.41	43.15
Internal Rate of Return (IRR), percentage	39.5	39.7	31.1	32.6	58.2	41.9

Source: Authors’ estimation using DREAM

Table B24 IR cowpea, “Business as usual” scenario with a 5-year regulatory delay

	Brong Ahafo	Northern	Upper East	Upper West	Other Regions	Total
Producers’ Benefits, Present value (PV), US$ mill.	0.287	2.679	0.290	2.759	0.338	6.352
Consumers’ Benefits, PV, US$ mill.	0.766	0.919	0.258	0.196	6.491	8.630
Total Benefits, PV, US$ mill.	1.053	3.599	0.547	2.955	6.829	14.983
Cost of Research, US$ mill.	0.193	0.815	0.223	0.657	0.221	2.109
Net present value (NPV), US$ mill.	0.860	2.784	0.324	2.298	6.607	12.874
Benefit/Cost, Ratio	5.44	4.41	2.45	4.49	30.86	7.1
Internal Rate of Return (IRR), percentage	23.0	21.3	17.0	21.3	38.4	25.1

Source: Authors’ estimation using DREAM

Table B25 NUE rice: Pessimistic Scenario with a 5-year regulatory delay

	Northern	Upper East	Volta	Other Regions	Total
Producers’ Benefits, Present value (PV), US$ mill.	0.768	0.455	1.032	0.443	2.698
Consumers’ Benefits, PV, US$ mill.	0.004	0.001	0.002	0.029	0.037
Total Benefits, PV, US$ mill.	0.771	0.456	1.035	0.472	2.734
Cost of Research, US$ mill.	0.521	0.405	0.555	0.454	1.934
Net present value (NPV), US$ mill.	0.251	0.051	0.480	0.018	0.800
Benefit/Cost, Ratio	1.48	1.12	1.86	1.03	1.41
Internal Rate of Return (IRR), percentage	13.0	11.3	14.5	10.8	12.7

Source: Authors’ estimation using DREAM

Table B26 NUE rice: Optimistic Scenario with a 5-year regulatory delay

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	26.912	15.270	48.122	20.371	110.675
Consumers' Benefits, PV, US$ mill.	0.149	0.042	0.102	1.214	1.506
Total Benefits, PV, US$ mill.	27.060	15.311	48.224	21.586	112.181
Cost of Research, US$ mill.	0.521	0.405	0.555	0.454	1.934
Net present value (NPV), US$ mill.	26.540	14.906	47.669	21.131	110.247
Benefit/Cost, Ratio	51.98	37.83	86.92	47.51	57.99
Internal Rate of Return (IRR), percentage	40.3	37.8	44.8	40.1	41.4

Source: Authors' estimation using DREAM

Table B27 NUE rice: "Business as usual" Scenario with a 5-year regulatory delay

	Northern	Upper East	Volta	Other Regions	Total
Producers' Benefits, Present value (PV), US$ mill.	1.109	0.687	1.245	0.534	3.575
Consumers' Benefits, PV, US$ mill.	0.005	0.001	0.003	0.039	0.048
Total Benefits, PV, US$ mill.	1.113	0.688	1.249	0.573	3.623
Cost of Research, US$ mill.	0.521	0.405	0.555	0.454	1.934
Net present value (NPV), US$ mill.	0.593	0.283	0.694	0.119	1.689
Benefit/Cost, Ratio	2.13	1.69	2.25	1.26	1.87
Internal Rate of Return (IRR), percentage	15.4	14.0	15.7	12.0	14.6

Source: Authors' estimation using DREAM

APPENDIX C

Table C28 IR cowpea: Sex-disaggregated benefits, pessimistic scenario

	Female	Male	Total
Producers' Benefits, Present value (PV), US$ mill.	0.569	2.539	3.109
Consumers' Benefits, PV, US$ mill.	1.527	2.031	3.558
Total Benefits, PV, US$ mill.	2.096	4.571	6.667
Cost of Research, US$ mill.	0.819	1.289	2.109
Net present value (NPV), US$ mill.	1.276	3.281	4.558
Benefit/Cost, Ratio	2.55	3.54	3.16
Internal Rate of Return (IRR), percentage	20.50	24.40	23.00

Source: Authors' estimation using DREAM

Table C29 IR cowpea: Sex-disaggregated benefits, optimistic scenario

	Female	Male	Total
Producers' Benefits, Present value (PV), US$ mill.	14.589	45.533	60.121
Consumers' Benefits, PV, US$ mill.	29.528	39.290	68.818
Total Benefits, PV, US$ mill.	44.117	84.823	128.940
Cost of Research, US$ mill.	0.819	1.289	2.109
Net present value (NPV), US$ mill.	43.297	83.534	126.831
Benefit/Cost, Ratio	53.83	65.79	61.14
Internal Rate of Return (IRR), percentage	69.40	73.80	72.20

Source: Authors' estimation using DREAM

Table C30 IR cowpea: Sex-disaggregated benefits, "business as usual" scenario

	Female	Male	Total
Producers' Benefits, Present value (PV), US$ mill.	1.937	7.703	9.639
Consumers' Benefits, PV, US$ mill.	4.733	6.298	11.032
Total Benefits, PV, US$ mill.	6.670	14.001	20.671
Cost of Research, US$ mill.	0.819	1.289	2.109
Net present value (NPV), US$ mill.	5.851	12.712	18.563
Benefit/Cost, Ratio	8.13	10.85	9.8
Internal Rate of Return (IRR), percentage	35.7	40.1	38.5

Source: Authors' estimation using DREAM

Table C31 NUE rice: Sex-disaggregated benefits, pessimistic scenario

	Female	Male	Total
Producers' Benefits, Present value (PV), US$ mill.	0.774	3.423	4.197
Consumers' Benefits, PV, US$ mill.	0.020	0.026	0.046
Total Benefits, PV, US$ mill.	0.794	3.449	4.243
Cost of Research, US$ mill.	0.747	1.187	1.934
Net present value (NPV), US$ mill.	0.046	2.262	2.309
Benefit/Cost, Ratio	1.06	2.9	2.19
Internal Rate of Return (IRR), percentage	11.3	20.6	17.8

Source: Authors' estimation using DREAM

Table C32 NUE rice: Sex-disaggregated benefits, optimistic scenario

	Female	Male	Total
Producers' Benefits, Present value (PV), US$ mill.	38.812	121.446	160.258
Consumers' Benefits, PV, US$ mill.	0.748	0.998	1.746
Total Benefits, PV, US$ mill.	39.560	122.444	162.004
Cost of Research, US$ mill.	0.747	1.187	1.934
Net present value (NPV), US$ mill.	38.813	121.257	160.070
Benefit/Cost, Ratio	52.93	103.15	83.75
Internal Rate of Return (IRR), percentage	57.6	68.5	65.0

Source: Authors' estimation using DREAM

Table C33 NUE rice: Sex-disaggregated benefit, "business as usual" scenario

	Female	Male	Total
Producers' Benefits, Present value (PV), US$ mill.	1.577	3.374	4.951
Consumers' Benefits, PV, US$ mill.	0.023	0.031	0.054
Total Benefits, PV, US$ mill.	1.600	3.405	5.005
Cost of Research, US$ mill.	0.747	1.187	1.934
Net present value (NPV), US$ mill.	0.852	2.218	3.071
Benefit/Cost, Ratio	2.14	2.86	2.58
Internal Rate of Return (IRR), percentage	17.6	20.5	19.5

Source: Authors' estimation using DREAM

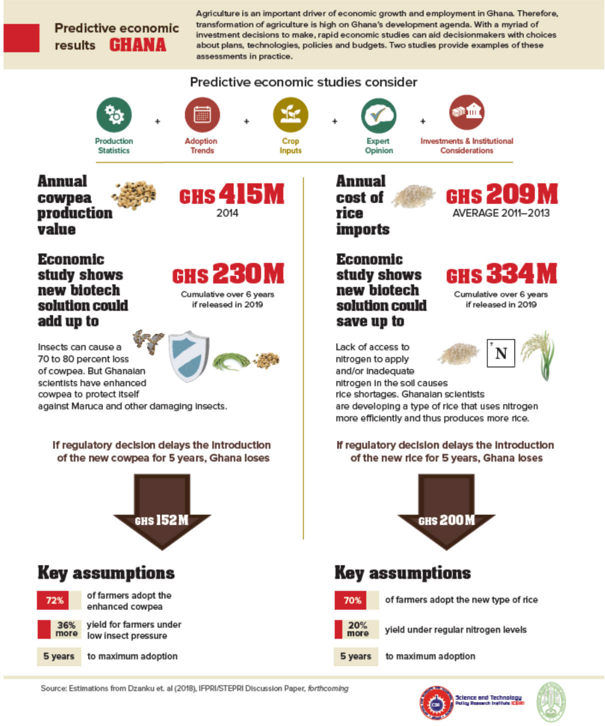
Table C34 NUE rice: Sex-disaggregated benefit, "business as usual" scenario, 5-year reg delay

	Female	Male	Total
Producers' Benefits, Present value (PV), US$ mill.	1.120	2.397	3.517
Consumers' Benefits, PV, US$ mill.	0.017	0.022	0.039
Total Benefits, PV, US$ mill.	1.137	2.419	3.556
Cost of Research, US$ mill.	0.747	1.187	1.934
Net present value (NPV), US$ mill.	0.390	1.232	1.622
Benefit/Cost, Ratio	1.52	2.03	1.83
Internal Rate of Return (IRR), percentage	13.2	15.2	14.5

Source: Authors' estimation using DREAM

APPENDIX D

Results for the optimistic scenarios for IR cowpea and NE rice were summarized in an infographic, shown below.



Predictive economic results GHANA

Agriculture is an important driver of economic growth and employment in Ghana. Therefore, transformation of agriculture is high on Ghana's development agenda. With a myriad of investment decisions to make, rapid economic studies can aid decisionmakers with choices about plans, technologies, policies and budgets. Two studies provide examples of these assessments in practice.

Predictive economic studies consider

Annual cowpea production value GHS 415M 2014

Economic study shows new biotech solution could add up to GHS 230M Cumulative over 6 years if released in 2019

Insects can cause a 70 to 80 percent loss of cowpea. But Ghanaian scientists have enhanced cowpea to protect itself against Maruca and other damaging insects.

If regulatory decision delays the introduction of the new cowpea for 5 years, Ghana loses GHS 152M

Key assumptions

72% of farmers adopt the enhanced cowpea

36% more yield for farmers under low insect pressure

5 years to maximum adoption

Annual cost of rice imports GHS 209M AVERAGE 2011–2013

Economic study shows new biotech solution could save up to GHS 334M Cumulative over 6 years if released in 2019

Lack of access to nitrogen to apply and/or inadequate nitrogen in the soil causes rice shortages. Ghanaian scientists are developing a type of rice that uses nitrogen more efficiently and thus produces more rice.

If regulatory decision delays the introduction of the new rice for 5 years, Ghana loses GHS 200M

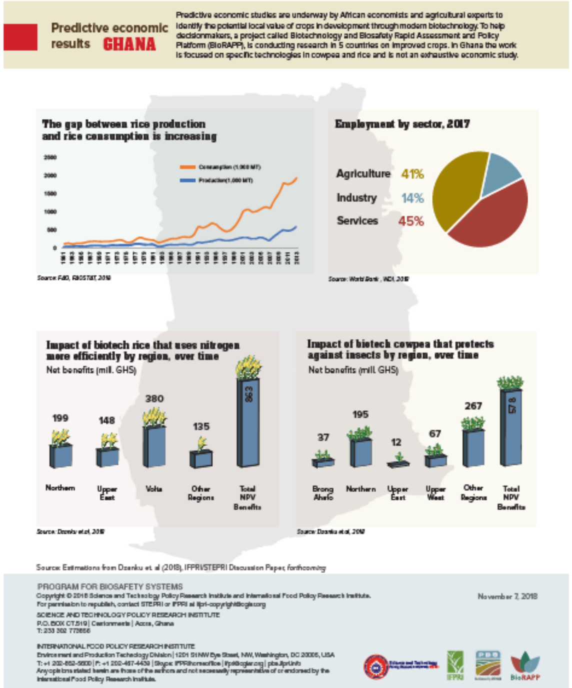
Key assumptions

70% of farmers adopt the new type of rice

20% more yield under regular nitrogen levels

5 years to maximum adoption

Source: Estimations from Dzanku et. al (2018), IFPRI/STEPRI Discussion Paper, *forthcoming*



Predictive economic results GHANA

Predictive economic studies are underway by African economists and agricultural experts to identify the potential local value of crops in development through modern biotechnology. To help decisionmakers, a project called Biotechnology and Biosafety Rapid Assessment and Policy Platform (BioRAPP), is conducting research in 5 countries on improved crops. In Ghana the work is focused on specific technologies in cowpea and rice and is not an exhaustive economic study.

The gap between rice production and rice consumption is increasing

Source: FAO, FAOSTAT, 2018

Employment by sector, 2017

Source: World Bank , WDI, 2018

Impact of biotech rice that uses nitrogen more efficiently by region, over time

Net benefits (mill. GHS)

Source: Dzanku et al, 2018

Impact of biotech cowpea that protects against insects by region, over time

Net benefits (mill. GHS)

Source: Dzanku et al, 2018

Source: Estimations from Dzanku et. al (2018), IFPRI/STEPRI Discussion Paper, *forthcoming*

PROGRAM FOR BIOSAFETY SYSTEMS

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The optimistic scenario described in this report differ from those presented in this infographic published November 7, 2018, before this report was finalized and reviewed. For clarity purposes, Table D34 compares the infographic results with the ones in this report, both for the optimistic scenario. Table D34 shows that the main difference comes from the assumed date of commercialization for each of the technologies. The commercialization date is less optimistic in this report compared to the one presented in the infographic. Comparing this report's estimations with those of the infographic show that one-year delay for IR cowpea (from 2019 to 2020) and 3 years for NUE rice (from 2019 to 2022) reduces the estimated benefits by 15 percent and 29 percent, respectively. As with any other assumption in this report, the selection of commercialization date is an estimate drawn from experts' opinions, which are formed from incomplete and many times uncertain data and are, not surprisingly, subject to change over time.

Table D34 Ghana: Infographic and Discussion Paper optimistic scenario

Items as mentioned in Infographic above	Crop	Optimistic Scenario A Discussion Paper	 B Infographics above	 Units	Difference between B and A
"...new biotech solution could add up to"	Cowpea	196	230	million GHS	+17%
	Rice	240	334	million GHS	+39%
"Cumulative over 6 years if released in…"	Cowpea	2020	2019	year	1 yr less
	Rice	2022	2019	year	3 yrs less
"If regulatory decisions delays the introduction of new *(crop)* for 5 years Ghana loses"	Cowpea	161	152	million GHS	-6%
	Rice	189	200	million GHS	+6%
" ...of farmers adopt enhanced (*crop*)"	Cowpea	70	72	percentage	2 % points
	Rice	60	70	percentage	10 % points
"more yield for farmers under low insect pressure"	Cowpea	30	36	percentage	6 % points
"more yield under regular nitrogen levels	Rice	20	20	percentage	none
" years to maximum adoption"	Cowpea	5	5	# of years	none
	Rice	5	5	# of years	none

Source: Authors' estimations using DREAM.

Note: To convert these results to USD, as they appear in this Discussion Paper, an exchange rate of 4.41 GHS/USD was used.

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