GM RICE COMMERCIALIZATION AND ITS IMPACT ON THE GLOBAL RICE ECONOMY

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Abstract

Genetically-modified (GM) rice is an important technology surrounded with controversy and uncertainty, hence it warrants more in-depth analysis. While GM rice is considered by its supporters as having promising potential, many still remain passionately against its use. This study assesses the impacts of GM rice commercialization on the global rice market. We use the Arkansas Global Rice Model (AGRM) and the RICEFLOW model to provide stochastic and dynamic analyses. Scenarios of adoption, diffusion and acceptance of *Bt* (*Bacillus thuringiensis)* rice by Bangladesh, China, Indonesia, Nigeria, and the Philippines are compared against baseline projections. The results focus on world trade, world and domestic prices, resource savings, domestic production, consumption, and stocks. *Bt* rice adoption has the potential to significantly impact the global and national rice economies. Total rice trade, international price, and domestic prices decline as global rice production, consumption, and stocks expand.

Keywords: GM rice, food security, technology change.

JEL Classification codes: Q16, Q55

INTRODUCTION

Forecasts point to a steady increase in the global demand for rice between 0.9 percent and 1.2 percent a year over the next decade, based primarily on population growth in important rice-consuming areas such as Asia, Africa, Central America, and the Middle East. They also suggest the supply side will have the ability to cope with demand and maintain relatively flat prices over the coming decade, due in part to the high level of market interventions across many Asian countries (Wailes and Chavez, 2014; OCDE/FAO, 2014). Yet rice yield growth lags behind population growth over the last several years, putting more pressure on already scarce resources to cope with demand and ameliorate the effect on food security, primarily of the poorest segments of the population (IRRI, 2010).

Given limited arable area for expansion, sustainability of production over the long run must come from productivity gains. The introduction of high-yielding rice varieties during the Green Revolution led to significant productivity increases and steady decreases in rice prices from 1975 to 2000. A new boost in rice productivity is urgently needed to cope with increasing demand and limiting production resources (Dawe et al., 2010), and the “gene revolution” may be one of the many tools that can help achieve the intended goal.

Adoption of new seed technologies with higher productivity potentials, including GM rice, is one of several approaches to improve rice land and water productivity. Yet rice and wheat, the two main food crops, are being held hostage by the controversy over GM technology (Demont and Stein, 2013).

Stem borer is the most significant rice insect pest in most Asian countries, particularly in irrigated systems, and therefore the *Bt* technology holds great potential to boost productivity in those environments. *Bt* rice contains genetic material from a strain of the naturally-occurring soil bacteria *Bacillus thuringiensis* that codes the production of the Cry proteins that kill insects with alkaline digestive systems (Romeis et al., 2006). GM rice varieties with agronomic and nutritional benefits have been in the pipeline for well over a decade (Demont et al, 2013). Herbicide-tolerant GM rice includes Liberty-Link rice (resistant to glufosinate), roundup-ready rice (resistant to glyphosate); insect-resistance rice includes *Bt* rice (resistant to lepidopterous pests of rice, including stem borers and leaffolders); second generation, nutritionally-enhanced GM rice includes golden rice (with higher content of beta-carotene, a precursor of Vitamin A), and high-iron content rice.

Despite the potential of these developments, no approval for commercialization has been granted thus far anywhere in the world except for *Bt* rice in Iran in 2004, after which the permit was canceled (Ruane, 2013). China granted biosafety clearance for *Bt* rice in 2009, a step thought by many to clear the way for GM rice in the coming years, but unexpectedly refused to renew the certificates in 2014 (Normile, 2014). Bio-terrorist attacks on golden rice field trials in the Philippines in 2013 also undermined efforts to commercialize the nutritionally-enhanced rice, a technology that could improve the health of millions of people (Dawe, 2002). Controversy over GM food in other Asian countries (e.g., *Bt* eggplant in India and Bangladesh) suggest that commercialization of GM rice still has a long way to go.

Assessments of benefits of GM rice vary by country, trait, assumed adoption rates, and modeling framework (for a review of this literature see Demont and Stein, 2013), and are relevant not only to ascertain the potential spread of a technology but also can help in the approval process. Mamaril and Norton (2006) use an economic surplus model to assess costs and benefits of *Bt* rice in the Philippines assuming a 66% adoption rate, estimating annual gains in total surplus at US$ 270 million, of which 77% accrued to producers. Using a framework and adoption rate similar to Mamaril and Norton (2006), Bayer et al (2010), estimate changes in total surplus at US$ 482 million, all of it accruing to producers. Finally, Hareau et al. (2005) used a computable general equilibrium model to assess the impact of full adoption of *Bt* rice and drought-resistant GM rice in Asia, estimating net global benefits of US$2,267 million a year, with all adopters earning benefits and non-adopters such as the U.S. and Latin America enduring losses.

This study aims at complementing previous analyses by using more detailed modeling frameworks of the global rice economy and updated databases, allowing for greater disaggregation of impacts across rice types and market players.

METHODOLOGY

The Arkansas Global Rice Model (Wailes and Chavez, 2010) and RICEFLOW model (Durand-Morat and Wailes, 2010) are used as frameworks of analysis.

The AGRM is a non-spatial, multi-country/regional statistical simulation and econometric framework. The rice market is disaggregated into 51 countries/regions. Each country or regional model includes a supply sector (harvested area and yields), a demand sector (per capita use), with trade, stocks and price linkage equations. All equations are either estimated using econometric techniques or are specified as identities.

Estimates are based upon a set of explanatory variables including exogenous macroeconomic factors such as income, population, inflation rate, technology development, and especially, government determined policy variables which reflect the various mechanisms by which countries intervene in their rice sector economy. Macroeconomic data are based on Global Insight projections. Individual country models are linked through net trade, a specification that highlights the interdependence of countries in the world rice economy. Net global rice trade for long grain and medium grain solves for the two market-clearing world reference long grain and medium grainprices, which are the Thai 5%B fob Bangkok and No.2 fob California prices, respectively.

Simulation is conducted for the purpose of generating ten-year projections that reflect the current state and the expected directions of the rice economies in the world by assessing their potential supply and demand paths over the next decade. This set of projections serves as a baseline for evaluating and comparing alternative macroeconomic, policy, weather, and technological scenarios. The estimates are intended for use by government agencies and officials, farmers, consumers, agribusinesses and other stakeholders who conduct medium- and long-term planning.

The baseline projections are grounded in a series of assumptions about the general economy, agricultural policies, weather, and technological change. Projections include national levels of production (area harvested and yields), consumption (population and capita use), net trade, stocks, and prices. The international rice market is unique because it is differentiated between long and medium grain markets and is also heavily distorted by various governments' policies. The model does not attempt to capture the imperfect nature of the international rice market. However, the model does not assume a perfectly competitive market structure. Government distortions are explicitly reflected in the model's structure. These policies are incorporated in the model's supply, demand, export (or import), stocks, and price transmission equations, and are thus implicitly reflected in the model solution. The model is continually updated with respect to data and model specifications.

Computationally, the simulation model solves for the set of farm level, retail level, and export (import) prices that simultaneously clears all markets (long and medium grain) in a given year for a given set of exogenous factors. Due to the dynamics of supply and demand, such market clearing prices must be obtained recursively for each future year simulated.

Supply Sector

The AGRM assumes that the rice supply is determined by profit-maximizing producers i.e., rice producers maximize their net revenue received subject to the technical and regulatory constraints imposed by their production function. Solving the producer's problem yields first-order conditions identifying the optimal level of inputs such that the value of the marginal product of the input will be equal to the price of the input. The relationships are expressed as functions of expected output prices and expected input prices. The input demand relationships can be aggregated without specification bias, if each individual farmer faces the same price. Under such an assumption, the industry equation describing planted area is a function of the expected output and input prices. Since for most countries in most years there is little difference between planted area and harvested area, a function for harvested acreage is specified and estimated in this model. Hence, the generalized relationship specifying harvested acreage is expressed as:

$$HA_t = f_1(HA_{t-1}, P_t^e, W_t^e, e_{1t})$$

where HA_t is harvested area, P_t^e is expected price received by producers, W_t^e is expected input price, and e_{1t} is the error term. One would anticipate positive coefficients for lagged area and expected price of rice and negative coefficients for input price. Yield is generally specified as a function of expected output, input prices, and technological change, expressed as:

$$Y_t = f_2(P_t^e, W_t^e, T_t, e_{2t})$$

Demand Sector

The AGRM assumes that rice demand is determined by utility-maximizing consumers. Rice consumers maximize their utility subject to their budget constraints. Solving the consumer's problem yields first-order conditions identifying the optimal level of commodities they buy. Therefore, the per capita rice demand is generally specified as:

$$D_t = f_3(M_t, RP_t, WP_t, e_{3t}),$$

where D_t is total rice demand on a per capita basis, M_t is per capita income in real terms, RP_t is rice retail price (weighted average of free market price and government ration price), and WP_t is wheat price and e_{3t} is the error term.

The demand for exports is a function of the difference between domestic production and consumption and export price (FOB), expressed as;

$$EXP_t = f_5(RESD_t, FOBt, e_{5t}),$$

where EXP_t is exports, $RESD_t$ is residual of total production net of total consumption, and FOBt is free on board export price measured in local currency, and e_{5t} is the error term.

Price Linkages

Farm price, Pt is generally modeled as a function of retail price.

$$P_t = f_6(RP_t, e_{6t}).$$

Retail price is generally a function of deflated FOB price and a time trend that captures improvements in marketing efficiency.

$$RP_t = f_7(FOBt, e_{7t}).$$

where FOBt is export price.

Export price is generally modeled as a function of Thai5%B fob.

$$FOBt = f_8(THAIFOBt, e_{8t}).$$

Market Clearance

Depending on the country, the AGRM treats either trade or ending stocks as residual to close the model. Equilibrium international prices are generated by balancing exports and imports.

The RICEFLOW model is a multi-region, multi-product, spatial partial equilibrium model of the global rice market.

Production is specified as a two-level, separable, constant-return-to-scale, CES technology. The CES derived demand equation for the production of output Z from N inputs X_k, $k = 1 - N$, with prices P_k and input technical change A_k is

$$X_k * A_k = Z\delta_k^{1/(\rho+1)} \left[\frac{(P_k/A_k)}{P_{ave}}\right]^{-1/(\rho+1)}, \qquad (1)$$

Where $P_{ave} = \left(\sum_{i=1}^{N} \delta_i^{1/(\rho+1)} \left(\frac{P_i}{A_i}\right)^{\rho/(\rho+1)}\right)^{(\rho+1)/\rho}$

At the highest level, inputs X_k are represented by two composites, namely value-added and intermediate input composites, while at the lowest level, inputs X_k in the value-added composite are factors of production, namely, land, labor, and capital; and in the intermediate input composite are seeds, fertilizer, pesticides, water, and energy.

In percentage-change form, (1) simplifies to,

$$x_k + a_k = z - \sigma(p_k - a_k - p_{ave}), \qquad (2)$$

where $p_{ave} = \sum_{i=1}^{N} S_i(p_i - a_i)$, S_i are cost shares, e.g., $S_i = V_i/\sum_{i=1}^{N} V_k$, σ represents the elasticity of substitution ($\sigma = 1/(\rho + 1)$), and lower case means percentage changes.

A number of technology variables A associated with the productivity of composite as well as individual factors and inputs are included.

Imports of commodity c into region r, $QM_{c,r}$, and domestic output c produced in r, $QD_{c,r}$, are assumed to be imperfect substitutes in the production of a composite output $QQ_{c,r}$. Substitution between imports and domestic production is specified as a CES similar to (2), where σ represents the Armington elasticity of substitution (Armington, 1969).

Factors of production are classified into perfectly mobile and sluggish. Mobile factors earn the same return across all production sectors; sluggish factors, on the other hand, earn different returns across sectors. Sluggish factor L gets allocated across production sectors c, l_c, according to a CET function. In linearized form,

$$l_c = l - \omega(pl_c - pl_{ave}), \qquad (3)$$

where l is the total supply of sluggish factor L, pl_c is the return to factor l in sector c, $p_{ave} = \sum_{c=1}^{N} SL_c pl_c$, SL_c are value shares, e.g., $SL_c = VL_c/\sum_{c=1}^{N} VL_c$, ω represents the elasticity of transformation, and lower case means percentage changes.

The total supply of factors of production can be specified as an upward-sloping supply function of rental prices, or as perfectly elastic or inelastic through changes in the closure of the model.

The model accounts for policy intervention on factors of production, intermediate inputs, total output, trade, and final consumption. All interventions are represented by their power, understood as the ratio between the agent and market price. For instance, $to_{c,r}$, the power of the tax on output c in region r, is defined as $to_{c,r} = PCP_{c,r}/PCM_{c,r}$, where $PCP_{c,r}$ and $PCM_{c,r}$ represent the producer and market price of output c in r, respectively.

Tariff-rate-quotas and minimum market access quotas are common trade policies used to protect domestic rice markets. The power of these interventions varies depending on the status of the quota (binding or not), and therefore the standard specification via the power of the intervention is not satisfactory. We specify bilateral TRQs following the approach developed Elbehri and Pearson (2005).

Final consumption of type t rice, QFC_t, is represented by an isoelastic demand function accounting for own and cross price as well as income effects. In linearized form,

$$qfc_t = \sum_{i=1}^{N} pr_i * \delta_{i,t} + y * \theta_t \tag{4}$$

Where pr_i represents the retail price for rice commodity i, $\delta_{i,t}$ represents the price demand elasticity matrix, y represents total expenditure, and θ_t represents the income demand elasticity of rice commodity t.

Finally, accounting equations guarantee that all markets (output, factors of production, intermediate inputs) clear at equilibrium, and that firms earn normal profits.

The model is flexible with regard to the specification of production technologies (including trade), which can be specified as a CES, Cobb-Douglas, or Leontief technology.

The database used to calibrate the RICEFLOW model represents the global rice market situation in calendar year 2013. It includes data on production (cost, volume and value), changes in inventories, bilateral trade, final and intermediate consumption, and policies (input, output, consumption, and trade), by rice type (long grain, medium grain, and fragrant) and milling degree (paddy, brown, and milled). The database is disaggregated into 68 countries and 5 aggregate regions.

SCENARIOS

AGRM Model

Two scenarios are analyzed using the AGRM model:

- ***Scenario A1:*** *Bt* adoption rate of 40% of the rice area in Bangladesh, China, Indonesia, Nigeria, and the Philippines.
- ***Scenario A2:*** *Bt* adoption rate of 20% for Nigeria and 40% for the other four countries to assess the effect of asymmetric adoption of technology.

The adoption function of *Bt* rice is assumed to follow the same pattern as GM crops in the U.S. (USDA, 2014) for a 9-year projection period up to 2023. *Bt* yield gain is assumed to be 5%.

RICEFLOW Model

RICEFLOW is updated to year 2023 using forecasts for key exogenous variables (e.g., population, GDP, and energy prices) from which a baseline is generated.

- ***Scenario R1***: *Bt* adoption rate of 40% of the acreage in the Bangladesh, China, Indonesia, Nigeria, and the Philippines. *Bt* rice generates a 5% yield gain over currently-used varieties, a 5% gain in the productivity of factors of production (land, labor, and capital), and a 50-percent reduction in pesticide use.

RESULTS AND DISCUSSION

AGRM RESULTS

The annual impacts of *Bt* rice adoption increase over the projection period, as the adoption schedule used in the analysis follows an increasing path until the full adoption is reached by the end of the period.

Over the 9-year period analyzed, the annual aggregate impacts of the *Bt* rice adoption on the global rice market for scenarios A1 and A2 are presented in Table 1.

Table 1 Impacts of scenarios A1 and A2 on international rice price and world supply & use

Variable	Version	Unit / Year	2015	2023	9-Year Average
International Reference Price Long grain	Baseline	US$/mt	404	422	412
	Scenario A1	*% Change*	*-1.36*	*-8.68*	*-5.67*
	Scenario A2	*% Change*	*-1.35*	*-8.60*	*-5.62*
Area Harvested	Baseline	(mil. ha)	160	161	161
	Scenario A1	*% Change*	*0.00*	*-0.32*	*-0.16*
	Scenario A2	*% Change*	*0.00*	*-0.32*	*-0.16*
Production	Baseline	(mil. mt)	483	520	502
	Scenario A1	*% Change*	*0.11*	*0.55*	*0.41*
	Scenario A2	*% Change*	*0.11*	*0.55*	*0.41*
Consumption	Baseline	(mil. mt)	487	519	504
	Scenario A1	*% Change*	*0.11*	*0.62*	*0.41*
	Scenario A2	*% Change*	*0.10*	*0.61*	*0.40*
Total Trade	Baseline	(mil. mt)	42	49	46
	Scenario A1	*% Change*	*-0.51*	*-2.69*	*-1.78*
	Scenario A2	*% Change*	*-0.51*	*-2.66*	*-1.77*
Ending Stocks	Baseline	(mil. mt)	103	84	92
	Scenario A1	*% Change*	*0.02*	*0.09*	*0.39*
	Scenario A2	*% Change*	*0.02*	*0.16*	*0.41*

The international long grain rice price declines on average by nearly 6% annually under both scenarios as a result of a lower demand for imports in *Bt* rice adopting countries. Production expands in all adopting countries to varying degrees, leading to a marginal global increase in production. Consumption increases in adopting and non-adopting countries alike as a result of lower equilibrium prices, leading to a marginal increase in global consumption.

There is significant import substitution in adopting countries, which is only partially offset by higher imports by non-adopters as a result of lower international prices.

Domestic rice prices in all five rice-importing countries decline by 1.7 to 6.2% per year.

Aggregate rice exports from Thailand, Pakistan, Myanmar, Vietnam, Cambodia, and India decrease by 2.1% (729 tmt) and 2.0% (722 tmt) under scenarios A1and A2, respectively (Table 2). There is a minor impact of each scenario on U.S. rice exports. The scenario impacts on exports differ across countries. For example, percent scenario impacts on Myanmar exports are relatively more substantial because of the bigger increases in rice per capita use in the country as a result of the lower prices under the scenarios, compared to the other countries like Thailand, India, and Pakistan. The relatively small percent changes for the major countries also reflect the relatively bigger shares of these countries in world baseline export trade. Thailand and India account for 25% and 22% of baseline global trade, respectively; while Myanmar's share is only 2.5%.

Table 2 Impacts of scenarios A1 and A2 on rice net exports of selected countries

Variable	Version	Unit / Year	2015	2023	9-Year Average
Thailand	Baseline	(1000 mt)	10188	11918	11349
	Scenario A1	*% Change*	*-0.69*	*0.36*	*-0.47*
	Scenario A2	*% Change*	*-0.69*	*0.36*	*-0.47*
Pakistan	Baseline	(1000 mt)	3479	4010	3676
	Scenario A1	*% Change*	*-0.76*	*-7.11*	*-4.11*
	Scenario A2	*% Change*	*-0.76*	*-7.04*	*-4.07*
Myanmar	Baseline	(1000 mt)	1054	1160	1074
	Scenario A1	*% Change*	*-2.18*	*-16.46*	*-11.14*
	Scenario A2	*% Change*	*-2.16*	*-16.30*	*-11.03*
Vietnam	Baseline	(1000 mt)	6488	8220	7418
	Scenario A1	*% Change*	-1.39	-3.86	-3.60
	Scenario A2	*% Change*	*-1.38*	*-3.82*	*-3.57*
Cambodia	Baseline	(1000 mt)	1241	1978	1594
	Scenario A1	*% Change*	*-0.09*	*-10.78*	*-5.77*
	Scenario A2	*% Change*	*-0.09*	*-10.68*	*-5.71*
India	Baseline	(1000 mt)	9065	10637	9604
	Scenario A1	*% Change*	*0.05*	*-0.73*	*-0.29*
	Scenario A2	*% Change*	*0.05*	*-0.72*	*-0.29*
USA	Baseline	(1000 mt)	2701	2337	2570
	Scenario A1	*% Change*	*-0.14*	*-5.76*	*-1.18*
	Scenario A2	*% Change*	*-0.14*	*-5.71*	*-1.17*

Table 3 shows that import substitution occurs in all the importing countries analyzed, with China experiencing the biggest average annual import decline of 48.7% (equivalent to nearly 1.49 mmt); followed by Bangladesh (13.4% or 237 tmt); and Indonesia (20% or 160 tmt). Rice imports by the Philippines decline modestly, i.e., by 3.7% or 31 tmt; while Nigeria's annual imports are down marginally, i.e., by 5 tmt per year.

In general, rice consumption expands from 0.3% to 0.6%, as domestic prices decline.

Table 3 Impacts of scenarios A1 and A2 on rice net imports of selected countries

Variable	Version	Unit / Year	2015	2023	9-Year Average
China	Baseline	(1000 mt)	2844	3129	2995
	Scenario A1	*% Change*	*-10.37*	*-85.66*	*-48.73*
	Scenario A2	*% Change*	*-10.37*	*-85.68*	*-48.74*
Indonesia	Baseline	(1000 mt)	1088	1193	848
	Scenario A1	*% Change*	*-2.29*	*-20.09*	*-20.00*
	Scenario A2	*% Change*	*-2.33*	*-20.65*	*-20.46*
Philippines	Baseline	(1000 mt)	1126	550	848
	Scenario A1	*% Change*	*-1.05*	*-2.88*	*-3.72*
	Scenario A2	*% Change*	*-1.08*	*-4.01*	*-4.18*
Bangladesh	Baseline	(1000 mt)	1065	1952	1713
	Scenario A1	*% Change*	*-7.44*	*-14.84*	*-13.38*
	Scenario A2	*% Change*	*-7.44*	*-15.17*	*-13.53*
Nigeria	Baseline	(1000 mt)	3402	3792	3619
	Scenario A1	*% Change*	*-0.05*	*-0.25*	*-0.12*
	Scenario A2	*% Change*	*0.05*	*1.10*	*0.64*

While the lower *Bt* adoption rate for Nigeria (20%) under scenario A2 has minimal impacts on the global rice market, it has significant implications for Nigeria, which expands its imports at lower world prices due to smaller domestic output gains than under scenario A1 (Table 4). The annual changes in international prices, production, consumption and trade are less than one percent per year. The same magnitude of changes occurs on domestic prices of all the countries analyzed.

Table 4 Impacts of scenarios A1 and A2 on Nigeria's rice supply & use

Variable	Version	Unit / Year	2015	2023	9-Year Average
Production	Baseline	(1000 mt)	3226	4697	3934
	Scenario A1	*% Change*	*0.23*	*1.91*	*1.23*
	Scenario A2	*% Change*	*0.11*	*0.81*	*0.54*
Consumption	Baseline	(1000 mt)	6611	8487	7545
	Scenario A1	*% Change*	*0.08*	*0.95*	*0.59*
	Scenario A2	*% Change*	*0.08*	*0.94*	*0.59*
Imports	Baseline	(1000 mt)	3402	3792	3619
	Scenario A1	*% Change*	*-0.05*	*-0.25*	*-0.12*
	Scenario A2	*% Change*	*0.05*	*1.10*	*0.64*

Under the 20% *Bt* rice adoption rate, changes in Nigeria's domestic rice market are substantially different from that of the 40%. Instead of declining, Nigeria's rice imports under the lower adoption rate increase by 24 tmt per year. The increase in the country's rice production under 20% adoption rate is less than that under 40% by 29 tmt, while the average increases in total rice consumption for both scenarios are comparable.

These results indicate that asymmetry in adoption of new technology such as *Bt* rice has important implications on relative domestic supply and demand hence an important food security issue especially for food-deficit countries like Nigeria. The rate of production growth under scenario A1 is more than double that of the rate under scenario A2, making Nigeria more dependent on imports under scenario A2.

RICEFLOW RESULTS

GM rice adoption as specified in scenario R1 is expected to marginally expand global rice supply (0.2%) and demand (0.2%), and reduce global trade by 2.0% (Table 5). The stochastic analysis suggests *Bt* rice adoption may also skew global production and trade slightly to the left (Figures 1 and 3). As a result of *Bt* rice adoption, the global value of production is estimated to decrease by US$ 3.9 billion[1] while savings from global rice consumption are estimated at US$ 5.1 billion. The technological improvement is expected to release the pressure on land demand, which is estimated to contract globally by 0.5%.

The long grain segment of the rice market is expected to experience the largest shocks due to the adoption of *Bt* rice. The segmentation of the impact follows from the assumption that biotechnology companies will first introduce *Bt* long grain rice varieties to take advantage of the size of the market[2]. Global supply and demand of long grain rice are expected to increase by 0.3%. The proposed technological change is estimated to slightly increase the skewness of long grain production to the left, while marginally decreasing the skewness of production of medium and fragrant rice (Figure 2).

Total trade of long grain rice is estimated to decrease by 2.7% (Table 5), and its distribution to become slightly more skewed to the left (Figure 3).

Spillovers to other segments of the rice market (medium/short grain, and fragrant rice) through factor markets and final consumption are for the most part marginal except for fragrant rice production in Vietnam and Pakistan, which increases by 1.0% and 0.4%, respectively, as a result of the increased price competitiveness vis-à-vis long grain rice. The increase in fragrant rice production in Vietnam and Pakistan expands their exports.

Production is estimated to increase among all GM rice adopting countries and leads to lower producer prices and improved competitiveness (Table 5 and Appendix Figure 1). The drop in producer prices more than offsets the increase in production in all adopting countries but Nigeria, resulting in decreases in the total value of rice production. For instance, the value of rice production in China and Indonesia is expected to drop by US$ 2.3 billion and US$ 654 million, respectively.

Nigeria is the most import-dependent among the adopters; with roughly 50% of final consumption in 2013 met through trade, primarily from India and Thailand. The adoption of *Bt* rice gives the domestic supply chain a competitive edge over imports that encourages a relatively

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[1] This does not mean a loss to producers worldwide since the assumption of zero (normal) profits is maintained throughout the simulation. This figure should be understood as the cost savings generated by the technology due to the improved efficiency in the use of production resources.
[2] Recall that scenario R1 assumes that GM rice is first introduced only on long grain rice to take advantage of the scale. Long grain accounts for roughly 85% of global rice production in 2013.

strong expansion of domestic production. This is possible also due to the availability of plentiful resources in Nigeria; and implicit in the results is the ability of this country to provide a friendly environment for investors to pursue the development of new land and irrigation projects.

Among non-adopters, the Vietnamese supply chain is expected to be the most adversely affected due to its strong trade linkages with adopting nations[3]. The volume and value of rice production is expected to decrease by 1.7% and US$ 200 million, while total exports shrink by 6.8%.

Consumers from all regions will benefit from lower prices. In relative terms, the largest drop in consumer prices is expected in the Philippines (-4.1%) and China (-3.5%). In absolute terms, the largest savings from rice consumption are forecasted to occur in China (US$ 3,257 million) and Indonesia (US$ 824 million). Meanwhile, Vietnamese consumers are expected to reap the largest benefits/savings among non-adopters. Appendix Figure 1 shows the cdf for consumer prices in the five *Bt* rice adopting countries. Estimations suggest that consumer prices in Bangladesh, China, and Indonesia will decrease with certainty in both the benchmark and scenario R1. Adoption of Bt rice increases the probability of consumer prices dropping only slightly in Nigeria and more significantly in the Philippines (Appendix Figure 1).

Demand for land eases and returns decrease in all countries except Nigeria and the Philippines. Land demand in China and India, which together account for 46% of total rice acreage in 2013, decreases by 0.3% or 190 thousand hectares as a result of *Bt* rice adoption. Although a marginal effect, the results show the importance of adopting land and water saving technologies to better cope with tighter resource supplies in the coming years. Most Asian countries face mounting pressures to improve land and water productivity to sustain rice production and food security.

CONCLUSIONS

The results suggest that the adoption of *Bt* rice in selected importing countries will generate significant import substitution effects that will ameliorate the substantial expansion in international trade forecasted over the next decade. Results from the AGRM model suggest that China might substitute over 85% of its imports by 2023. More moderate changes are estimated using the RICEFLOW model.

Consumers worldwide are expected to benefit from lower prices as a result of the adoption of *Bt* rice, primarily those from adopting countries except Nigeria. The largest benefits accrue to consumers of long grain rice.

Adoption of Bt rice eases the pressure on land demand and leads to lower land rental prices in most countries except Nigeria.

At the global level, impacts are for the most part marginal except for the international reference price, which is estimated to decrease by 6% a year as a result of the *Bt* rice adoption rates and yield gains assumed in this study.

Lagging in *Bt* rice adoption can have significant welfare costs as estimated for the case of Nigeria. This provides the incentive for countries to keep up with the leaders in adopting new technologies.

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[3] Around 45% of Vietnam's rice exports went to *Bt* rice adopters (Bangladesh, China, Indonesia, Nigeria, and the Philippines) in 2013.

Figure 1 Box plot for accumulated 2013-23 global rice production and consumption by scenario

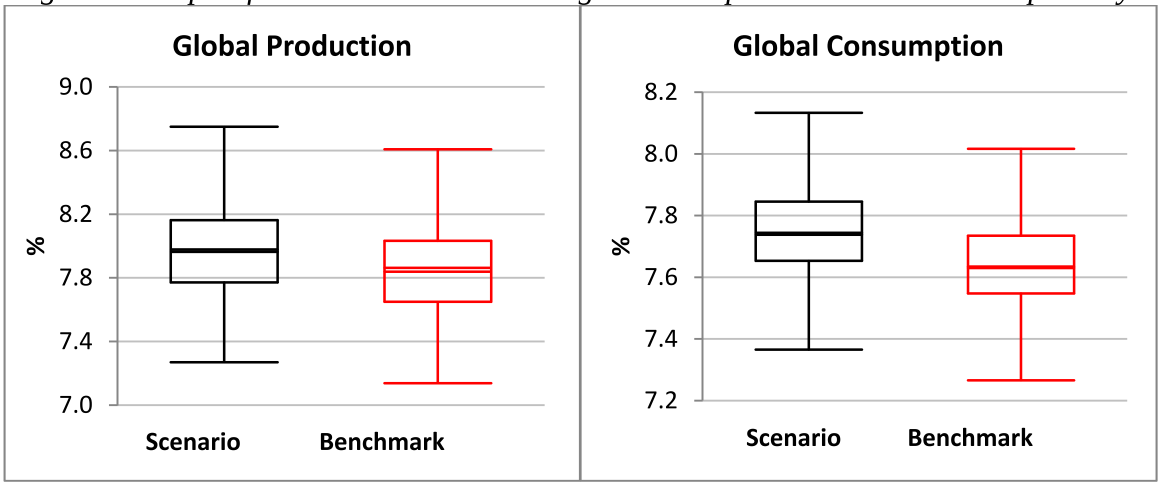

Figure 2 Box plot for accumulated 2013-23 rice production by type and scenario

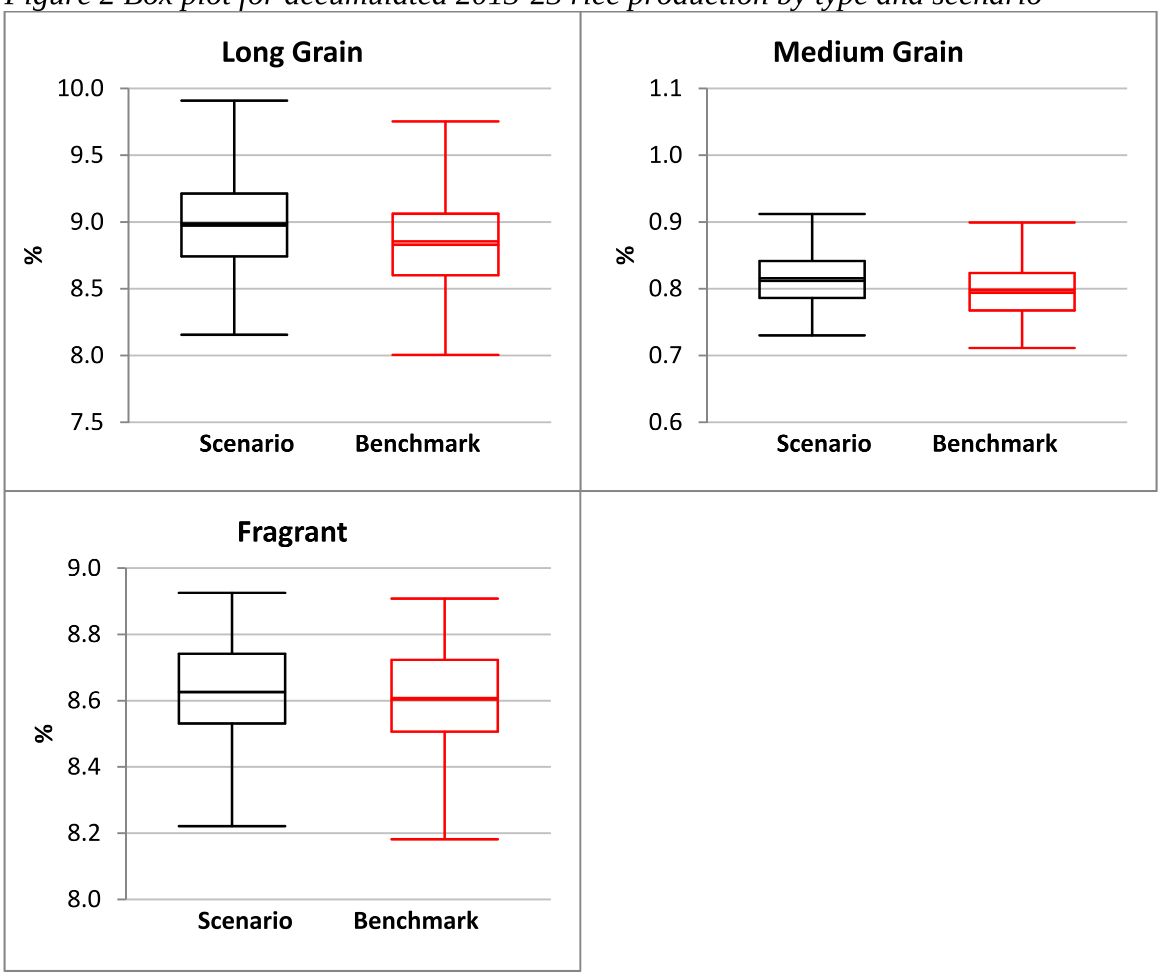

Figure 3 Box plot for accumulated 2013-23 global rice trade by type and scenario

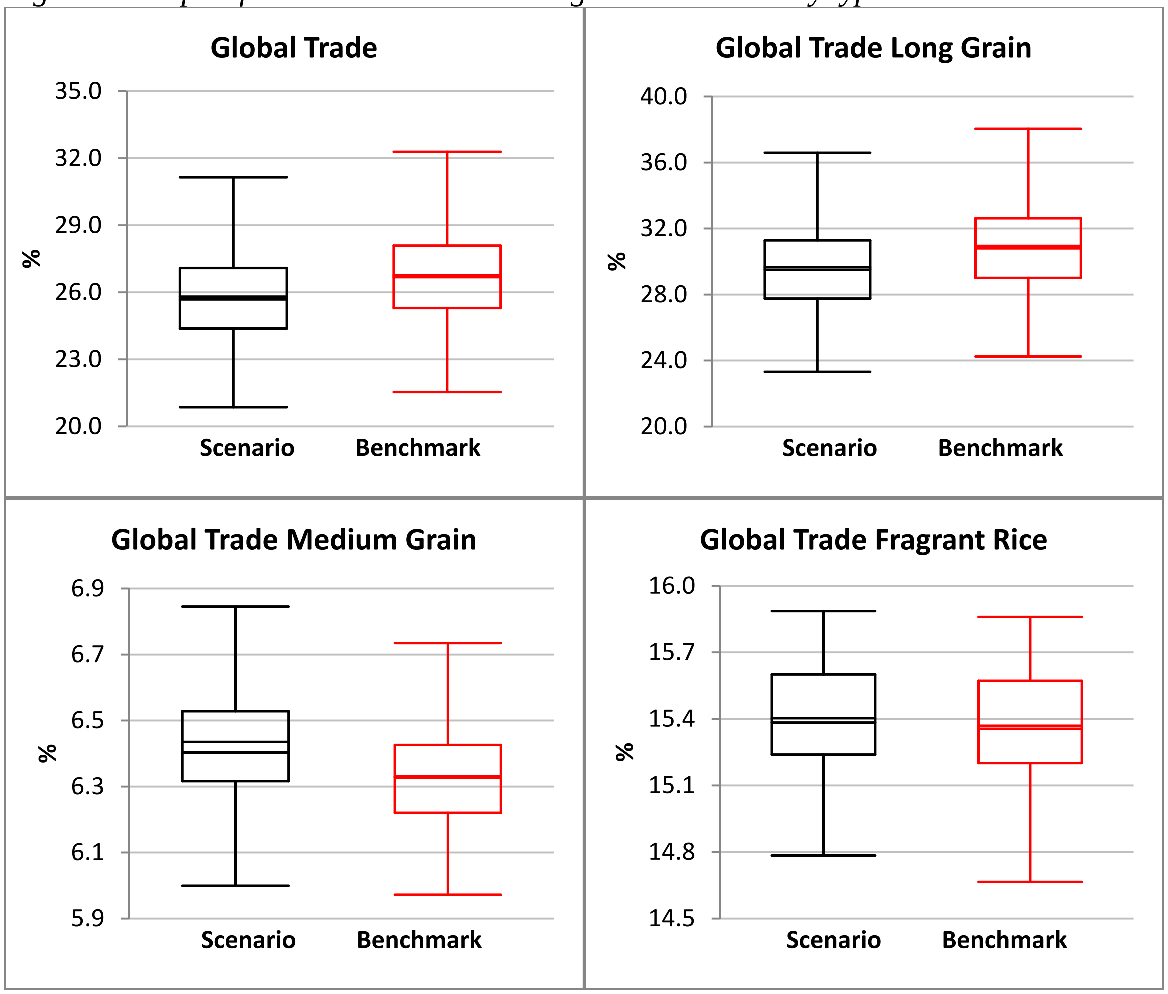

Table 5. Impact of scenario R1 (vis-à-vis the benchmark) on selected variables and countries

Variables	WORLD [a]	BAN	CHI	INDO	NIG	PHI	VIE	IND	PAK	THA	USA	MYA	MAL
Production	**1.7 (0.2%)**	**0.1%**	**0.9%**	**0.7%**	**4.7%**	**2.4%**	**-1.7%**	**-0.1%**	**-0.5%**	**-0.5%**	**-0.1%**	**-0.4%**	**-0.3%**
LG	*1.8 (0.3%)*	*0.1%*	*1.3%*	*0.7%*	*4.7%*	*2.4%*	*-1.8%*	*-0.1%*	-1.0%	-0.6%	-0.1%	-0.4%	-0.3%
MG	*-0.1 (-0.1%)*	--	*-0.1%*	--	--	--	--	--	--	--	*-0.1%*	--	--
FR	*0.0 (-0.1%)*	--	--	--	--	--	*1.0%*	*0.0%*	0.4%	-0.1%	--	--	--
Producer Prices	--	**-2.8%**	**-3.5%**	**-3.2%**	**-1.0%**	**-4.7%**	**-0.4%**	**-0.1%**	**-0.3%**	**-0.1%**	**-0.1%**	**-0.3%**	**-0.1%**
LG	--	*-2.8%*	*-4.5%*	*-3.2%*	*-1.0%*	*-4.7%*	*-0.4%*	*-0.1%*	-0.3%	-0.1%	-0.1%	-0.3%	-0.1%
MG	--	--	*-0.2%*	--	--	--	--	--	--	--	*-0.1%*	--	--
FR	--	--	--	--	--	--	*-0.3%*	*-0.2%*	-0.3%	-0.1%	--	--	--
Value Production [b]	**-3,880.9**	**-340.1**	**-2,282.8**	**-654.1**	**43.3**	**-229.5**	**-200.4**	**-72.1**	**-14.3**	**-49.3**	**-6.3**	**-25.8**	**-3.9**
LG	*-3,779.0*	*-340.1*	*-2,196.4*	*-654.1*	*43.3*	*-229.5*	*-203.1*	*-66.1*	*-15.4*	*-41.7*	*-4.4*	*-25.8*	*-3.9*
MG	*-91.2*	--	*-86.4*	--	--	--	--	--	--	--	*-1.9*	--	--
FR	*-10.8*	--	--	--	--	--	*2.8*	*-6.1*	*1.0*	*-7.6*	--	--	--
Consumption	**1.1 (0.2%)**	**0.0%**	**0.5%**	**0.5%**	**0.1%**	**1.2%**	**0.1%**	**0.0%**	**0.1%**	**0.0%**	**0.0%**	**0.0%**	**0.1%**
LG	*1.2 (0.3%)*	*0.0%*	*0.7%*	*0.5%*	*0.1%*	*1.2%*	*0.1%*	*0.0%*	0.1%	0.0%	0.0%	0.0%	0.1%
MG	*-0.1 (-0.1%)*	--	*-0.2%*	*-0.1%*	--	--	--	--	0.0%	--	0.0%	--	0.0%
FR	*0.0 (-0.1%)*	--	*-0.2%*	*-0.1%*	*0.0%*	*-0.2%*	*0.0%*	*0.0%*	0.0%	0.0%	0.0%	--	0.0%
Consumer Prices	--	**-2.6%**	**-3.5%**	**-3.1%**	**-0.4%**	**-4.1%**	**-0.4%**	**-0.1%**	**-0.3%**	**-0.1%**	**-0.1%**	**-0.3%**	**-0.2%**
LG	--	*-2.6%*	*-4.2%*	*-3.1%*	*-0.4%*	*-4.1%*	*-0.4%*	*-0.1%*	-0.4%	-0.1%	-0.1%	-0.3%	-0.2%
MG	--	--	*-0.2%*	*-0.1%*	--	--	--	--	-0.1%	--	-0.1%	--	-0.1%
FR	--	--	*-0.2%*	*-0.1%*	*-0.1%*	*-0.2%*	*-0.3%*	*-0.2%*	-0.2%	-0.1%	-0.1%	--	-0.1%
Value Consumption [b]	*-5,136.9*	**-426.6**	**-3,257.2**	**-823.4**	**-44.6**	**-396.6**	**-32.3**	**-27.6**	**-4.0**	**-11.4**	**-8.8**	**-11.7**	**-3.5**
LG	*-4,983.6*	*-426.6*	*-3,141.0*	*-823.4*	*-44.6*	*-396.6*	*-32.1*	*-26.2*	*-2.2*	*-6.4*	*-4.2*	*-11.7*	*-3.4*
MG	*-124.0*	--	*-114.5*	*0.0*	--	--	--	--	*0.0*	--	*-2.9*	--	*0.0*
FR	*-29.3*	--	*-1.7*	*0.0*	*0.0*	*0.0*	*-0.2*	*-1.4*	*-1.8*	*-4.9*	*-1.8*	--	*-0.1*
Imports	**-0.8 (-2.0%)**	**-8.2%**	**-14.6%**	**-10.5%**	**-2.2%**	**-17.3%**	**-12.5%**	**-0.1%**	**3.4%**	**-1.2%**	**0.1%**	**-1.8%**	**0.7%**
LG	*-0.8 (-2.7%)*	*-8.2%*	*-16.2%*	*-10.6%*	*-2.2%*	*-17.5%*	*-12.5%*	*-0.1%*	5.2%	-1.2%	0.4%	-1.8%	0.8%
MG	*0.0 (0.0%)*	--	--	*-0.1%*	--	--	--	--	0.0%	--	--	--	--
FR	*0.0 (0.1%)*	--	*0.1%*	*0.0%*	--	*-0.2%*	--	--	-0.5%	0.0%	0.0%	--	0.1%
Exports	**-0.8 (-2.0%)**	--	**2.8%**	--	--	--	**-6.8%**	**-1.1%**	**-0.2%**	**-1.5%**	**-0.2%**	**-3.8%**	--
LG	*-0.8 (-2.7%)*	--	*43.7%*	--	--	--	*-7.8%*	*-1.7%*	-0.6%	-1.8%	-0.2%	-3.8%	--
MG	*0.0 (0.0%)*	--	*0.7%*	--	--	--	--	--	--	--	-0.2%	--	--
FR	*0.0 (0.1%)*	--	--	--	--	--	*1.1%*	*-0.1%*	0.7%	-0.5%	--	--	--
Rice Acreage	**-0.75 (-0.5%)**	**-1.7%**	**-0.5%**	**-1.3%**	**1.5%**	**0.0%**	**-1.5%**	**-0.1%**	**-0.4%**	**-0.4%**	**-0.1%**	**-0.4%**	**-0.3%**
Land Rental Price	--	**-5.4%**	**-1.7%**	**-4.6%**	**13.2%**	**0.0%**	**-5.5%**	**-0.4%**	**-2.2%**	**-1.6%**	**-0.5%**	**-2.1%**	**-1.4%**

a. Nominal values in million metric tons or hectares. b. Million 2013 US$

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APPENDIX

Appendix Figure 1CDF of accumulated 2013-23 change in consumer prices among Bt rice adopters