Potential Benefits of Transgenic Rice in Asia: A General Equilibrium Analysis[1]

Guy G. Hareau, George W. Norton, Bradford F. Mills, and Everett Peterson[2]

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[2] Graduate research assistant, professor, associate professor, and associate professor respectively, Virginia Tech, Blacksburg, Virginia

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Abstract

A general equilibrium model is developed to analyze the welfare effects of transgenic technologies for both the irrigated and non-irrigated rice ecosystems in Asia. Drought resistance, a technology of particular importance to unfavorable environments, is worth as much as *Bt* rice, a technology of primary importance to favorable environments.

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Rice is the most important source of calories for almost half of the world's population. Within Asia, it is more than 30 percent of total calorie supply; with more than half of the calories consumed by the poor obtained from rice. Asia accounts for 90 percent of the world's rice production and consumption. Demand for rice in the region is expected to increase about 70 percent over the next three decades, implying a need to raise yields from about 3.7 tons per hectare on average to about 6.3 tons, assuming current lands remain in production (RiceWeb).

Roughly 75 percent of the world's rice is produced under irrigation (on roughly 55 percent of the rice area), but the remainder is grown in fragile rain-fed lowlands, rain-fed uplands, and flood prone areas (Table 1). More than half of Asia's poor obtain at least 50 percent of their calories from rice grown in these fragile environments. Farmers in these environments face drought and submergence, numerous insects and diseases, and poor soils (IRRI, 2004).

Rice biotechnology research is underway to address quantity and quality constraints in both favorable and fragile ecosystems for existing self pollinated varieties, for cultivars based on the new plant type developed by the International Rice Research Institute (IRRI), and for hybrid rice (IRRI, 2004). For favorable environments, C4 genes are being incorporated into *indica* rice with the purpose of increasing photosynthesis. Field testing of transgenic lines conducted in collaboration between IRRI and national agricultural research and extension systems (NARES) have shown excellent resistance against stemborer and bacterial blight in irrigated environments. These lines contain the

Bt gene for stemborer control and the *Xa21* gene for bacterial blight. Stem borer is the most significant rice insect pest in most Asian countries, causing yield losses that average 2-5 percent, but in some locations and years are much greater (Savary et al). Bacterial blight is a fungus that at times can cause significant losses. Provitamin A, iron, and zinc have been incorporated into breeding lines through a combination of conventional and transgenic means to improve nutritional quality. In addition, two private firms, Aventis (now part of Bayer) and Monsanto have developed herbicide-resistant rice varieties: Liberty Link rice (Aventis) is resistant to glufosinate, while Roundup Ready rice (Monsanto) is resistant to glyphosate (Giannessi et al.). Weeds represent the largest source of yield loss in rice and a significant source of labor costs. This herbicide-resistance technology may have the largest impact on rice in Asia in the long run as labor costs continue to rise.

Table 1: Rice ecosystems

Ecosystem	Area (% of world)	Production (% of world)	Technology	Farm type
Rainfed Lowlands	25	17	Rainfall dependent	Farm families, most densely populated and poorer rural and urban regions
Uplands	13	4	Non-flooded, very low yields	Subsistence family farming
Flood prone	7	4	Uncontrolled flooding	Rice only crop can be grown, more than 100 million people in poor farm families
Irrigated	55	75	Water control	Commercial farms. Major supply for urban consumers

Source: IRRI, 2002b

For fragile ecosystems, biotechnology research in rice has focused on a series of abiotic stresses in addition to blast fungus resistance and nutrient enhancement. Tolerance to drought, submergence, salinity, and zinc deficiency are all the subject of research at IRRI, and in the long run development of these types of tolerances is where the largest impacts from biotechnology may be expected in these ecosystems. However, transgenic rice cultivars with enhanced plant protection and nutritional improvements are expected to be the first technologies released for fragile environments (IRRI, 2004).

Research Balance

According to their current medium term plan, IRRI is now devoting roughly twice the resources to research (including transgenic) on fragile environments compared to favorable environments. Research aimed at fragile environments has higher risks and lower expected adoption rates due to a higher heterogeneity of the environments. Therefore some have argued that for rice research in most countries, an emphasis on favorable environments would achieve greater impacts even on the poor as product and factor market adjustments might counter balance negative first round distributional effects (David and Otsuka). However, such arguments presume that (1) impediments to product and factor market adjustments that would help the poor are minimal, (2) alternative investments (to research) that can more efficiently mitigate adverse distributional effects will in fact be made, and (3) incentives for private research differ little across environments.

In some countries, irrigated rice is by far the predominate type, but in others, just the opposite is true, suggesting a need to strike a balance with public research across both types of environments unless the private sector undertakes sufficient research investments for favorable areas to allow the public sector to focus on fragile areas. For rice in Asia, the private sector has been slow to develop transgenic solutions for any environment for several reasons. Very little rice in Asia is hybrid rice to date, and with the negative response to terminator technology, it is difficult for companies to capture the benefits once the technology is released and farmers start replanting their seeds. Hand labor is still prevalent for weeding with wages still relatively low, reducing the demand for the one "off-the-shelf" technology the private sector already has available, herbicide resistance. This technology will eventually become important, but in the meantime, underdeveloped regulatory systems in most countries in Asia, have added substantial risk and high costs to the research and development process for transgenic products. Companies will remain slow to invest in a transgenic solution to a pest or other problem until there is a transparent, science-based regulatory system in place (Pray and Naseem).

Public-private partnerships have allowed IRRI and its public consortium members to gain access to patented genes and biotech processes at low cost and allowed the myriad of technologies mentioned above to be developed or commence development. However, several factors have slowed progress in the public sector as well. First, the public sector faces the same underdeveloped bio-safety and other regulatory processes that the private sector does, especially when it comes to commercial release. Second, resources for both international and for national public agricultural research have become increasingly constrained. IRRI has experienced major budget cuts over the past five years in particular, forcing it to prioritize technologies and environments and slow down or put on hold the development of technologies, especially those that may be perceived as the most controversial, for example *Bt* rice. Third, most transgenic pest management technologies in rice in Asia are potentially problematic with respect to resistance development. It will be very difficult to require Asian rice growers to maintain areas of refugia and stick to resistance plans that have proven difficult enough to enforce in the United States. Countries are resistant to jump on a potential biotech treadmill given the experience of some with the pesticide treadmill. Fourth, public opinion is still evolving in Asian countries with respect to GMOs. Most countries and IRRI have taken a cautious attitude as the debate over GM rice's role in the food system is highly polarized in the Philippines and elsewhere in the region. Fifth, the technology they hope to release first, rice with enhanced vitamin A, has little hope of being broadly adopted unless it is released in the latest cultivar that has high yields, reduced pest problems, appropriate taste, etc, (unless it costs the consumer less which is not likely).

Distributional concerns

A number of distributional concerns arise because of the potential for biotech products to be produced for favorable versus unfavorable environments or in the public versus the private sector (or some combination) or in some countries but not others. Many of the poorest farmers in fragile environments were not reached by the green revolution and may be bypassed by the gene revolution as well unless research disproportionately targets those areas as proposed by IRRI. On the other hand, the overall demand for rice continues to grow and targeting areas with the highest overall impact may result in the greatest reductions in aggregate poverty through change in product and factor markets. Still, if regulatory systems can be improved across Asia, the private sector may serve the favorable environments, saving scarce public biotech resources for fragile areas and special nutrient needs.

The imperfectly competitive nature of markets when one or a limited number of private biotechnology firms hold intellectual property rights over the technology should be considered when assessing the likely development and spread of (and gains from) the technology (Moschini and Lapan; Moschini, Lapan, and Sobolevsky; and Falck-Zepeda, Traxler, and Nelson). In partial equilibrium (PE), monopoly power improves research incentives, increasing the chances for overall gains while shifting a higher percentage of the gains to the biotechnology firms as opposed to farmers and consumers. However, to better capture distributional effects and potentially important factor effects, a general equilibrium approach may be useful as it allows for factor adjustments and production shifts that may occur not only across countries but across crops as relative prices change.

The above discussion raises a large set of issues, but in this paper the analysis is focused on total versus distributional effects from emphasizing favorable versus fragile environments. Cross-country distributional effects of GM rice were recently examined by Mamaril, using a partial equilibrium model with examples from the Philippines and Vietnam. This paper employs general equilibrium analysis in a preliminary application of the GTAP (Global Trade Analysis Project) model to explore the total and distributional effects of GM rice aimed at favorable versus fragile environments. Additional work is underway to further refine the technology assumptions used for favorable and unfavorable areas in the model and to analyze impacts of public versus private research.

Methods

The welfare implications of differential adoption of agricultural technologies across eco-systems have been assessed in previous studies using both partial equilibrium and general equilibrium approaches. For example, Mills employed a single-commodity, multi-market economic surplus model to investigate regional changes in income as a result of adopting four sorghum technologies in four agro-climatic zones in Kenya. Scobie and Posada used a partial equilibrium model to assess income distribution effects among rural and urban households as a result of adopting improved irrigated rice technology in Colombia, They distinguished between effects on irrigated versus upland and rain-fed areas. Coxhead and Warr used a general equilibrium model to analyze the income effects of technical change in rice production in the Philippines, distinguishing between irrigated and non-irrigated rice and among technologies with different factor biases across those environments. Renkow also applied a general equilibrium framework to examine distributional effects of adopting wheat technologies in irrigated versus rain-fed areas of Pakistan. Effects were analyzed for three agricultural household types (small and large farms and landless) and for two urban groups (rich and poor).

While either a partial equilibrium or a general equilibrium framework can be applied to assess distributional effects of rice technologies across countries and eco-systems, the latter has the advantage of ease of accounting for income effects and for the many factor and product market adjustments that may occur when, for example, production substitution possibilities exist and alternative crops can be grown in response to changes in relative prices. In this paper, the General Trade Analysis Project (GTAP) general equilibrium model is applied with eight countries: China, India, Indonesia, Bangladesh, Vietnam, Thailand, the Philippines, and Japan, (representing approximately

80 percent of the world's rice production); and the Rest of Asia (ROA), Latin America, the United States, Africa, and the Rest of the World included as additional regions. A previous application of the GTAP model, assuming a generic biotechnology and using aggregated regions in the world, can be found in Anderson, Nielsen, and Robinson. That study, however, did not disaggregate by countries within Asia or by ecological rice zones.

A general description of the basic GTAP model is found in Hertel, but briefly, each country or group of countries in the GTAP database corresponds to a regional household that collects all income corresponding to the region. Income is distributed to three institutions within each region: a private household representing all consumption expenditures, the government, and a savings sector. Production occurs in the private sector, and a Rest of the World institution accounts for international trade. Private firms purchase domestic and imported intermediate inputs from domestic firms and the rest of the world, which combined with primary factors supplied by the regional household, produce tradable commodities for sale to the domestic market and for export. The regional household receives value-added income from its primary factors (land, skilled and unskilled labor, capital, and natural resources) and from tax payments, and distributes the total income to private consumption, government consumption, and savings. Private households and government both consume domestic and imported commodities, while the savings sector invests in domestic and imported commodities and a capital goods sector.

The regional household is assumed to have an aggregate Cobb-Douglas utility function. At the second level of the demand system, per capita expenditures of the private household respond to a non-homothetic constant difference elasticity (CDE) expenditure function, allowing consumption shares of different commodities and elasticities to change at different income levels. Government preferences are governed by a per capita Cobb-Douglas utility function and there is a constant budget share for public goods in private consumption. Savings is also on a per capita basis and must equal the amount of capital goods produced from commodities. Firm behavior is modeled as nested constant elasticity of substitution (CES) function with constant returns to scale technology.

GTAP offers the advantage of providing a unified database and a commonly used model for policy analysis, hence facilitating comparison of results with other studies. It also identifies rice and processed rice as separate sectors in the model allowing for analysis of linkages between them and between rice and other sectors. The model was originally constructed from Social Accounting Matrices (SAMs) and the data in the aggregate model can be used to reconstruct the SAMs for each of the regions of choice. The SAM structure provides a description of the underlying technologies of the economic activities, and while maintaining the original closure, secondary data can be used to transform the SAM according to specified criteria to create a new SAM. For the present study, the original paddy rice sector in GTAP was split into two sectors, one for favorable and one for fragile rice environments. This modified SAM was then used to alter the GTAP database as required for the analysis.

The data required to modify the SAM were provided by two basic sources. First, area, yield, and production statistics for each region and for favorable and unfavorable environments were obtained from Huke and Huke, IRRI (1993 and 2002a), and Greenland. A summary of the percent distribution of total paddy rice production by region and eco-system are provided in table 2.

Table 2: Distribution of Total Paddy Rice Production by Region and Ecosystem

	Irrigated (%)	Rainfed (%)	Upland (%)	Flood-Prone (%)
China	95.8	3.5	0.6	0
India	57.9	36.9	3.5	1.8
Indonesia	67.1	28.5	4.4	0
Bangladesh	40.9	51.4	1.7	6.0
Vietnam	72.5	25.1	1.3	1.1
Thailand	17.0	78.2	1.5	3.4
Philippines	71.5	26.9	1.6	0
Japan	100	0	0	0
Rest of Asia	62.6	33.6	2.1	1.6
USA	100	0	0	0
Latin Amer.	64.7	5.4	28.9	1.0
Africa	42.2	23.6	21.2	13.0
ROW	97.7	0	2.3	0

Source: based on Huke and Huke, IRRI (1993, 2002a) and Greenland.

Second, basic data on input use and factor returns for rice production in both favorable and unfavorable environments were obtained from country studies in David and Otsuka. The data were collected using village surveys in each environment and analyzed using a common economic framework for all countries, making the results compatible across countries. Some data were also obtained from Tran, Hossain and Janaiah and from Yap.

Per hectare factor returns and input use for each country and environment were calculated and the resulting factor use and returns proportions for each region and environment were used to modify the paddy rice sector in the original SAM. Information on fertilizer use by environment, available from the same sources was used to modify the chemicals sector. Production proportions by ecosystem in table 2 were also used to modify the SAM.

Assessing the effects of transgenic rice in Asia using this general equilibrium framework optimally involves a series of analyses that account for differences in effects by country (and region) and by type of environment (irrigated, rain-fed, upland, and flood-prone) for (1) transgenic technologies for favorable and unfavorable environments and (2) technologies developed by the public versus the private sector (with implied differences in pricing). Expected effects on production, prices, trade, income, and factor adjustments by country and type of household can then be assessed. In this paper, results of analyses on only the first of these two issues is addressed, and in a somewhat preliminary fashion, as more detailed assessment of differential technology impacts, including factor biases by region, is still under investigation. The benefits of two technologies, *Bt* rice for stem borer control and drought resistant rice, are projected. The former is relatively more important in favorable areas and the latter in rain-fed fragile areas. Technological shocks are applied to the paddy rice sector by eco-system for each technology for each country. The model is also disaggregated to include the following sectors: irrigated and non-irrigated paddy rice, processed rice, all other crops, all other agriculture, other processed food, chemicals, manufactured products and services. Results are analyzed in terms of welfare changes (equivalent variation) for each country (region) and in terms of changes in production and price of rice and processed rice, trade patterns, and factor demands for each region and environment. Analyses are still underway to refine the technology impacts more finely and to examine the implications of imperfect competition in the seed market.

Preliminary Results

Basic rice production and trade data for a recent year and the technology shocks applied to the model by country and ecosystem are presented in Table 3. The magnitude of the shocks was determined from estimates of crop losses caused by stem borers and drought as a percentage of the maximum potential farm yield. For stem borers, Savary et al. found average annual yield losses of 2.3 percent in different lowland areas of tropical Asia. To account for the larger incidence of stem borers in irrigated environments, the shock applied to non-irrigated areas is 1.0 percent. More specific information exists for some countries. Widasky and O'Toole assessed average annual crop losses for irrigated and non-irrigated (rain-fed) ecosystems in Eastern India of 2.15 and 1.65 percent. In Bangladesh, the losses were estimated at 2.76 and 1.43 percent (Dey et al.). Losses in lowland areas of Indonesia were estimated at 3.16 percent (Jatileksono). In China, Lin and Shen estimated the losses in irrigated areas at only 0.14 percent. This low level, however, does not account for the fact that insect control is high in China and based on what some studies have suggested is an overuse of insecticides in the country (Widawsky et al.). Therefore the shock applied to China is 2.3 and 1.0 percent.

Drought is a severe constraint because the rice crop demands larger amounts of water to produce one unit of biomass than any other relevant commercial crop. Drought affects the rain-fed ecosystems, where regularity and amount of precipitation are highly uncertain, and the irrigated areas due to shortages in water sources and reduced control of the irrigation systems. The three critical stages at which rice is affected are seedling, vegetative and anthesis. Average annual yield losses have been estimated at 3, 7, 17 and 1 percent for the irrigated, rain-fed lowland, upland and deepwater ecosystems respectively (Dey and Upadhyaya). The shocks applied to the model weight these estimates for each region using the production proportions in table 2, and further consider that a drought resistant variety would help recover 50 percent of the losses in irrigated eco-systems and 60 percent in the non-irrigated ones.

Table 3. Rice Production and Trade, and Technology shocks due to Transgenic Rice

	Production (million T) Year 2000	Exports (million T) Year 2000	Imports (million T) Year 2000	% Prod. Shock *Bt* Rice for Stemborer		% Shock Drought Resistance	
				Irrig.	Non-irrig.	Irrig.	Non-irrig.
China	189.8	3.1	0.2	2.30	1.00	1.50	5.09
India	131.5	1.5	0.01	2.15	1.65	1.50	4.55
Indonesia	51.9	1.0	1.4	3.16	1.00	1.50	5.00
Bangladesh	37.6	0	0.5	2.76	1.43	1.50	4.01
Vietnam	32.5	3.5	0.2	2.30	1.00	1.50	4.34
Thailand	25.6	6.1	0	2.30	1.00	1.50	4.16
Philippines	12.4	0	0.6	2.30	1.00	1.50	4.54
Japan	11.9	0	0.6	1.50	0	1.50	0
Rest of Asia	55.9	2.3	7.8	2.30	1.0	1.50	4.38
USA	8.7	2.7	0.3	0	0	0	0
Latin Amer.	20.5	1.6	0.9	0	0	0	0

Africa	17.6	0.4	4.5	0	0	0	0
ROW	6.5	0	4.5	0	0	0	0

Preliminary results from running the GTAP model with the shocks listed in table 3 are presented in tables 4 and 5. Results illustrate that the large gainers from either type of transgenic rice will be China, India, Indonesia, Japan and to some extent Bangladesh, and that the gains for these countries will be much greater than for others. Countries such as Thailand and Vietnam that are leading rice exporters will experience declining terms of trade that will offset part of their potential gains. In fact Thailand may experience very little increase in equivalent variation for *Bt* rice, both because of the terms of trade effect and because the country has a significant proportion of its rice production in less favorable rain-fed environments. Of course these results assume that all countries in Asia adopt the technologies at the same time. If Thailand were to adopt first, it would experience larger gains. Thailand does experience larger gains for drought-resistant than for *Bt* rice because of its extensive upland production.

China receives the largest gains of any country for the stem borer technology. Interestingly, these gains are derived from technical efficiency changes that reduce the demand for own-seed production. That factor saving actually reduces the projected overall production of rice. It is also possible that the gains for China from *Bt* rice are overstated, because stemborer may be less of a problem in the northern portion of its irrigated rice eco-system.

The United States, Latin America, Africa, and the rest of the world are assumed not to adopt the technologies and experience terms of trade and welfare losses. Because stem borer is almost non-existent as a problem outside of Asia, with the exception of a small problem in the middle east, that is not a bad assumption. Drought is also not too much of a problem in the United States as most of the crop is irrigated. Latin America loses due to the terms of trade effect, while Africa neither gains nor loses much, but would likely have gained had we assumed technology adoption in that region.

Japan is an interesting case for two reasons. First, it produces primarily *Japonica* rice, which has less of a yellow stem borer problem than the *Indica* rice in more tropical areas. Second, it produces mostly irrigated rice, which reduces its gains from drought resistant rice, but it still receives a significant gain from both technologies. The reason it gains is the high support price for rice (roughly ten times the world price). In a separate analysis that was done, Japan gained significantly more if it removed its paddy and processed rice tariffs than if it adopted the new transgenic technologies. Because of higher labor costs than other Asian countries, Japan would seem to be a good candidate for herbicide-resistant rice technology, a case not analyzed here, but there is strong opposition to transgenic rice in Japan, which may cause it to forgo significant potential economic benefits from that technology.

Total income gains for the world are projected to be approximately $2.9 billion for drought-resistant rice and $2.4 billion for stem borer-resistant rice. The former is more suitable in upland areas where the farmers are poorer on average. Therefore, if the costs of producing the two technologies were the same and the private sector were equally likely to ignore each technology, then the argument could be made that the public sector may want to focus on the technology for the fragile upland area. In reality, *Bt* rice is significantly closer to market than drought tolerant rice. In addition, the gains to *Bt* rice may be understated because no adjustments were made in the model to reduce pesticide use as a result of the technology. Such a reduction might result in additional income and environmental gains.

Table 4. Change in Rice Production, Domestic Price, Trade, and Welfare Effects due to *Bt* Transgenic Rice

	Production (% change)			Domestic Price (% change)		Exports (% change)		Imports (% change)		EV (mil. US$)
	Irrig. rice	Non-irrig. rice	Proc. rice	Paddy rice	Proc. rice	Paddy rice	Proc. rice	Paddy rice	Proc rice	
China	-0.28	0.05	0.13	-3.33	-1.17	8.34	0.92	-1.96	0.76	537.72
India	0.21	0.09	5.39	-2.91	-2.22	6.35	5.42	-1.48	-0.45	520.35
Indonesia	0.35	0.36	0.36	-4.16	-2.6	12.38	8.28	0.25	-1.7	267.94
Bangladesh	-0.12	0.07	0.16	-3.52	-2.06	8.83	5.43	-0.93	0.36	100.25
Vietnam	0.69	0.72	0.91	-2.86	-2.52	1.46	3.93	0.00	-1.71	26.22
Thailand	0.93	0.1	0.15	-2.03	-1.65	1.07	0.33	-0.22	-0.69	12.95
Philippines	0.01	0.16	0.27	-3.17	-2.45	7.96	7.51	-0.95	-1.29	81.22
Japan	0.1	0	0.1	-1.85	-1.39	4.72	2.58	-0.67	-1.34	411
Rest of Asia	0.25	0.27	0.47	-2.92	-2.38	5.48	6.28	-1.20	-1.63	445.4
USA	-0.79	o	-1.34	-0.15	-0.02	-2.16	-2.6	6.18	2.71	-37.53
Latin America	-0.11	-0.03	-0.11	-0.03	-0.01	-3.66	-1.45	0.21	0.59	-17.58
Africa	-0.15	-0.12	-0.14	-0.02	-0.01	-5.79	-3.08	0.47	2.92	0.21
ROW	-0.72	-0.32	-0.53	-0.19	-0.11	-4.52	-2.82	2.20	1.58	40.48

Table 5. Change in Rice Production, Domestic Price, Trade, and Welfare Effects due to Drought Resistant Transgenic Rice

	Production (% change)			Domestic Price (% change)		Exports (% change)		Imports (% change)		EV (mil. US$)
	Irrig. rice	Non-irrig. rice	Proc. rice	Paddy rice	Proc. rice	Paddy rice	Proc. rice	Paddy rice	Proc rice	
China	-0.22	-0.14	0.03	-2.41	-0.86	4.84	-1.83	-0.86	5.36	431.61
India	0.29	-0.08	6.88	-3.92	-3	4.59	6.91	-1.35	-1.03	740.78
Indonesia	0.35	0.34	0.35	-4.25	-2.67	7.86	6.67	0.19	0.88	285.88
Bangladesh	0.17	0.06	0.31	-5.46	-3.67	8.33	11.22	-1.03	-1.43	174.31
Vietnam	0.48	0.2	0.6	-3.11	-2.74	1.03	2.23	-0.07	-1.74	29.02
Thailand	1.98	1.75	2.03	-4.90	-3.86	0.44	5.82	-0.09	-5.25	59.72
Philippines	0.09	-0.22	0.26	-3.67	-2.86	6.29	7.59	-0.92	-0.81	99.94
Japan	0.07	0	0.05	-1.86	-1.4	5.66	0.8	-1.33	-0.25	427.62
Rest of Asia	0.35	0.21	0.57	-4.12	-3.36	5.90	8.88	-1.21	-0.45	618.12
USA	-0.64	0	-2.03	-0.13	-0.02	-1.62	-3.53	4.20	4.98	-36.64
Latin America	-0.1	-0.04	-0.14	-0.02	-0.01	-8.53	-1.95	0.15	0.72	-19.06
Africa	-0.17	-0.15	-0.19	-0.02	-0.02	-13.78	-4.37	0.32	3.83	1.27
ROW	-0.76	-0.49	-0.8	-0.19	-0.1	-3.64	-4.24	1.33	2.3	55.73

Analyses in Progress

Several types of analyses are currently underway to refine the models and the data and to estimate the effects of alternative transgenic rice biotechnologies in favorable and unfavorable environments produced through public and private sources. First, estimates of the production cost savings of the new rice biotechnologies by eco-system will be refined. Second, the technology shocks will be sequenced, reflecting current estimates on their individual release in general and within each country. Third, the model will have equations added to model the effects of private sector monopolists for some technologies (such as herbicide resistance) but not for others. This adjustment will entail adding a monopolist price setting mechanism and a direct link between monopolist markups and rates of technology adoption. GTAP has been adjusted in other settings to reflect a situation where a country is a monopolist. However, in this case, a monopolist from another country enters into a previously competitive market and takes profits out of the country.

Conclusion

Rice biotechnologies will have significant cross country and cross sector effects, and the presence of diverse ecologies combined with both public and private research will influence the level and distribution of benefits from the technologies. The preliminary general-equilibrium-model results highlight the significance of product and factor adjustments when technologies favor specific environments. It appears that a technology for unfavorable environments, such as drought resistance, may be worth as much as a technology for favorable environments such as *Bt* rice. Arguments about which type of technology the public sector should focus its efforts on depend as well on how the private sector responds in the future as hybrid rice becomes more important in irrigated areas around the world, as bio-safety regulations are designed and implemented, and as other changes occur that provide incentives for the private sector to develop transgenic technologies. The effects of one transgenic technology not addressed here, herbicide tolerance, may eventually overwhelm the effects of both of the cases presented here due to savings in losses due to weeds, and to savings in labor costs.

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