Transgenic Rice in Asia: A General Equilibrium Assessment of Potential Welfare Effects and Regional Distribution

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(ABSTRACT)

The unequal distribution of gains from technology between favorable and unfavorable rice environments in Asia can widen if future transgenic rice varieties cannot be adopted in less favored regions. This study investigates the potential economic impacts of three transgenic rice technologies: stemborer resistance, for favorable irrigated environments; drought resistance, for unfavorable non-irrigated environments; and herbicide resistance, which can potentially benefit any of the environments but can only be adopted in areas under direct seeding. Specifying individual technologies contributes to a better comparative assessment of impacts from transgenic rice. The simulation uses a modified version of the Global Trade Analysis Project (GTAP) model with several innovative features: the database and code represent the distinct rice environments for both paddy and seed sectors; monopoly power is included in the model as a markup tax instrument when private firms sell herbicide resistant rice seed; and private rents can be transferred between regions and change income computation in the model.

Equivalent variation measures obtained from simulations are similar at 2.3 billion, 2.5 billion and 2.2 billion dollars for stemborer, drought and herbicide resistance respectively. All technologies increase global rice output and reduce rice prices, while keeping labor wages at stable levels. Private provision of herbicide resistance rice generates benefits of 2.05 billion dollars while creating 122 million dollars in private profits. Although profits increase with higher markups, there are still large social benefits to realize from herbicide resistance technology. However, producers' response to reduced profitability is not accounted for and adoption is an exogenous variable in the model.

The results suggest that the large expected impact from drought resistant rice supports public research investment on this technology. Joint efforts between public and private research sectors can increase the probability of success, and mechanisms to promote private research for unfavorable environments should be developed. Public policies should also remove obstacles that prevent firms from undertaking joint research with the public sector. Outcomes from public research, such as improved germplasm and spread of direct seeding techniques, also benefit the private sector and should act as an incentive for firms to build strategic alliances.

To my loved ones: Elena, Sylvie, Chantal and Etienne.
To my parents.

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Chapter 1. Introduction

1.1. Problem statement

> *"He who has food has many problems. He who has no food has only one problem"*
>
> (Byzantine proverb, cited in Pinstrup-Andersen and Schiøler, 2000)

Poverty, hunger and malnutrition are a recurrent problem for more than 800 million people in the world. In developing countries, the proportion of people living on less than one dollar a day decreased from 27.9 percent in 1990 to 21.3 percent in 2001. However, this proportion still accounts for more than 1 billion people and the decline in the figure has almost stalled since 1997. The pattern of development is not equal across countries, with some regions making large advances in reducing poverty while others lag far behind. While economic progress in the last 25 years reduced the absolute number of poor in Asia by more than 230 million, setbacks in Sub-Saharan Africa pushed another 90 million below the poverty line. Meanwhile, the number of people that do not meet their daily needs for food has remained almost constant at 815 million. There are now 65 million fewer people suffering from chronic hunger in Eastern Asia, South-Eastern Asia and Latin America and the Caribbean, but 55 million more in Western and Southern Asia and Sub-Saharan Africa have seen their energy intake reduced below the required minimum. Malnutrition affects the most vulnerable group of the world population, children, with more than 150 million of underweighted children under the age of five (United Nations, 2005).

The eradication of poverty, hunger and malnutrition is considered the first of eight Millennium Development Goals set forth by the international community to uphold the principles of human dignity, equality and equity at the global level. The specific targets are to halve, between 1990 and 2015, the proportion of people living on less than one dollar a day and those who suffer from hunger. Other Millennium Development Goals include improving primary education, gender equality, empowerment of women and maternal health, decreasing child mortality, combating HIV/AIDS, malaria and other diseases, ensuring environmental sustainability, and creating a global partnership for development (United Nations, 2000).

Poverty, hunger and malnutrition feed on each other, creating a vicious circle from which poor people can not escape without targeted policies. The incidence of poverty is higher in rural areas, amongst landless laborers and small farmers who do not earn enough daily income to buy enough nutritious food. Deteriorating health conditions may then extend to the rest of the members of the household: mothers cannot adequately nourish their children, and undernourished children experience developmental maladies and lack access to basic education that would help them to improve their current conditions in the long run. The concept of food security was developed as a comprehensive approach to the interrelated consequences of poverty, hunger and malnutrition. It evolved from concerns about the availability of food at the national level to a micro approach that considers households' entitlement to food in terms of availability, stability, accessibility and nutritional content. The following World Bank definition of food security is still widely accepted:

> *"Food security is the access by all people at all times to enough food for an active, healthy life"* (The World Bank, 1986)

Food security indicators move in close parallel with poverty indicators. In the past 30 years some regions have achieved remarkable progress in improving food security, while the conditions of scores of people in other regions have worsened. There is confident hope now in Asia, where a large share of the world's population and poor live. The proportion of undernourished in China has decreased from 30 percent in the late 1970's to 12 percent in the early years of the 21st century. In the same period, India's undernourished decreased from 38 percent to 20 percent of its population, Indonesia from 24 to 6 percent, Bangladesh from 39 to 30 percent, Philippines from 27 to 19 percent, and Vietnam from 37 to 17 percent. Yet these countries are home to more than 450 million people who at the end of the day, every day of the year, do not have enough food to cover their daily needs. In contrast to Asia, countries in Sub-Saharan Africa have made little progress toward improving food security. In this region the number of undernourished has increased to more than 200 million people, 80 million more than 25 years ago (FAOSTAT, 2006).

Reductions in world poverty and increases in food security slowed significantly after 1990, although by how much is controversial (Deaton, 2002). World population continues to increase, although at a slower pace than in the past, and achieving food security for all remains a daunting challenge. Between 1980 and 1990, the six Asian countries cited above reduced their undernourished population by more than 165 million people, while in the 12 years since then, they added only another 50 million sufficiently nourished people. At the same time, Sub-Saharan Africa added 43 million people to the undernourished in the 1980's and 37 million more in the 1990's. The slowdown in the trend is further demonstrated in the proportion of undernourished people, which fell in Asia and the Pacific from 32 to 20 percent between 1980 and 1990, and to only 16 percent since then. For the whole developing world, the undernourished fell from 28 to 20 percent before 1990 and to only 17 percent since then (FAOSTAT, 2006). Much work remains for the national governments and the international community if commitments to end poverty and hunger are to succeed.

For millions of people living in the less-developed regions, there is a lot of room to improve the capacity to secure such basic needs as food security, clothing, housing, health care and education. Efforts to remove obstacles that hinder future progress in this direction need to be strengthened and deserve close collaboration between public and private sectors in both the developed and the developing world. Reducing poverty (and therefore hunger and malnutrition) and achieving food security has long been linked to sustained economic growth (Fischer, 2003; Dollar and Kraay, 2002). Given that most of the poor live in rural areas and earn their income from agricultural activities, economic growth in these countries has a strong correlation with growth in the agricultural sector. Therefore, policies to decrease poverty must involve the agricultural sector (Mellor, 1995).

After taking stock of the impacts of the Green Revolution, the role of agricultural technology in reducing poverty and improving food security is apparent. New improved varieties of rice, wheat and maize have lifted millions of small farmers out of hunger since the early 1960's. These new varieties have also created new sources of employment for the rural landless and have saved millions of hectares of marginal land from cultivation with unsustainable practices (Hazell and Ramasamy, 1991). The impacts are even more dramatic when comparing against a counterfactual scenario in which food production and population growth continued at the prevailing rate before 1960. In fact, it has been estimated that the percentage of malnourished children would have increased between 6 and 8 percent without the adoption of these modern varieties (Evenson and Gollin, 2003).

Two types of criticisms have been leveled against the Green Revolution. First, there have been concerns expressed about the negative environmental externalities caused by the increased use of chemicals and irrigation that accompanied the adoption of high-yielding varieties (Robinson and Harris, 2004). Second, income gains were not evenly distributed and were much smaller (if any, some argue) in the marginal land areas, where the poorest of the poor live and where the modern variety package had the least impact. This unequal distribution of gains seems to have contributed to increased income inequality. More extreme views also claim that during the Green Revolution social structures in rural Asia were destroyed (Shiva, 1991). Despite these criticisms, the available evidence suggests that the Green Revolution improved the conditions of millions of people around the world[1].

But the contribution of Green Revolution technologies to poverty alleviation, in some developing regions such in Asia, seems to be fading. Adoption of the modern varieties technological packages have reached their ceiling even in the initially lagging marginal lands, and yields gaps between experimental stations and farms are closing. Although the evidence is still inconclusive, complacency with past achievements may prevent continued poverty reduction and thwart the welfare standards of future population (Pingali et al., 1997; Rosegrant and Hazell, 2000). During the 1990's, several Asian countries continued to reduce poverty by means of introducing economic reforms that improved trade and reduced domestic distortions. Yet the agricultural sector remains an important factor as a source of overall economic growth and also holds a large share of the poor. Therefore, improving its performance is still a major priority for national governments (Vyas, 2005; Rao, 2005; The World Bank, 2005). A new big push in technology is needed, and going on with *"business as usual"* may fail to do it (Pinstrup-Andersen, 2005).

The developments in the past decade suggest that biotechnology is at the center stage for taking on the role of the high-yielding varieties of the 1960's and 1970's. The ability to insert targeted genes to introduce specific traits into crops such as soybean, maize, cotton, rice and others has produced transgenic varieties that are resistant to pests, reduce the use of chemicals, increase tolerance to abiotic stresses such as drought, and improve nutritional quality. Some of

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[1] The term "Green Revolution", intuitively suggesting the image of healthier crops and contrasting with the concept of "evolution", has also a political interpretation. Some claim that when the term was coined in 1968 by Dr. William S. Gaud, then director of the United States Agency for International Development (USAID), it was deliberately opposing the "Red Revolution" that was being fought in the Vietnam War at the same time. Reducing food insecurity was a strategy to reduce unrest in the hunger-prone nations of Asia and gain the will of the population against the tactics of the Communist Party (Jirström, 1996). This rationalization is behind the reason why Dr. Norman E. Borlaug, considered the father of the Green Revolution, was given in 1970 the Nobel Peace Prize (Wu and Butz, 2004).

these crop improvements are difficult if not impossible to obtain with traditional plant breeding methods. Biotechnology has not only produced better crops but has also become a research tool that reduces research costs and accelerates the development and spread of new research products. However, the technique is focus of a much heated debate on two issues: the environmental impacts and related ethical concerns, and the political economy surrounding the production and commercialization of transgenic crops. Regarding the environmental impacts and ethics, it is now accepted that clear scientific information and monitoring is warranted through biosafety procedures. On the other hand, some suggest that blocking the use of the technology based on the precautionary principle may unnecessarily delay access to its potential benefits by poor farmers in developing countries (Pinstrup-Andersen and Schiøler, 2000). Many developing and developed countries, initially wary of biotechnology, have recently begun establishing biosafety procedures to regulate the approval of transgenic crops for planting and commercialization.

From the political economy standpoint, there is something inherently different about the conditions under which biotechnology is reaching farmers compared to Green Revolution technologies. In particular, public and private sector roles and interaction have dramatically changed. The Green Revolution was mostly an outcome of public investments, with most of the technologies being developed by national agricultural research systems (NARS) in association with publicly funded international agricultural research systems (the Consultative Group for International Agricultural Research, CGIAR). The private sector played a limited role, participating in certain seed markets (hybrids) and providing input supplies (chemicals, machinery). The wake of biotechnology and the development of associated intellectual property rights (IPRs) have given rise to a larger private sector involvement in research and development (R&D) of transgenic crops. In fact, much of the increase of agricultural R&D investments in developed countries in the past 15 years is due to the presence of the private biotechnology sector. In developing countries, however, agricultural R&D investments continue to be predominantly public, due to either a weak legal framework for private R&D companies or to an unattractive small market size (Pray, 2002). Some developing country concerns are that property rights and private commercialization of transgenic crops by multinational companies will reduce the benefits of the technology through higher seed prices, and that benefits will not remain in the country. These concerns are also shared by consumers advocates in developed nations, particularly in the European Union, who are battling what they believe is an increasing control of the world's food chain by biotechnology companies (Paul and Steinbrecher, 2003).

Although full reliance on the private sector to develop transgenic technologies is an option, it has the potential of failing to provide the smaller and poorer farmers in marginal lands with timely and appropriate technologies, a revival of the distributional concerns seen during the Green Revolution. The private sector will produce technologies for which returns to research, including the ability to enforce their property rights, are higher. These conditions are predominantly found in favorable environments. Without the presence of the private sector, the allocation of public research resources has relied on producing technologies for the more favorable environments and letting the less-favored areas receive the benefits through factor-market adjustments, as was the case with the Green Revolution in Asia (David and Otsuka, 1994). The presence of the private sector, however, can be seen as a complementary investment freeing up research resources that can then be allocated to produce technologies for the less-favored environments. In this sense, the private sector presence is an opportunity for producing 124long-demanded technologies for marginal environments, reducing their dependence on the spill-over effects from the most favorable environments.

With more than 60 percent of the world's undernourished, the needs for yield-increasing agricultural technologies are high in Asia, where rice is the major crop and a staple food. The International Rice Research Institute (IRRI), in association with the NARS, will play a key role in technology generation. This type of institutional framework produced and disseminated the high-yielding varieties that characterized the Green Revolution. The challenge ahead is to continue supplying appropriate technologies under a new institutional setting, with a stronger presence of a private R&D sector.

1.2. Objectives of the study

This study investigates the potential economic impacts of the adoption of transgenic rice technologies in Asia. The impacts of three different technologies are evaluated: *Bt* rice, a technology developed to combat a common rice insect, the stemborer; drought resistant rice, a technology not yet developed but which could help millions of farmers in less-favored areas; and herbicide resistant rice, a technology that has not been commercialized but could reduce the cost and improve the effectiveness of weed control. Economic impacts are analyzed in terms of global welfare and its distribution across countries and regions. The effects of the adoption of transgenic rice technologies on factor markets are also analyzed, in particular with respect to labor and land markets.

The specific objectives of the study are:

1) To assess the potential impacts of three transgenic rice technologies (stemborer resistance, drought resistance and herbicide resistance) and the cross-country and distributional effects.
2) To address the distributional implications of biotechnologies aimed at favorable and unfavorable environments. While the drought resistance technology is more suitable to the unfavorable environments, stemborer resistant rice has higher impacts in favorable ones.
3) To compare the impacts of technologies developed by the private sector (herbicide resistant rice) with those of technologies that are expected to be public sector releases. This private sector technology allows for the assessment of the effects of monopoly power on the benefits produced by the technologies.

The results of the study are expected to provide more refined estimates of the economic impacts of transgenic technologies in developing countries. Such estimates are also expected to inform research investments by both the public and private sector, and help decision makers in public research institutions to understand the implications of allocating the increasingly scarce research resources to target research to favorable and unfavorable environments.

1.3. Dissertation structure

The dissertation proceeds as follows. Chapter 2 addresses the importance of rice in the world, rice production environments and the role of rice research. Chapter 3 describes the applied computable general equilibrium model used in the study. The model simulates both perfectly and imperfectly competitive conditions, with the latter modeled as a monopoly tax in the market for transgenic seed. Chapter 4 describes the simulated technologies and presents the model results under both the perfect and imperfect competition models. Chapter 5 concludes the study, discusses the most relevant policy implications and suggests further research.

Chapter 2. The rice economy in Asia: Challenges for rice research

This chapter documents the importance of rice in Asia and describes the different rice production ecosystems. The differential impacts of the Green Revolution across favorable and unfavorable environments are discussed, along with the importance that these zones play in defining rice research priorities. The transgenic rice technologies being developed for each environment are then briefly characterized, followed by a discussion of prospects for public and private collaboration for each technology. The chapter concludes with a section reviewing previous literature on the impacts of technological change on rice production.

2.1. The role of rice consumption and production

> *"Toyota means bountiful rice field. Honda means the main rice field"*
>
> (Maclean et al., 2002)

Rice is the most important source of calories for more than 3 billion inhabitants in the world. It supplies 21 percent of the calories for the world population, but in Asia, where more than 90 percent of the world's rice is grown and consumed, at least 30 percent of the daily caloric intake is from rice. In Cambodia, Bangladesh, Vietnam, Lao PDR and Myanmar, per capita annual consumption of more than 160 kilograms of rice provides more than 70 percent of total calories. A significant proportion of rice consumers are the 250 million small farmers who grow rice in Asia and consume half of their own production. Planted on 150 million hectares every year worldwide, rice is the second most cultivated crop (in area) after wheat, but the first in terms of food production (Maclean et al., 2002). China is the largest single rice producer in Asia, harvesting 190 million metric tons in 2000, followed by India with 132 million in 2000 and Indonesia with 52 million metric tons. The populations of these three countries generate large domestic demand, however, and thus external trade in rice from these countries is relatively small. Thailand and Vietnam, on the other hand, generate much lower production levels. However, due to lower internal demand in Thailand and Vietnam, they are the world leaders in rice exports with 6 million metric tons and 4 million metric tons, respectively. This role arises from the relative small share of rice traded internationally, with only six to seven percent of the world's rice production traded internationally in 2000 (table 2.1).

Table 2.1. Rice production and trade**.**

	Production[2]	Exports	Imports
	(Million metric tons in 2000)		
China	189.8	3.1	0.2
India	131.5	1.5	0.0
Indonesia	51.9	1.0	1.4
Bangladesh	37.6	0.0	0.5
Vietnam	32.5	3.5	0.2
Thailand	25.6	6.1	0.0
Philippines	12.4	0.0	0.6
Japan	11.9	0.0	0.6
Rest of Asia	55.9	2.3	7.8
USA	8.7	2.7	0.3
Latin Amer.	20.5	1.6	0.9
Africa	17.6	0.4	4.5
ROW [3]	6.5	0.0	4.5

Source: FAOSTAT, 2004.

Rice is grown in four different production systems, each one requiring a different set of technologies (table 2.2). Since the rice crop requires a large amount of water per unit of biomass produced, the production systems are described in terms of access to and control of water sources. The classification describes the major characteristics and constraints faced in each of four basic ecosystems, although it hides the enormous amount of heterogeneity in rice production, in particular in the less-favorable (non-irrigated) environments[4].

Irrigated rice is grown on bounded fields that guarantee continuing water supply to the rice crop from either rainfall or irrigation in both wet and dry seasons. Productivity during dry seasons is on average higher due to higher solar radiation and to a more accurate water supply

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[2] Production refers to paddy rice only, while trade figures are the sum of paddy, husked, milled/husked, milled paddy and broken rice as it appears in the FAOSTAT database.

[3] Rest of the World.

[4] The remainder of this section is based on Maclean et al., 2002.

control. Better control of the environment in irrigated systems allows higher input use (particularly fertilizers and pesticides) and the cultivation of fertilizer-responsive varieties that contribute to the higher yields seen in these production systems. Crop specialization is high and in many areas two and even three crops are harvested each year. In these irrigated areas adoption of modern rice varieties, like the IR8 developed by IRRI, was widespread in the 1960's and 1970's. Rice grown in irrigated areas amounts to 75 per cent of total world production and for the major volume of rice traded in international and domestic markets.

Table 2.2. Rice production ecosystems.

Ecosystem	Area (% of world)	Production (% of world)	Technology	Farm type
Irrigated	55	75	Water control	Major supply source for urban consumers and trade
Rainfed Lowlands	25	17	Rainfall dependent, lack of water control	Family farms, 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

Source: IRRI, 2002a.

The rainfed lowland rice fields are also bounded but water control is lower because of random flooding (defined as water depths of more than 100cm for less than 10 days) and drought throughout the cropping period. Within the high variability of production conditions found in the rainfed ecosystems, the most favorable ones have yields and productivity that are close to those of irrigated areas, but for the most part uncontrolled flooding and drought prevent farmers from achieving the full potential of high-yielding rice varieties. Conservative, low-risk strategies are used instead to prevent major crop failures and to ensure that a minimum amount of rice is harvested at the end of each season for subsistence. Varieties used in rainfed ecosystems show lower response to fertilizers than those used in irrigated ecosystems. Production technologies are labor-intensive (mainly from farmers' own labor) and use of purchased inputs is low. As a part of the subsistence goal, farmers also grow other crops during the year.

In the upland ecosystems, rice is grown in rotation with other crops and water supply is completely rainfall dependent. The poor quality of soils is a major production constraint, and shifting cultivation is a common practice in some upland rice systems. In areas of permanent cultivation, rice is one of several crops included in a rotation. Use of inputs and productivity are very low and, except in some areas of Brazil, subsistence farmers grow upland rice as a complement to other crops.

Flood-prone ecosystems are characterized by the permanent submergence of the rice plant in water depths of more than 100cm for more than 10 days during the cropping season. This type of ecosystem includes rice crops that are permanent flooded and floating rice. The stressful growing conditions and the very low quality of soils cause low and highly variable yields and rice is the only food crop that can be grown in these ecosystems. Sometimes, irrigated rice is grown in the non-flooding seasons if water control is possible (boro rice). Extremely variable accross years and specific conditions, rice yields and input use in flood-prone areas are very low.

The four rice ecosystems are frequently referred to as either favorable or unfavorable environments. Irrigated ecosystems are considered favorable environments, since the controlled growing conditions allow expression of most of the rice yield potential. The rainfed, upland and flood-prone environments, where lack of water control and poor soils reduce rice yields substantially, are considered unfavorable environments. The latter sometimes are also referred to as fragile or marginal environments.

The proportion of each ecosystem varies by country and affects average national yields and total production (table 2.3). Of the eight major producing countries in table 2.1, only Japan produces 100 percent of its rice under irrigated conditions, although in China the proportion is also high at more than 95 percent. In Vietnam, the Philippines and Indonesia, the share of irrigated rice is around 70 percent. In India and Bangladesh the shares are 58 and 40 percent respectively, while in Thailand only 17 percent of rice production is under irrigation. Thailand produces a high-quality and low-yielding variety of rice (Jasmine rice) that is adapted to the predominant rainfed conditions and receives a price premium in the world markets, making the country a major rice exporter despite the large proportion of unfavorable environments. In the rest of Asia, 62 percent of the rice is irrigated, although this share includes very different conditions such as the high yielding irrigated areas of Pakistan and the low productivity conditions in Myanmar. Other regions of the world include the United States, where 100 percent of rice production is irrigated, Latin America, with 65 percent irrigated rice, Africa with 42 percent, and the Rest of the World with 98 percent (including rice producing countries in the Middle-East and Europe).

Table 2.3. Distribution of total paddy rice production by country and environment (%).

	Favorable	**Unfavorable**			
Country	Total	Total	Rainfed lowland	Rainfed upland	Flood-prone
China	95.8	4.1	3.5	0.6	0.0
India	57.9	42.2	36.9	3.5	1.8
Indonesia	67.1	32.9	28.5	4.4	0.0
Bangladesh	40.9	59.1	51.4	1.7	6.0
Vietnam	72.5	27.5	25.1	1.3	1.1
Thailand	17.0	83.1	78.2	1.5	3.4
Philippines	71.5	28.5	26.9	1.6	0.0
Japan	100.0	0.0	0.0	0.0	0.0
Rest of Asia	62.6	37.3	33.6	2.1	1.6
USA	100.0	0.0	0.0	0.0	0.0
Latin Amer.	64.7	35.3	5.4	28.9	1.0
Africa	42.2	57.8	23.6	21.2	13.0
ROW	97.7	2.3	0.0	2.3	0.0

Source: based on appendix A.

2.2. The impacts of the Green Revolution on the rice economy

New rice varieties and input technologies developed through targeted research were responsible for large gains in productivity that occurred in most Asian regions since the beginning of the Green Revolution in the mid 1960's. As a consequence, world rice production multiplied three-fold, from 215 million tons in 1961 to nearly 600 million tons in 2002, while the area planted increased less than 50 percent, from 115 to 147 million hectares. World average yield increased from 1.9 to almost 4 tons per hectare during the same period (IRRI, 2006). Similar productivity increases achieved in wheat and maize has allowed the supply of staple foods to met demand increases associated with large population growth in developing countries.

Rice research has been historically conducted by an array of international and national institutions led by the International Rice Research Institute (IRRI) in the Philippines. Together with the West African Rice Development Association (WARDA) and the International Center for Tropical Agriculture (CIAT), these international centers are members of the Consultative Group on International Agricultural Research (CGIAR). Their collective mandate is to increase sustainable rice production and contribute to poverty alleviation. Joint investment in basic and applied rice research by the three centers amounted to 48 million dollars in 2001, 16.4 percent of the total annual commodity investment of the CGIAR (CGIAR, 2004). The international rice research system is complemented by national agricultural research institutions (NARs) in each of the countries where rice is grown. The CGIAR centers are providers of basic rice technologies and germplasm to the NARs, who in turn conduct adaptive research to adjust basic technological packages to local conditions. The range of adaptive research has varied from direct adoption of germplasm developed by the international centers to crossing with local varieties and further adjustments in input requirements.

The high-yielding new varieties developed by the rice research system during the Green Revolution tackled the most important constraints of rice production at the time. Rice productivity was low, and adding fertilizer had little impact because the long and weak straw of conventional varieties would not resist the vegetative growth causing the plant to collapse to the ground, a phenomenon called “lodging”. Thus, the research system developed a semi-dwarf rice plant with shorter and stronger straw that was responsive to a more intensive input package, including larger doses of fertilizers and use of irrigation. The firsts such varieties were not rapidly adopted because they were more susceptible to pest infestation, but after pest resistance was incorporated, adoption started to pick up. By the late 1990’s, the totality of rice production in China was coming from modern varieties, and almost 60 percent from hybrid rice, which yields an additional 15 to 20 percent over conventional varieties. In the Philippines, adoption of modern varieties was almost complete at 97 percent. Other Asian countries also recorded impressive adoption figures: 85 percent in Vietnam, 78 percent in Indonesia, 72 percent in India and 62 percent in Bangladesh. In Thailand, the proportion under modern varieties was low (15 percent) because the country grows Jasmine rice for a particular market niche (IRRI, 2006).

While there is little doubt that total rice supply increased more than demand during the Green Revolution, controversy arises regarding the winners and losers associated with the new technologies. Ex-post evaluations have shown that the high-yielding varieties have unequally reached the poorest farmers in the poorest regions, causing some negative distributional impacts (Hossain et al, 2000; Hossain, 2001). Moreover, while income inequality decreased in the adopting regions with access to irrigation sources, those areas with little access to irrigation facilities were unable to widely adopt the new varieties, increasing the income differential with the more favored regions (Hazell and Ramasamy, 1991). Results obtained in other studies fuel the debate. Estudillo et al. (2001) found that inequality in total income distribution in five rice villages in the Philippines increased between 1985 and 1998, the inequality mainly due to the availability of non-farm income sources. Farm income, however, was a progressive source of equality. The study also found that differences in total income between different production environments declined in the period. In a large and comprehensive series of studies across different countries and environments, David and Otsuka (1994) found that despite increased specialization in rice production, higher income from rice and larger land returns obtained in favorable environments with the adoption of modern varieties, households in unfavorable environments have compensated by increasing non-rice income and as a result income distribution has not significantly worsened in most Asian countries. The non-rice income sources were alternative agricultural activities and off-farm labor opportunities, some of them through increased labor demand from favorable areas. They concluded that favorable environments should be targeted by rice research for most of the countries, letting the product and factor market adjustments counterbalance the distributional effects that occur particularly in terms of income. They also suggested that for unfavorable environments, alternative investments with higher returns (i.e., land development) can be made to more effectively address distributional inequalities and that trade-offs between research emphasis on favorable or unfavorable environments must be evaluated on a case-by-case basis. For example, a strong allocation of research resources to unfavorable environments is justified in some South-Asian countries where these ecosystems represent a large proportion of total agricultural area and where few alternative crops can be grown. This last conclusion is strongly supported by Fan and Hazell (2000), who found that decreasing marginal returns to investment in favorable environments have equalized the returns to investment in rural infrastructure, agricultural technology and human capital between irrigated and low potential rainfed areas. However, investments in low potential areas have now a larger impact on poverty reduction than those in irrigated and high potential areas, and are therefore better suited to the public sector's mandate. This same evidence led Hossain (1996, 2001) to argue that the objectives of public research in rice should be to shrink the productivity gaps between environments and to contribute to reduce income inequalities. Hossain also suggests that instead of focusing on incorporating pest and herbicide resistance into varieties, which favor the high-yielding environments, public sector research should concentrate on resistance to abiotic stress (e.g., drought, flooding, salinity) and improved grain quality because these are the problems found in most unfavorable regions.

The rice research system is at a crossroads. With increasingly scarce public resources to meet the ever-expanding demands of the population, research investment decisions have to maintain a balance between contributing to overall growth and reaching the poor. While looking for new means to raise rice yield potentials, priorities also need to attend to equity objectives, a shortcoming of the Green Revolution that societies are committed to address. The future success on achieving the broad mandate of the public research system rests, in part, on properly resolving this issue.

2.3. Research allocation for the rice environments

The rice research system, mainly represented by IRRI, is aware of the issues presented in the preceding section and has already taken measures to address it. Analysis of IRRI's Medium Term Plan for 2003 – 2005 shows that two major research programs, one for favorable environments and another for unfavorable environments, received nearly 26 million dollars each for the entire planning period, representing 65 percent of IRRI's budget (IRRI, 2002b). The most recent Medium Term Plan for the 2006 – 2008 triennium increases the allocation for favorable and unfavorable environments programs to roughly 36 and 37 million dollars respectively, keeping the share at 65 percent of IRRI's total budget (IRRI, 2005). Unstable funding imposes additional pressure on IRRI to define priorities and concentrate on those activities that best support the achievement of the Institute's mandate. The description of two projects on genetic enhancement of rice in IRRI's Medium Term Plan throws some light on where public rice research is heading. One of the projects targets favorable environments while the other focuses on fragile environments. The 2003 – 2005 Medium Term Plan allocated 7.4 million dollars to the former and 14.3 million to the latter, a ratio of 0.5 between them. The ratio was 0.67 in 2001, and is 0.72 for the 2005 – 2008 Medium Term Plan. The changing ratio may represent an indication that budget cuts affect more research on favorable environments while trying to stabilize research funding for fragile environments. While sending the message that unfavorable environments are already a research priority, the figures also highlight the debate within the public research sector on whether research should target favorable, high-yielding environments or marginal environments. The dichotomy does not only arise because of the double mandate of increasing rice production and reducing poverty, but also because scarce resources force the rice research system to consider the efficiency with which this mandate is achieved. In most cases, research aimed at less productive environments has higher risks (and therefore lower probability of success) and lower expected adoption rates due to the higher heterogeneity of unfavorable environments. This lower adoption rate also means higher costs and lower pay-offs for research investment, which could be an issue if research funding is based on efficiency criteria only. On the other hand, research for favorable environments helps increase food production faster and reduces food prices for urban consumers, while keeping farmers' profits at reasonable levels by reducing unit costs. In policy terms, then, the question is whether public agricultural research should be concerned about distributional impacts for producers while developing technologies that improve the efficiency performance of crops.

On a narrower regional basis, research allocation between the different environments becomes a more subtle issue and IRRI's criteria cannot be taken across-the-board in the different countries where rice research is conducted. The broad decision by IRRI to equally allocate funding between favorable and unfavorable environments may be justified if one considers that the overall proportion of land occupied by each of them is roughly 50 percent (see table 2.2). However, conditions are different in each of the major rice producing countries. While China has 96 percent of its 30 million hectares of rice under controlled irrigation, in India more than 42 percent of its 44 million hectares of rice depend on rainfall, in Indonesia 33 percent (more than 5 million hectares) and in Bangladesh nearly 60 percent (more than 8 million hectares). In Vietnam, almost 50 percent of its 7.6 million hectares are non-irrigated and in Thailand more than 80 percent out of 10 million hectares are also rainfall dependent (appendix A). Thus, priorities in each region are different according to their proportion of unfavorable environments, and the pressure on the international rice research system from each national counterpart needs to be carefully balanced to make sure that all demands are properly assessed.

2.4. Rice biotechnologies and the rice environments

As rice yields reached their full potential in the more favorable environments, productivity growth slowed during the 1990's. Research institutions are exploring new ways to continue to develop improved rice technologies. Biotechnology has emerged as a modern research tool that can create the products needed for the next leap in productivity and solve the more difficult rice production constraints experienced in unfavorable environments. Since the first *Bt* cotton crop was planted in 1996 in the United States, the global area of transgenic crops has been increasing every year, as more farmers in more countries continue to adopt them. In 2005, more than 90 millions hectares of transgenic crops were planted in 21 countries by 8.5 million growers, of which 90 percent were poor farmers in developing countries. Varieties of soybean, maize, cotton, canola, squash, papaya and, for the first time, rice, have been genetically modified with genes conferring herbicide tolerance and insect resistance and are commercially available in the markets (James, 2005). The concept of an ongoing Gene Revolution is becoming popular (Wu and Butz, 2004).

Understandably, the Green Revolution pursued productivity goals because more food was urgently needed. However, although the sense of urgency cannot be completely disregarded, demands are now more broad and complex. If the Gene Revolution is to be successful it needs to address issues that were largely ignored by the Green Revolution, such as negative environmental externalities and unequal distribution of gains (Evenson, 2002). Wu and Butz (2004), drawing on lessons learned from the Green Revolution, identified four challenges for the Gene Revolution: a) resulting technologies must be affordable for farmers in developing countries, b) large investments by the public sector are required, c) agricultural development must be considered a priority by recipient and donor countries, and d) developing countries must assess the full risks and benefits of biotechnology. The agricultural sector is now required to produce not only more, but also better food, without damaging the environment and while improving the lives of small farmers and the rural poor. Societies in both developed and developing countries are calling for inclusive agricultural growth (Dollar and Collier, 2002).

Some potential negative externalities in the environment have been associated with biotechnology. For instance, gene migration from transgenic plants into the environment, causing unexpected changes in the biology of non-target plants (i.e., weed and pest resistance), has been raised as a potential indirect effect that could negatively impact the environment. Biotechnology-based research processes also raise concerns about possible indirect effects on food safety and human health[5]. In many regions, notably the European Union but also to some extent in other countries such as Japan and the Philippines, concern over food safety has resulted in very low acceptance of transgenic products amongst consumers (Verdurme et al., 2002). In some countries, the precautionary principle has been invoked to ban the production and commercialization of transgenic products. These public concerns increase the uncertainty of private returns and raise the research costs of the public R&D sector as well. Moreover, they also increase farmers' uncertainty in terms of adopting new transgenic varieties.

Research priorities in the rice sector have incorporated the food safety, environmental and equity demands into rice research programs. The expanded goals of rice research are now to increase the yield potential of rice varieties, to reduce the productivity gap between favorable and unfavorable environments, and to enhance the quality of the rice grain (Hossain, 2001; Khush, 2001). In accordance with these goals, rice biotechnology research has focused on improving yields and reducing unit costs of production, increasing stress-tolerance to drought, salt, freezing and biotic infections, and improving grain quality and nutritional contents (vitamin A, iron and zinc).

Both public and private institutions are currently conducting research to produce genetically modified rice varieties. Two private firms, Bayer and Monsanto, have both developed cost reducing herbicide-resistant varieties. Liberty Link® technology (Bayer) is resistant to glufosinate, a herbicide that can control red rice in the main production areas of the United States. The Roundup Ready® technology developed by Monsanto is resistant to glyphosate (Giannessi et al., 2002). Neither of these varieties, however, have been commercially released due to market policies established by the United States Rice Federation (USA Rice Federation, 2006). If a herbicide resistant rice variety were developed for Asian conditions, it is likely that

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[5] de Kathen (2000) describes several health risks associated with genetically modified organisms.

adoption would occur in those areas where rice is direct seeded, as opposed to transplanted (De Datta, 2004).

In the public research sector, IRRI has developed a *Bt* rice variety by introducing genes from *Bacillus thuringiensis* into selected germplasm to produce toxins for insect resistance[6]. The technology is aimed at controlling the stemborer, a caterpillar pest that causes significant yield losses in Asia. The *Bt* genes were initially acquired by IRRI from two private biotechnology firms, Novartis (Switzerland, now part of Syngenta) and Plantech (Japan) (IRRI, 1997). Until recently, *Bt* rice varieties were not commercially available in any region. It is only in 2005 that *Bt* rice officially started to reach farmers' fields in Iran in very limited quantities (four thousands hectares), with the purpose of producing seed volumes for commercial release in upcoming seasons (James, 2005). China has also produced four rice varieties that are insect-resistant using both the *Bt* gene and a cowpea trypsin inhibitor (*CpTI*). These varieties are still in pre-production trials, and it is believed that China's authorization for commercial release could trigger similar decisions about genetically modified rice in the rest of the world. Farm-level data in China on *Bt* rice show that benefits include improvements in productivity (up to 9 percent) and as much as an 80 percent reduction in pesticide use. Farmers also reported lower adverse health effects caused by reduced pesticide intoxication (Huang et al., 2005)[7]. The benefits from *Bt* rice are expected to accrue mostly to irrigated environments, where the larger vegetative growth of the plant attracts insects and generates larger crop losses.

Due to the complexity of the problem, IRRI is using novel approaches in order to address drought constraints in unfavorable environments. Their strategy combines traditional breeding methods, crop management techniques and biotechnology. Progress has been made toward identifying genes that influence drought resistance. The goal of this research program is to create a variety that is able to maintain grain quality and produce high yields in water-reduced conditions. Such a development would benefit rice growers in unfavorable environments where most of the poor live and where *"a 1-year drought creates a 5-year problem"* (Barclay, 2005).

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[6] *Bacillus thuringiensis* is a soil-inhabitant bacteria that produces crystal proteins with insect toxicity effect (toxins). The specific *Bt* genes that have been introduced in rice varieties are the *Cry* forms *CryIA(b), CryIA(c) and CryIIA* (Datta, 2004).

[7] It is interesting to note that these results have been questioned and debated. Greenpeace and environmental scientists have concerns about assessing benefits without proper consideration of environmental impacts and technology costs. Scientists from IRRI, on the other hand, warn that farmers' perceptions about the technology can influence pest management practices beforehand, and therefore not all of the pesticide use reductions may be attributable to the insect-resistance varieties (Science Letters, 2005).

Public and private rice biotechnology research also includes quality-enhancing objectives. In 2002, the CGIAR launched a major research program in several selected crops to improve their micronutrient content using traditional breeding methods and biotechnology (CGIAR, 2002). The program has now developed into an international and interdisciplinary effort to produce nutrient-dense crops and includes rice as one of the priority crops. The varieties released under this program are initially targeted for Bangladesh, India, Indonesia, Vietnam and the Philippines (Harvestplus, 2006). One of the most important deficiencies of rice-based diets is vitamin A, which affects more than 400 million rice consumers in the world. The deficiency causes irreversible blindness to more than five hundred thousand children annually. Research has focused on improving the contents of β-carotene, a precursor of vitamin A, in the rice grain, but until now success had been limited using a carotenoid source from the daffodil *psy* gene. The amount of less than 2 μg of β-carotene per gram of rice produced with the early Golden Rice was not enough to offer a viable solution to vitamin A deficiency. Using a different *psy* gene found in maize, scientists from Syngenta reported in 2005 that a new line of rice (Syngenta Golden Rice 2, SGR2) was developed containing between 20 and 30 μg of β-carotene per gram of rice, a sufficient concentration to supply the daily requirements of vitamin A for rice consumers (Paine et al., 2005). This technology offers hope to millions of poor people whose diet is based on rice, and the challenge is now to develop it into commercial varieties that can be planted in farmers' fields.

There are several other rice research programs relying on biotechnology to remove constraints that are difficult to address with traditional research methods. Transgenic rice varieties are being developed to resist bacterial leaf blight (*Xa21* gene), sheath blight (Chitinase), yellow mottle virus (*ORF2*), and to confer tolerance to salt and low temperatures (*TPSP, DREB*). Nutritional improvements are sought for enhanced contents of iron and zinc (ferritin). C_4 rice with enhanced photosynthesis efficiency is also being developed. These technologies combat constraints found in both favorable and unfavorable production conditions in developing countries (Datta, 2004). The public research sector in these countries is engaged in a significant effort in the biotechnology area, but more is needed to strengthen collaboration between national and international rice research systems and between public and private sectors, both in research and for future development of the final products that are required in farmers' fields (Cohen, 2005).

2.5. Current state of public and private interaction in rice biotechnology research

Despite moderate (or even stagnant) spending growth by the public sector, investments in agricultural research in developed countries have increased significantly in the past 20 years, driven by increased participation of the private sector. Private R&D investment growth rates have more than doubled as compared to investments in the public sector, and private expenditure is almost half of the total R&D expenditure in agricultural research. Private biotechnology companies have been major players in this trend, motivated by the potential returns obtained from investments in proprietary technology (Alston et al., 2001). Although the private sector was present during the Green Revolution as supplier of chemicals, machinery and hybrid varieties, the ability to claim intellectual property rights over plant varieties developed through biotechnology processes boosted private R&D investments after the mid-1980's.

In developing countries, however, private R&D investments have lagged far behind the public sector, and represent only about 10 percent of total agricultural research expenditures. The private sector has not been a significant source of growth for agricultural R&D investments in developing countries, and total R&D investments in these countries are already at very low levels compared to developed regions. To improve agricultural innovation and promote agricultural growth, developing countries need to: a) increase public investment in agricultural R&D, to produce public technologies with high social rates of return, and b) create adequate conditions to attract private investment in agricultural R&D for marketable technologies. Meeting these conditions requires enforceable IPR laws, sufficient market size, a fostering business climate, and a strong public sector that provides R&D inputs (such as basic knowledge and trained human resource) and helps to maintain private R&D costs at a manageable level (Pray, 2002).

Until recently, research priorities in the public sector were focused on productivity constraints, a legacy of the needs that triggered the Green Revolution. New demands, however, are driving public research into relatively new areas while coping with funding scarcity and a broader mandate. These demands include increased environmental and food safety concerns, and the availability of agricultural technologies for small farmers and less-favorable areas. The public sector is obliged to adapt to this new institutional mandate for the successful delivery of public goods (Byerlee et al., 2002).

The presence of a strong private agricultural R&D sector creates larger areas of overlap with the public sector. Such overlap also provides an opportunity for the public sector to concentrate on areas where private sector returns are lower and therefore a strong private investment is not expected. Reinforcing this strategy is the fact that some of the areas that might be neglected by private research are also part of the new demands facing the public sector (such as environmental and food safety concerns, and non-commercial agriculture). Enhanced public and private sector research interactions hold the promise of increasing delivery of new technologies to farmers. Although at much smaller scale than today, this type of interaction was in place during the Green Revolution, when the private sector concentrated on producing hybrid varieties of maize and sorghum, while the public sector produced open pollinated public varieties of wheat, rice and maize.

Public-private interaction in biotechnology, however, has been somehow blurred by other issues that arise due to the proprietary nature of the technology. There have been concerns that the IPR which private multinational companies hold over transgenic seeds and some biotech processes could result in pricing strategies that price transgenic seed beyond the reach of poor farmers in developing countries. This monopoly power could in turn lead to reduced adoption and prevent developing countries from reaping the full technology benefits. At the same time, multinational biotechnology companies, with their focus on commercial crops, would not offer solutions for small scale farmers and for less-favorable lands. Finally, intellectual property rights and genetic use restriction technologies lead to concerns regarding the exploitation of, and access to, genetic resources (Pray and Nasseem, 2003). These issues have led the public sector in several developing countries, and in particular the public international research sector represented by the CGIAR, to engage in biotechnology research in order to close a gap that multinational biotechnology companies may not be willing to fill. A sense of confrontation grew over these issues, and development of productive public-private partnerships has been slow. Spielman and von Grebmer (2004) argue that constraints for a successful public-private interaction also come from different incentive structures, insufficient minimization of cost and risks of collaboration, inability to reduce competition over key assets and resources, and insufficient knowledge of successful partnership models.

The path rice biotechnology research has followed has been influenced by these issues, but at the same time shows promising outcomes from dual participation of both the private and public sectors. Initially, significant public and private investment and collaboration was undertaken in the description of the entire rice genome. Being the smallest of all cereal genomes, biotechnology scientists thought it would serve as a benchmark for work on other major crops. In 2000 Monsanto, in collaboration with the University of Washington (Seattle), first released a draft genome of the *Japonica* subspecies. In 2001, the Beijing Genomics Institute (BGI) released a draft sequence of the *Indica* subspecies and a few months later, in 2002, Syngenta announced a new draft sequence of the *Japonica* subspecies. The BGI and Syngenta groups applied a different technique ("shotgun") than the traditional approach used by Monsanto (Normile and Pennisi, 2002). The rice genome sequence was finally completed in December 2004 and described in 2005 by the International Rice Genome Sequencing Project (IRGSP), an international effort of public institutions led by Japan (IRGSP, 2005). Despite this milestone resulting from a large level of mutual cooperation between public and private institutions, the controversies and issues that had to be sorted out are clearly exemplified by the fact that the journal *Science* agreed to publish (and explained why) the information reported by Syngenta, without requiring the company to submit a copy of the rice genome sequence to the journal's public database, GenBank.

The motivation of private companies to sequence the rice genome was not to obtain high returns from genetically engineered new crop varieties. "Nobody makes money on the rice seed", is the belief of a rice scientist quoted by Normile and Pennisi (p. 33). Despite developments in herbicide resistant rice targeted for the irrigated and commercial areas of the United States, private sector motivation lays in the potential for translating the rice knowledge to more profitable crops, such as maize, wheat and barley. However, private efforts in rice research are winding down because the series of private mergers that occurred in the past have produced low returns and it has also been difficult to overcome public and regulatory hurdles. As a result, multinational companies are refocusing their research efforts on crops and regions with higher returns. Thus, the public sector may prove to be the key agent in future progress in rice biotechnology research (Barry, 2005).

These appear to be busy times in which rice biotechnology research, both private and public, is relocating resources and redefining priorities, with the public sector taking a greater role. For instance Dr. Gerard Barry, a former biologist at Monsanto, is now head of the Intellectual Property Management Unit at IRRI, in what seems to be an effort to strengthen how patent protection and IPR issues are resolved by the public sector. Adequate capacity to manage IPR is relevant not only for development of commercial transgenic products but also for the use of biotechnology tools and techniques that are common inputs in the research process.

With significant progress made in rice biotechnology research and the ensuing stock of information publicly available, opportunities to successfully tackle production constraints for distinct rice environments are increasing. While private decisions may remain to eschew future efforts, it is clear that the public sector has benefited from the cooperation with private entities and that conflicting interests should be carefully addressed to the benefit of all parties involved. Blocking private participation due to concerns about the monopoly power of firms can prevent farmers from realizing unit cost reductions that in the aggregate may be larger than the private rents. If the latter turns out to be true, then public policies could concentrate on creating conditions to attract private firms as providers of technologies for commercial production systems, while public research systems attack production constraints encountered by small farmers and in less-favorable environments, increase the stock of basic knowledge and develop improved germplasm. Assessments of potential research benefits are crucial to inform decision makers of the economic trade-offs involved and to support strategic investments. Understanding global and regional economic impacts of technologies that favor specific environments supports resource allocation decisions at the international and national level. Evaluating the magnitude of private benefits also helps to determine the incentives available for firms and the relevance of potential distortions arising from their monopoly power. These are the areas in which the present study intends to shed significant new light.

2.6. Methods to evaluate impacts of rice technologies

This section first presents a review of previous literature evaluating the impacts of agricultural technology across different environments. Next, more recent work assessing the impacts of biotechnologies with general equilibrium models is reviewed, particularly those studies that have primarily focused on rice[8].

2.6.1. Agricultural technology and environments

The welfare implications of differential adoption of agricultural technologies across environments have been assessed in previous studies using both partial equilibrium and general equilibrium approaches. For example, Mills (1997) employed a single-commodity, multi-market economic surplus model to investigate regional changes in economic surplus as a result of adopting four sorghum technologies in four agro-climatic zones in Kenya. The expected technological change and adoption patterns were assumed to vary between regions and for each type of technology. To account for the market clearing conditions in each region and the fact that some regions were net producers while others were net consumers, the spatial distribution of prices was modeled by including price wedges between each zone. Scobie and Posada (1978) 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 irrigated, upland, and rain-fed areas of Colombia. Declining rice prices were found to be the major factor in improving income of the urban poor, where rice is a major staple food. Declining prices also worsened the income position of producers, particularly those in upland and rainfed areas not benefited by the innovation. The Scobie and Posada empirical model focused on net benefits, with national research costs accruing to income groups according to their contribution to rice research funding through taxation. That particular structure of the model increased the benefits of the urban poor because of their lower tax burden relative to other groups. Coxhead and Warr (1991) used a general equilibrium model to analyze 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 (1993) also applied a general equilibrium framework to examine distributional effects of adopting wheat technologies in irrigated versus rain-fed areas of Pakistan. Effects of wheat technology adoption were analyzed for three agricultural household types (small and large farms and landless) and for rich and poor

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[8] For a recent survey on economic impact studies of transgenic crops in developing countries, see Qaim and Matuschke (2005).

urban groups. Technological change was assumed to differ between technologies and across regions and the results were compared under both endogenous wheat prices and government intervention scenarios.

The income distribution effects of technological change in rice in the Philippines were investigated earlier by Hayami and Herdt (1977), in a model that accounted for semi-subsistence agriculture and therefore partial consumption of farm output, a common feature in developing countries' agriculture. Their model assumed two types of farmers, small and large, who differ in their proportion of farm output that is sold to the market. They concluded that technological change promotes a more equal distribution of income, with small farmers, landless workers and urban poor benefiting from increased production and reduced rice prices, while large farmers' income is reduced. Since the model concentrated on income effects, welfare measures were not compared and therefore the welfare distribution was not assessed directly. Ahmed and Sampath (1992) used a modified version of Hayami and Herdt's partial equilibrium model to estimate poverty reduction and income effects of technological change in irrigated rice in Bangladesh. Their findings show that poverty measures improved due to the innovation, although income distribution within the farm sector deteriorated.

These studies suggest that the question about the distributional effects of technological change in agriculture is empirical. Although, in general, a shift of the production function in agriculture improves welfare measures and distribution of income through market effects, the specific magnitude and direction of the changes are sensitive to the type of technological change analyzed, the region under consideration and the commodity to which it applies. These studies also show that general equilibrium models can be used to account for income effects and for factor and product market adjustments that may occur, such as production substitution possibilities between rice and alternative crops.

2.6.2. Agricultural biotechnology and general equilibrium models

General equilibrium models have been used to evaluate the impacts of biotechnology to account for the different simultaneous effects of sectoral reallocation, inter-regional distribution, preference shifts and biased technological change. Van Meijl and van Tongeren (2004), for example, used a modified version of the Global Trade Analysis Project (GTAP) to analyze potential benefits of international knowledge spill-overs through adoption of transgenic soybean and corn, and the Common Agricultural Policy (CAP) in the European Union (EU)[9]. They concluded that although the CAP protects EU farmers from income variability, the EU as a region foregoes significant benefits from technological change.

Other ex-ante general equilibrium studies have focused on rice biotechnologies. Anderson et al. (2002) estimated the economic effects of adoption of transgenic rice, corn, soybean and cotton in a sixteen-region, seventeen-sector aggregate version of the GTAP standard model. Their model assumed a primary factor and intermediate input increase in productivity of 5 percent and perfect competition in the transfer of the technology. For rice, they identified the following adopting regions: North America, the Southern Cone of Latin America, China, East Asian non-industrialized countries (NICs), India and the Rest of South Asia. Their results indicated that impact in each region depends on the proportion of paddy rice that is processed, and the share of processed rice in total consumption. The estimated total Equivalent Variation (EV) was 6.2 billion dollars. The welfare decomposition found that most of the impact was generated by technical change effects, although for specific regions, allocative efficiency effects were large when production shifted away from a previously highly-protected sector. Specific regions may have trade gains or losses from the productivity shock. The highly aggregated regions of the model, however, do not allow more detailed comparisons between specific countries, and between rice production ecosystems. The authors suggested that further research could include differentiating economic impacts between specific sectors in different countries, modeling of negative and positive externalities (i.e., environmental effects, quality-enhancing technologies) and the effects of biased technological change.

Anderson et al. (2004), also using a version of the GTAP model, compared potential welfare effects between two types of rice technologies: productivity-enhancing and quality-enhancing transgenic rice. Although significant benefits were estimated from a transgenic rice inducing productivity shocks, the potential effects expected from a transgenic rice variety with improved quality (such as Golden Rice) were found to be several times larger.

In another study based on GTAP, Huang et al. (2004) evaluated benefits from adoption of *Bt* cotton and transgenic rice in China with policy experiments simulating a ban on imports of

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[9] The GTAP model is an applied general equilibrium model integrating software and a large database with several sectors and regions. A more detailed description of the model is provided in Chapter 3.

grains from China and the costs of labeling. They found joint welfare gains from both transgenic crops to be in the order of five million dollars, with rice providing four times more benefits than cotton, due to the size of the rice sector in China’s economy. They also estimate that these gains more than cover the country’s research investments in biotechnology and that they are not significantly reduced by trade bans or by imposing voluntary labeling.

While either a partial or a general equilibrium framework can be applied to assess distributional effects of rice technologies across countries and environments, 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. This supports the selection of a general equilibrium model for the study, which is described in detail in the following chapter.

Chapter 3. Methods and empirical model

This chapter presents the structure of the empirical model used in the study and the underlying economic theory. The first section introduces basic general equilibrium concepts and the microeconomics foundations of monopoly power. The section also discusses how monopoly power can be accounted for in analytical models. The second section describes the theory and assumptions underlying the applied GTAP model and basic information for the interpretation of results from policy experiments. Finally, the last section details the model assumptions and data that support the construction of the empirical GTAP model.

3.1. General equilibrium: Basic concepts

As defined in Varian (1992), general equilibrium theory focuses on how goods are allocated amongst different agents in an economy according to their relative prices. In a competitive general equilibrium where multiple firms and consumers are price takers, consumers maximize utility and firms maximize profits, constrained by income and production technology, respectively[10]. All prices are variable and all markets have to clear. Walrasian equilibrium is achieved when aggregate consumer demand for goods is equal to aggregate production plus aggregate initial endowments. Formally, let $\boldsymbol{x_i(p,y)}$ be the individual i's vector of demand functions for goods as a function of the price vector $\boldsymbol{p}$ and income y, for $i=1,\dots,n,$; $\boldsymbol{q_j(p)}$ is the supply function by the j^{th} firm in the economy, $j=1,\dots,m$; and $\boldsymbol{w_i}$ the individuals' initial endowments; then the general form of the aggregate excess demand function $\boldsymbol{z(p)}$ can be represented as:

$$z(\mathbf{p}) = \sum_{i=1}^{n} x_i(\mathbf{p}, y) - \sum_{j=1}^{m} q_j(\mathbf{p}) - \sum_{i=1}^{n} w_i. \qquad (1)$$

Walras' law states that in equilibrium, $\boldsymbol{pz(p)} = 0$ for all p, implying that the budget constraint is satisfied and the value of excess demand is zero.

In applied models, the purpose of general equilibrium analysis is to investigate shocks in one or more markets of the economy and how these shocks affect vertically or horizontally related

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[10] For the existence and uniqueness of equilibrium, non-behavioral constraints such as continuity in the excess demand and supply functions need to be considered.

markets through changes in relative prices. The general equilibrium framework implies that changes in equilibrium prices and quantities in the market subject to policy experiments affect equilibrium prices and quantities in related markets because agents decide on the allocation of resources based on relative prices. Changes in relative prices in product and factor markets also affect income generation and the associated agents' demand. At the same time, substitution along production possibility frontiers of firms occurs while the optimal input mix changes. Changes in relative prices between domestic and imported goods also modify the trade pattern of the economy (import/export ratios). The linkage between markets through prices is the distinctive feature of general equilibrium compared to partial equilibrium models, where only the prices of the markets under consideration are allowed to vary and prices in related markets are assumed exogenous. This relationship between markets in general equilibrium is usually described through a system of equations in applied models.

3.1.1. Structure of applied general equilibrium models

Applied (or computable) general equilibrium models consist of a system of equations linking production, demand and income of different agents in the economy; export supply and import demand; market clearing constraints; price equations; and accounting identities. Robinson (1989) identifies four techniques that are traditionally used to solve general equilibrium models:

a) Fixed point algorithms to find a point in a mapping of prices to prices,
b) Solving a set of non-linear algebraic equations by mathematical techniques,
c) Linearization of the model and solving by matrix inversion (the Johansen technique),
d) Solving a non-linear programming problem.

Data to calibrate and solve applied general equilibrium models can be obtained from Social Accounting Matrices (SAMs) describing the structure of the economies in the model. The SAM also provides information to derive basic parameters that are required in most applied models (i.e., cost and expenditure shares and elasticities). Although general equilibrium theory is based on perfectly competitive behavior by all agents and standard neo-classical assumptions, applied models can accommodate a variety of departures from standard theory (Robinson, 1989). These departures include, for instance, specifying variable elasticities of substitution between goods produced and demanded, and between factors of production (elasticity-structuralist models);

changing market assumptions (micro-structuralist models); and introducing macro constraints (macro-structuralist models)[11]. Some of the most common micro-structuralist modifications of general equilibrium models are fixing sectoral capital, prices (particularly wages) and exchanges rates. Introducing any of these features implies modifying the general model closure (selection of exogenous and endogenous variables). For instance, fixed wages can be represented by dropping the labor supply equation and specifying in the corresponding market constraint that labor demand is always met by supply. When some product prices are fixed, they create markups and excess profits. The most common solving technique is then to specify quantity adjustment mechanisms and to drop the profit maximizing supply behavior assumption. Since general equilibrium models calculate relative prices, when a fixed price exists it must be related to another variable (for example, the numeraire), and market clearing mechanisms must be specified since prices are no longer free to adjust[12]. Markups and rationing schemes also represent macro constraints since they impose a link between nominal and real variables, while pure neo-classical general equilibrium models only deal with real variables. When using a mix of fixed and flexible prices, the latter bear the burden of any adjustments in the models.

Sadoulet and de Janvry (1995) define applied general equilibrium models as static medium-term equilibrium models. They are static because, as in partial equilibrium, the transition between two different equilibria (before and after the shock) is not modeled. Because the transition period continues until all markets are cleared again, they are medium-term models, with no major changes in the fundamentals of the economy being represented (like changes in total endowments or preferences). Once all changes are in place, a new equilibrium is then reached in the post-shock situation.

The equations in applied general equilibrium models are derived from behavioral assumptions of the economic agents (e.g., firms, households and government), from market clearing conditions, and from macroeconomic constraints such as balance of payments, savings-investment balance, government budget constraint and factor supply conditions (i.e., full employment or assumptions about factor mobility). Construction of the model begins with the

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[11] Robinson (1989, p. 915) attributes to Hollis Chenery the assertion that "…most developing countries are better characterized as a mix of elasticity and micro-structuralist models…" and that results from strictly neo-classical general equilibrium models applied to developing countries can be misleading for policy analysis due to the existence of widespread market imperfections.

[12] Robinson (1989) also mentions that existence proofs may become an issue with fixed prices but have not been reported as such in applied models.

preference representation of households and governments and the specification of production technologies for firms. By solving the appropriate maximization problem for each agent, the initial choice of functional forms determines consumption, input demand and product supply equations. Consumers and the government maximize utility subject to budget constraints, and firms maximize profits subject to technology constraint.

Formally, consider a single consumer in an *n*-goods economy. The demand system is derived as a solution to the following problem:

$$\underset{\mathbf{q},\lambda}{Max}: u(\mathbf{q}) + \lambda(I - \mathbf{p}'\mathbf{q}). \tag{2}$$

In this system, consumer's utility *u(.)* is a function of the vector of quantities consumed ***q***, λ is the Lagrange multiplier, *I* is consumer's income, and ***p*** is the vector of *n* prices. The solution to the maximization problem yields the Marshallian demand equations for each good *i* as a function of *all* prices and income:

$$q_i = q_i(\mathbf{p}, I), \qquad for\ i=1,\dots,n. \tag{3}$$

Sadoulet and de Janvry (1995) identify two different approaches to solve applied general equilibrium models. The first is to derive complete demand and supply systems from the initial specification of functional forms for consumers' preferences and producers' profit or cost function (which represent technology). The derived system of equations can then be solved regardless of the starting equilibrium point in the model, and the result constitutes a new starting point for subsequent analysis. The second approach is pragmatic and arises from the difficulty in obtaining information about the true functional forms that describe agents' behavior, needed in the first approach. Comparative static analysis is derived from log-linearization of demand and supply systems. Shocks under this approach are only marginal and do not represent a new equilibrium since all the model equations are a tangent hyperplane approximation to the true functional form. This approach can be mathematically derived by complete differentiation of the generalized form for demand equation (3) above. After some manipulation, the log-linearized form of the demand equation becomes:

$$\dot{q}_i = \sum_j \varepsilon_{ij}\dot{\mathbf{p}}_j + \eta_i \dot{I}\ , \qquad for\ all\ i, j=1,\dots,n. \tag{4}$$

Equation (4) represents the changes in a consumer demand system in local elasticity form, with the upper dot representing percentage changes of the variable. The structure of the system implies *n* income elasticities η_i and n^2 price elasticities ε_{ij}[13].

Appropriate assumptions on consumer behavior can be imposed to reduce the number of parameters in the demand system. Two commonly used assumptions are homogeneity of degree zero of prices and income, and symmetry of Slutsky cross-price substitution effects. Formally, these conditions are expressed as follows:

$$\sum_j \varepsilon_{ij} + \eta_i = 0, \qquad \textit{homogeneity condition.} \qquad (5)$$

$$\varepsilon_{ij} = \frac{s_j}{s_i}\varepsilon_{ji} + s_j(\eta_j - \eta_i), \qquad \textit{symmetry.} \qquad (6)$$

The symmetry condition accounts for the income effect (the second term in the right hand side with income elasticities $\eta_{i,j}$), and for the substitution effect through the budget shares $s_{i,j}$. Another commonly used assumption is that of separability, which further reduces the number of parameters in the model.

Consider now the maximization problem of firms. Input demand, factor demand, and supply equations are derived from the corresponding profit maximizing or cost minimizing problem. For producers choosing a certain level of output *y*, given output price *p* and input price vector ***w***, the problem is:

$$\underset{y}{Max}\,\pi = py - C(\mathbf{w}, y). \qquad (7)$$

In this problem, *C(**w**,y)* is the cost minimizing function associated to output level *y*. By Sheppard's lemma, input demand functions are derived differentiating the cost function with respect to input prices:

$$q_i = \frac{\partial C(\mathbf{w}, y)}{\partial w_i}, \quad \textit{for all } i = 1,\ldots,n. \qquad (8)$$

Again, total differentiation of equation (8) yields the log-linearized form of input demand equations:

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[13] If *i=j*, own-price elasticity; cross-price elasticities otherwise. The latter represents links between different markets.

$$\dot{q}_i = \sum_{j=1}^{n} \varepsilon_{ij} \dot{w}_j + \phi_i \dot{y} , \qquad \textit{for all i,j = 1, ... ,n.} \tag{9}$$

Note that $ø_i$, the output elasticity of input demand, depends on the assumptions about technology. With constant returns to scale, $ø_i$ equals one, while with increasing returns to scale $ø_i$ is less than one. Making use of the identity $\varepsilon_{ij} = \theta_j \sigma_{ij}$[14], where σ_{ij} is the elasticity of substitution between inputs *i* and *j*, and θ_j is the cost share of input *j* in total cost, and substituting in equation (9) above, one obtains:

$$\dot{q}_i = \sum_{j=1}^{n} \theta_j \sigma_{ij} \dot{w}_j + \phi_i \dot{y} . \tag{10}$$

The key parameters in equation (10) are the elasticities of substitution between inputs, which is a common form to represent technology properties. Combined with an additional assumption of nested functional forms, this specification reduces data requirements in applied models by specifying only one parameter for each nest instead of for all inputs.

The maximization problem for the producer also leads to the first order condition from which price equations can be derived. The first order condition equates output price to marginal cost:

$$\frac{\partial \pi}{\partial y} = p - \frac{\partial C(\mathbf{w}, y)}{\partial y} = 0 . \tag{11}$$

Perfectly competitive markets characterized by free entry and exit of firms also imply that average cost and marginal cost are equalized (as in constant returns to scale technologies). Therefore we can write:

$$\frac{\partial C(\mathbf{w}, y)}{\partial y} = \frac{C(\mathbf{w}, y)}{y} = \frac{C(\mathbf{w}) y}{y} = C(\mathbf{w}) . \tag{12}$$

Substitution into the first order condition (11) above and total differentiation yield the following log-linearized expression:

$$\dot{p} = \sum_{j=1}^{n} \theta_j \dot{w}_j , \qquad \textit{for all j = 1, ... ,n.} \tag{13}$$

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[14] The identity is derived from Uzawa's definition of the Allen elasticity of substitution in terms of the cost function (Blackorby and Russell, 1989).

Here θ_j is the cost share of input *j* in total cost. The change in output prices is therefore equal to the cost-share weighted average of input price changes. Equation (13) also represents zero profit conditions with perfectly competitive markets.

The system of equations presented above is usually referred to as *the core* of general equilibrium models. Full model representation under perfect competition assumptions is completed by adding appropriate market clearing and accounting equations. However, perfect competition assumptions can be relaxed to represent different non-competitive features. The next section describes how one such feature, monopoly power, can be introduced in the core of general equilibrium models.

3.1.2. Monopoly power in general equilibrium

The general equilibrium theory developed thus far is based on the assumption of perfect competition in all markets, with agents responding individually as price takers. Monopoly power is a departure from perfect competition and occurs when a firm has control in a certain market and can exclude other firms from participating in it. This section derives the basic monopoly rule and demonstrates how it can be introduced in a simple stylized general equilibrium model in which producers have the choice between two input technologies, one supplied by a monopolist and the other by a competitive sector. The model is presented for discussion purposes but is not used in the empirical model of the study. In the last sub-section, an alternative representation of monopoly power in general equilibrium is presented. This simplifed model, with monopoly power included as a markup tax, forms the basis for the modifications introduced in the empirical model.

i) The monopoly rule

Monopoly is characterized by the presence of only one firm as a supplier in a particular market. Unlike in perfect competition, where several firms are suppliers in the same market (or can enter the market at any time and at no cost), the monopoly firm is a price-maker instead of a price-taker, and faces a downward sloping demand curve (Varian, 1992). The firm is still a profit-maximizer, but it can now choose the quantities supplied to the market (and therefore the supply price). The monopolist's maximization problem becomes:

$$\underset{y}{Max}: p(y)y - C(y)\,. \tag{14}$$

In this problem the monopolist chooses output level *y,* obtains total revenue *p(y)y* and produces at cost *C(y)*. Note that now output price *p(.)* is a function of output level *y*, and prices are no longer exogenous as in the perfectly competitive case described by equations (1) to (13). The first order condition equalizes marginal revenue to marginal cost (with the prime *'* representing first order partial derivatives):

$$p'(y)y + p(y) = C'(y)\,. \tag{15}$$

Rearranging terms, the first order condition can be expressed as a function of the perceived price elasticity of demand *ε*:

$$p(y)\left[1 + \frac{\partial p}{\partial y}\frac{y}{p}\right] = p(y)\left[1 + \frac{1}{\varepsilon}\right] = C'(y)\,. \tag{16}$$

Equation (16) represents monopolist's rule for profit maximization. Several issues arise from monopolist's rule. First, for the equality to hold, the absolute value of the perceived elasticity must be greater than one ($|\varepsilon|>1$), otherwise the monopolist's marginal revenue would be negative. This generates the standard fact in market theory that monopolists always operate in the elastic portion of consumers' demand curve. Second, when the perceived demand is infinitely elastic ($|\varepsilon|\to\infty$), as in perfectly competitive markets, the monopolist's rule is the standard competitive first order condition where price equals marginal cost. This second fact is no surprise since the first order condition is derived from a standard maximization problem of firms.

Oftentimes, economic analysis is interested in the market power a firm is able to enforce in its own market. The monopolist's first order condition in equation (16) is then transformed into the *markup formula*, which shows the difference between the price charged by the monopolist and the marginal cost as a function of the price elasticity of demand:

$$\frac{p(y) - C'(y)}{C'(y)} = \left|\frac{1}{\varepsilon + 1}\right|. \tag{17}$$

Equation (17) is also called the price-cost margin index (*PCMI*). Another common representation of the degree of market power is Lerner's formula (or Lerner index):

$$\frac{p(y)-C'(y)}{p(y)}=\frac{1}{|\varepsilon|}=PCMI\Big/1+PCMI\,. \tag{18}$$

How can the degree of monopoly power be included in general equilibrium models? Dervis et al. (1982) see the departures from perfect competition assumptions as extensions of the original solution in general equilibrium models, with prices still representing market-clearing conditions. Although they do not suggest specific algebraic representations, their suggested procedure is to model perceived demand elasticities in the demand equations for the product or factor where monopoly exists, and to include economic profits as arguments in supply functions. Similarly, François and Roland-Holst (1997) indicate that monopolist's first order condition substitutes for the marginal cost pricing equation and a definition of economic profits is included in general equilibrium models.

Drawing on this framework, the next section describes a stylized general equilibrium model with monopoly power.

ii) Monopoly power in general equilibrium: a stylized model

This section presents how the monopoly power rule can be introduced in a stylized general equilibrium model. As mentioned before, the section is presented for purposes of discussion although the framework is not used in the empirical model. In the model, there is one competitive sector that can choose either of two technologies, conventional or superior. Both technologies produce a single and homogenous output and can be adopted simultaneously. The technologies are embedded in one of the production function's inputs, for example seeds of different crop varieties. The conventional technology is competitively supplied and priced at marginal cost. The superior technology, on the other hand, improves production efficiency but is supplied by a monopolist and priced accordingly. Without loss of generality, one can assume that this case describes the rice sector faced with two choices of rice seeds. The superior technology is represented by transgenic seeds, while the conventional technology is the actual competitively priced seed that producers use. The model developed below describes the decision rule for producers when a superior seed enters the market at a higher price. The rice producers' profit maximization problem is:

$$\max_{y_c, y_t} \pi = p\left(y_c + y_t\right) - C_c\left(w_c\right) y_c - C_t\left(w_t\right) y_t, \tag{19}$$

where *p* is the price of rice output, y_c is the amount of conventional rice produced, y_t is the amount of transgenic rice produced, w_c and w_t are the respective prices of conventional and transgenic seed, and C_c and C_t are the cost functions for producing conventional and transgenic rice. Because it may be possible not to use one of the technologies, the Kuhn-Tucker conditions are used to represent the first-order conditions for profit maximization:

$$\frac{\partial \pi}{\partial y_c} = p - C_c\left(w_c\right) \leq 0,\ y_c\left[p - C_c\left(w_c\right)\right] = 0\text{, and} \tag{20}$$

$$\frac{\partial \pi}{\partial y_t} = p - C_t\left(w_t\right) \leq 0,\ y_t\left[p - C_t\left(w_t\right)\right] = 0\,. \tag{21}$$

Note that if both technologies are to be used in an equilibrium, $C_c\left(w_c\right) = C_t\left(w_t\right)$. If one technology always has lower per-unit cost, that technology will be used exclusively. The price of transgenic seed, which adjusts in the model, equilibrates these two unit cost functions.

The input demand functions for conventional and transgenic seed are:

$$x_c = \frac{\partial C_c\left(w_c\right) y_c}{\partial w_c}\text{, and} \tag{22}$$

$$x_t = \frac{\partial C_t\left(w_t\right) y_t}{\partial w_t}\,. \tag{23}$$

The consumer demand for rice is:

$$x_R = D\left(p\right). \tag{24}$$

The zero-profit condition (i.e., supply function) of conventional seed is:

$$w_c = MC_c\left(z_c\right), \tag{25}$$

where MC_c is the marginal cost of producing conventional seed and z_c is a vector of exogenous input prices facing the conventional seed sector. The supply of transgenic seed is determined by the optimal price relationship of the monopolistic transgenic seed sector:

$$w_t = \frac{\varepsilon_t}{\varepsilon_t + 1} MC_t\left(z_t\right), \tag{26}$$

where ε_t is the elasticity of demand facing the monopolist and MC_t is the marginal cost of producing transgenic seed. Finally, the market clearing condition for rice is:

$$x_R = y_c + y_t . \tag{27}$$

In this model, there are 8 equations (20 – 27) and 8 unknowns: p, y_c, y_t, w_c, w_t, x_c, x_t, and x_R. A market clearing condition is not necessary for conventional seed due to the assumption of perfectly elastic supply. For the monopolistic sector, there is no supply function, and thus no market clearing condition. Also note that the demand facing the monopolist is discontinuous. If the monopolist sets its price too high relative to the conventional technology, then the superior technology will not be adopted. Thus, the model explains not only how the monopoly rule is included, but also the decision rule of producers facing two technology choices that can coexist, a common situation in crop production.

In applied models, alternative specifications of monopoly power can be used that do not entail fully modeling the monopoly rule. The next section describes one of these alternative formulations, which is then used to build the empirical model of the study.

iii) Monopoly power as a markup tax

Studying the impact of capital income taxation in the corporate sector of the United States, Harberger (1962) develops an analytical general equilibrium model and specifies how such a model could accommodate monopoly markups. The model consists of two sectors, corporate (*X*) and non-corporate (*Y*), using two inputs (capital *K* and labor *L*), with the corporate sector enjoying some degree of monopoly power. Production functions are assumed to be homogeneous of degree one. From the standard property that all income is exhausted in factor payments, the following equation is obtained[15]:

$$dp_x = \theta_L dp_L + \theta_K dp_K \,. \tag{28}$$

Equation (28) represents the change in price p_x of industry output X as a function of changes in the prices of labor (p_L) and capital (p_K) inputs, weighted by the corresponding cost share (θ_L and θ_K). Monopoly power is then modeled as a constant markup m over the industry price, and introduced in the price equation as follows[16]:

$$dp_x = \left[\theta_L dp_L + \theta_K dp_K\right](1+m) \,. \tag{29}$$

The rest of the model's equations change accordingly by substitution with the previous expression[17]. Drawing on Harberger's approach, Keller (1980, p.256) models the monopoly power in general equilibrium as an ad-valorem constant tax on output charged by the monopoly firm, which also collects all tax receipts through a special fiscal institution (multi-fisc models). The firms' behavior is otherwise similar to perfect competition with constant returns to scale technologies. The tax rate value is equal to the markup and, as any other tax, creates welfare distortions due to monopolist's excess-profits. The model can accept, for instance, second-best policies as a tax on excess-profits collected by the government and redistributed back to tax-payers to neutralize the markup effect. Since Keller's model is based on several oligopoly firms (of which monopoly is an extreme case), the markup tax rate t^* for good n is modeled (using monopolist's rule) as follows:

$$t_n^* = \frac{p(y) - C'(y)}{C'(y)} = \left|\frac{1}{1+F\varepsilon}\right|, \qquad \text{with } F = \frac{1}{a^f} \,. \tag{30}$$

Equation (30) is similar to equation (17). Here a^f is the output share of firm f in total industry output and F is the number of firms in the industry (assuming all firms are identical). The

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[15] Equation (28) is an extension of Euler's law.

[16] In Harberger's model a tax T on the use of capital is included, but the general expression remains similar to the one presented here. Shoven and Whalley (1992, p.135) give a full derivation of Harberger's model.

[17] Harberger also pointed out that the monopoly markup could not be excessively high and should be kept in the order of magnitude between 0 and 0.2. Amongst different reasons that justify keeping the markup within those levels, he cited the existence of reasonable close substitutes for the firms' products (and therefore the presence of other firms) and the "perennial threat of entry" with high markups.

formula applies for pure monopoly when $F=1$, and therefore $d^f=1$. The markup is then incorporated as a tax coefficient link in the price equations:

$$p_n^m = t_n p_n^a, \tag{31}$$

where $t_n = 1 + t_n^*$, p^m is the market price of good n (what consumers pay) and p^a agents' (or firms') price. Total tax or markup revenues (rents) M are:

$$M = \sum_n (p_n^m - p_n^a) q_n\ , \tag{32}$$

with q_n being the market clearing quantity of the n^{th} good. A similar formula for monopoly prices is given in Harris (1984):

$$p_m = m \times p_c, \tag{33}$$

with p_m being the monopolist's price for a certain good, p_c the competitive price (equal to the marginal cost of producing that good), and m the markup value.

Another formulation for markup pricing is given by Ginsburgh and Keyzer (1997) and cited as the Amoroso-Robinson formula. The formulation represents an equilibrium condition for a Cournot duopoly problem with two producers facing a downward sloping market function. The link between competitive and non-competitive prices is given by the following specification:

$$p_n(1 - \varepsilon^{-1}\theta) = C'(y), \tag{34}$$

where θ is industry's market share (for a monopoly, $\theta=1$). The formula states that the price of good n exceeds the marginal cost $C'(y)$ by a markup of magnitude $p_n \varepsilon^{-1}\theta$. Ginsburgh and Keyzer also view markup pricing as an ad-valorem output tax whose proceeds accrue to firms (and indirectly to consumers if they own the firms) instead of to the government. In that sense, the procedure is similar to Keller's model and income of firms' owners must be increased by $\mu\theta q_n$, with μ being the markup rate for good n[18]. The increase in income will therefore affect demand, an inconsequential issue in partial equilibrium analysis, but one that changes the general

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[18] The authors discussed the existence and uniqueness of equilibrium in models with imperfect competition under alternative assumptions (and therefore alternative model formulations). They concluded that theoretical solutions of models with imperfect competition are dependent on the model specification, and that markups are the best way to represent the non-competitive market structure. They argued that when a theoretical solution is not guaranteed to exist, it is still possible to find numerical solutions in applied models.

equilibrium solution. Once the income issue is addressed, the general equilibrium solution proceeds as for any other tax[19].

The present study selects the markup tax framework just presented to model the monopoly power of multinational firms producing transgenic rice seeds. One of the advantages of this particular specification is the coherence of introducing a markup tax in the GTAP model, which deals with several tax specifications. The next section describes the GTAP model and then explains the empirical model in more detail.

3.2. The Global Trade Analysis Project (GTAP)[20]

The GTAP model for applied general equilibrium analysis was developed through a project that started in 1992 at Purdue University *"…with the objective of lowering the cost of entry for those seeking to conduct quantitative analyses of international economic issues in an economy-wide framework"*. Since then, the GTAP model has been reviewed and new versions are released periodically. The model consists of a large database and a software program that conducts trade and general equilibrium policy experiments under a unified economic theory. The present study is based on database version 5.0 and model version 6.2 of GTAP (GTAP, 2006). The purpose of this section is to describe salient features of the model's theory in order to justify the modifications required in this empirical application and to understand the origin and implications of the study results.

3.2.1. Institutions in the GTAP model

Each country or group of countries in the GTAP database corresponds to a *regional household* that collects the region's income. Income is then distributed to three different institutions within each region: a *private household* representing all private consumption expenditures, the *government*, and a *savings* sector which is a proxy for future consumption.

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[19] In their game-theoretic approach, Ginsburgh and Keyzer identify two different stages in the process of optimizing a general equilibrium solution with non-competitive markets: the anticipation stage, in which non-competitive firms anticipate the reactions of competitive firms to their own actions (and therefore form expectations about the final prices), and the market clearing stage, where they use the solutions of the anticipation stage to maximize their objective function.

[20] The section is based on Hertel (1997).

Production is accomplished by *private firms*, and a *rest of the world* institution accounts for international trade.

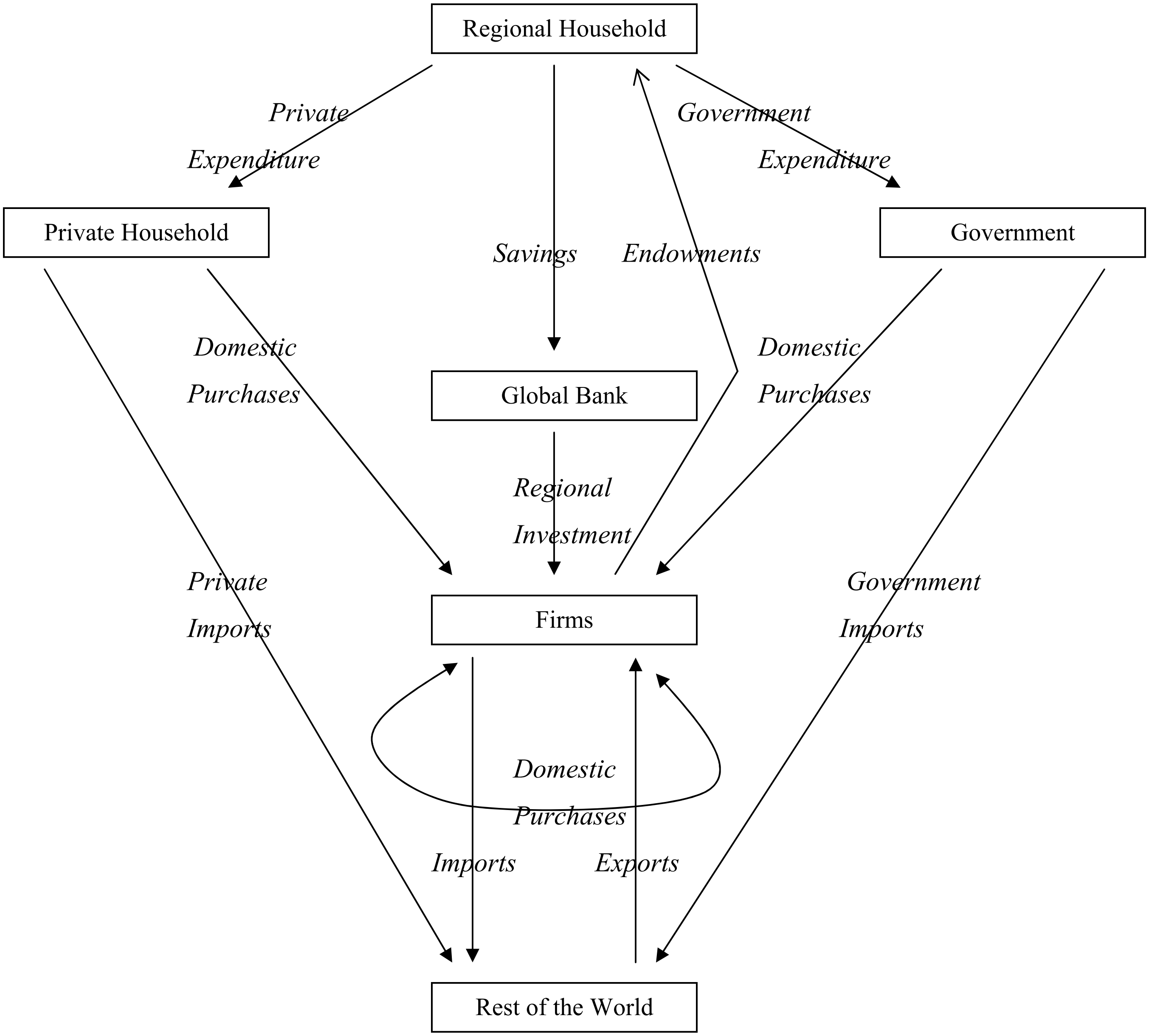

Figure 3.1. Institutions in the GTAP model and flow of payments for a multi-region open economy (Source: Hertel, 1997).

Private firms purchase domestic and imported intermediate inputs from domestic firms and from 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 endowment (land, skilled and unskilled labor, capital and natural resources) and from tax payments, and distributes total income for private consumption, government consumption and savings. Private households and the government consume both domestic and imported commodities, while the savings sector invests in domestic and imported commodities and a capital goods sector. Each sector produces a single output and therefore corresponds to a single commodity. The institutional framework and the flow of payments (without taxes) between different agents are represented in figure 3.1.

The flow of transaction payments between agents in the economy is completed with exhaustive accounting of taxes, accruing to the region where they are collected.

3.2.2. Model behavior

The behavioral structure of the model is that of a weakly separable demand system with multiple levels (or nests). The first level is the regional household with an aggregate Cobb-Douglas per-capita utility function of the form:

$$U = C \prod U_i^{B_i}, \tag{35}$$

where U is regional household's utility, C a scale parameter, U_i is the utility level of the i^{th} agent, and B_i is the distribution parameter for the i^{th} agent (*p:* private household, *g:* government, *s:* savings). The regional household allocates income received to the second level of the demand system: private household, government, and savings. Private household's per capita expenditures respond to a non-homothetic constant difference elasticity (CDE) expenditure function of the form:

$$G(z,u) = \sum_{i=1}^{N} B_i u^{b_i e_i} z^{b_i} \equiv 1, \tag{36}$$

where G is the general form of the expenditure function, z is a normalized price vector, u is private household's utility, b_i is the substitution parameter ($0<b_i<1$, or $b_i<0$), e_i the expansion parameter ($e_i>0$), and B_i the scale parameter (>0).

The CDE functional form reproduces the desired consumption behavior in the model, allowing consumption shares of different commodities and price elasticities to change at different income levels (non-homothetic preferences). Variable consumption and price elasticities are in contrast to the homothetic Cobb-Douglas or Constant Elasticity of Substitution (CES) functional forms, where these parameters are invariant to income levels. However, from the CDE functional form, several well-known functional forms can be derived by setting specific values for the expansion and substitution parameters as follows:

	e_i	b_i
Leontieff	1	1
Cobb-Douglas	1	0
CES	1	b
Homogeneous CES	e	b

Government preferences are governed by a per-capita Cobb-Douglas utility function which is based on two assumptions of private households' behavior: a) separability in consumption of private and public goods, and b) identical marginal rate of substitution between public goods. These assumptions lead to constant budget shares for public goods in private consumption, justifying the selection of the Cobb-Douglas per capita form for government's preferences.

The third agent in the model, savings, is also based on per-capita form. Aggregate savings must equal the amount of capital goods produced from commodities. For allocation purposes, savings by regional households are distributed through a global bank sector in the multi-region model. Regional allocation can follow on of two approaches: allocate so as to invest the same amount saved by the region (fixed composition approach), or allocate so as to equalize rates of return across regions (rate of return approach).

The last agent in the model is the producers' sector. Firms' behavior is modeled as a nested CES function with constant returns to scale technology. At each level, the production technology responds to a CES functional form:

$$Y = \alpha \left(\sum_{i=1}^{j} \delta_i x_i^{-\rho}\right)^{\frac{-1}{\rho}}, \qquad (37)$$

where Y is total output, α an efficiency parameter ($\alpha > 0$), δ_i are the distribution parameters for the i^{th} input, and x_i the i^{th} input. As for any CES functional form, the elasticity of substitution for this technology is constant and equal to $\sigma = 1 / (1+\rho)$.

There are two types of inputs under the firms' upper level nest: intermediates and value-added. In each level, the elasticity of substitution is the same for all inputs on the same nest but may differ between two nests. For example, the elasticity of substitution between all intermediate inputs is the same and equal to σ_D, and the elasticity of substitution between value-added inputs is the same and equal to σ_{VA} (figure 3.2). The elasticity of substitution between the intermediates and value-added is σ_T, which in the GTAP model is set to zero. This assumption defines a Leontieff technology in the first level of the firm's production function, implying no substitution possibilities between intermediates and value-added. Firms' technology also identifies intermediate inputs by their origin (Armington approach) resulting in a third-level nest for domestic and imported intermediates.

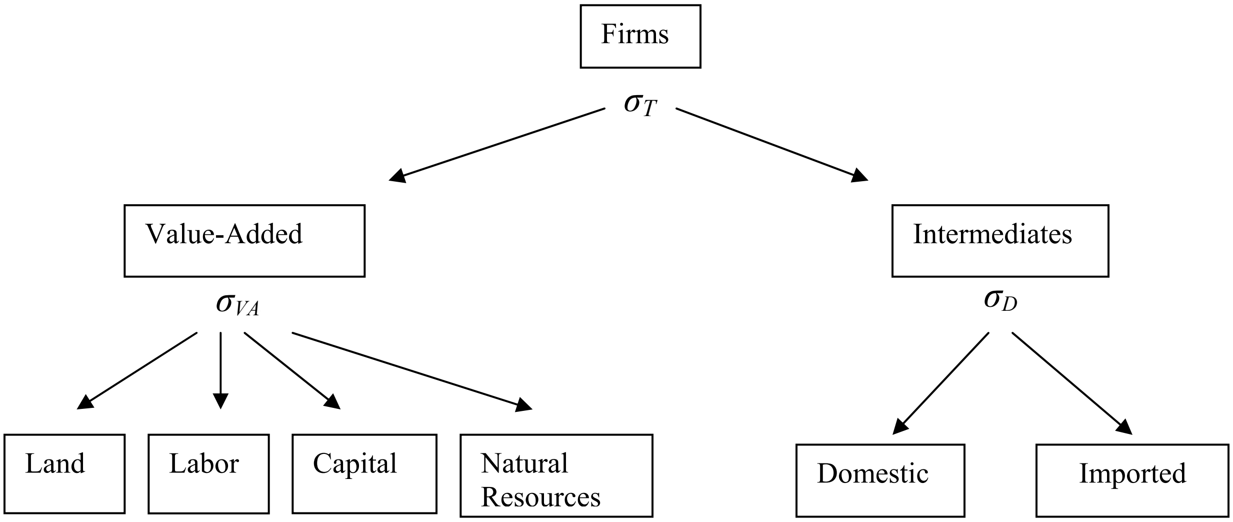

Figure 3.2. Structure of technology in the GTAP model (Source: Hertel,1997).

The next section describes how technological change is included in the production function of firms in the model.

3.2.3. Technological change in the GTAP model

This section presents a brief description of how technological change is treated in the GTAP model. The focus is on how demand for intermediate inputs is derived from the technology tree (figure 3.2) and how technological change enters in the corresponding equations. The notation introduced in this section follows notation used in the GTAP model code.

From the technology structure presented in the previous section, the linearized input-demand equations can be derived (Hertel, 1997, p.38). The percentage change in demand for domestic intermediates inputs i from industry j in region r (qfd_{ijr}) is as follows[21]:

$$qfd_{ijr} = qf_{ijr} - \sigma_D \left(pfd_{ijr} - pf_{ijr} \right). \tag{38}$$

Here qf_{ijr}, the demand for composite intermediate inputs (domestic and imported), represents the expansion effect. The second term in the right hand side represents the substitution effect as a function of the elasticity of substitution between intermediate inputs (σ_D), and the ratio of their domestic price (pfd_{ijr}) to the price of composite intermediates (pf_{ijr}). Demand for composite intermediates inputs at the top level (total output) nest is defined as:

$$qf_{ijr} + af_{ijr} = qo_{jr} - ao_{jr}, \tag{39}$$

where qo_{jr}, the percentage change of industry output j in region r, is the expansion effect. The equation is similar to that of intermediate inputs demand above, but due to the assumption of Leontieff technology the substitution effect disappears. The output equation also introduces the technological change variables. At the top level nest, ao_{jr} represents an output-augmenting, Hicks-neutral technical change variable. At the intermediates nest, af_{ijr} is the input-augmenting technological change variable. As inferred from the equation, in the absence of any type of technical change, change in input demand is equal to output expansion owing to constant returns to scale technology. Technical change that increases production efficiency ($ao_{jr} > 0$) reduces demand for composite inputs, while technical change that increases the efficiency of input use ($af_{ijr} > 0$) expands output or reduces input requirements for a given output level. At the intermediates nest, technical change enters in the following form:

$$qf_{ijr} + af_{ijr} = qo_{jr} - ao_{jr} - \sigma_{Dj} \left(pf_{ijr} - af_{ijr} - ps_{jr} - ao_{jr} \right). \tag{40}$$

At this point it is convenient to illustrate the simultaneous effect of technical change with a certain tax levied on input usage increasing the price that firms pay for this input (pfd_{ijr} in equation 38). The substitution effect in equation (38) drives demand away from the input, while at the same time technological change in (39) increases demand through the expansion effect ($qf_{ijr} > 0$). The aggregate result will then be determined by the relative impact of each type of

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[21] Hereinafter, lower-case variables represent percentage change and upper-case variables represent levels or values.

effect. It is possible that, driven by technological change, input demand increases despite being simultaneously taxed. Since taxes are collected as income by the regional household in GTAP, then the aggregate effect has implications on the global welfare resulting from the policy experiment. The next section describes in more detail the sources of welfare in the GTAP model.

3.2.4. Welfare decomposition in the GTAP model

Welfare changes in GTAP are given as an equivalent variation (EV) measure. This welfare measure can be further decomposed into unique sources by region and commodity: allocative efficiency, technical change or terms of trade effects. It is useful to understand how the first two welfare sources are derived based on the theory of the model. Huff and Hertel (2001) give a detailed explanation which is summarized next.

Figure 3.3a presents a simple economy with two sectors (*A* and *B*) and only one factor of production (*L*), with fixed endowment L_e. Lines *aA* and *bB* represent the marginal value product of *L* in each sector. In the absence of any distortions, the Pareto-efficient allocation that maximizes welfare is given by *E*, where the marginal value product of *L* in *A* and *B* is equal. Now, if the use of *L* by *A* in the initial equilibrium is taxed by an amount *t*, then the effective marginal value product curve becomes aA^*. This leads to a new initial equilibrium in E^*, with input use L^* and a deadweight loss represented by the shaded triangle in figure 3.3a.

Consider now a reduction from the original tax rate *t* to *t'*, represented in figure 3.3b. The new $MVPL_A$ curve is *aA'*, and the equilibrium allocation moves to *E'*, in the direction of the Pareto-efficient allocation. New equilibrium input usage is *L'*. This tax rate change reduces the initial deadweight loss and is welfare improving. The allocative efficiency effect is represented by the shaded trapezoid in figure 3.3b. The magnitude of the welfare change depends on the size of the tax reduction (*t* - *t'*) and the size of the allocative effect improvement (*L** - *L'*).

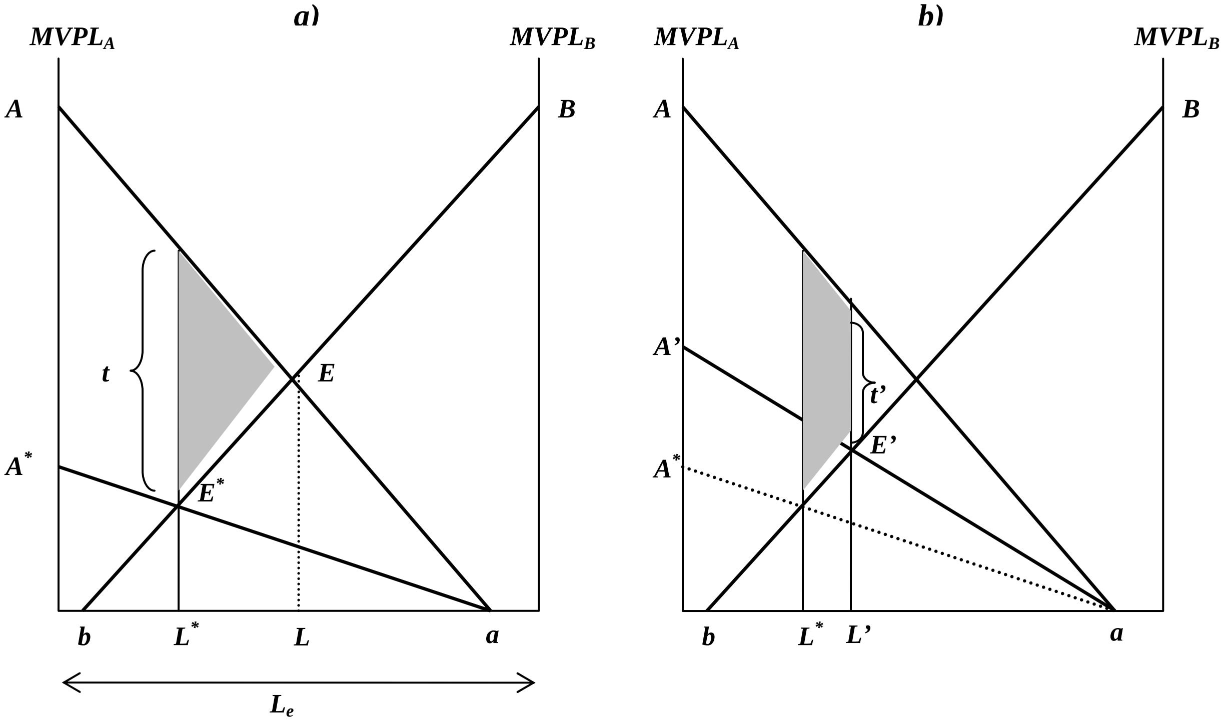

Figure 3.3. Welfare decomposition in the GTAP model: reduction in deadweight losses (Source: Huff and Hertel, 2001).

Now, consider a technological change that improves the efficiency of factor *L* use in sector *A* (figure 3.4). The new improved and undistorted (without taxes) $MVPL_A$ curve is *aA'*. The actual (distorted) $MVPL_A$ pivots similar to the undistorted curve to *aA***, new equilibrium is *E***, and equilibrium input usage increases to *L***. Figure 3.4 shows that technological change in the presence of distortions also creates allocative efficiency effects, because it stimulates the use of a factor of production that was below its Pareto-efficient level. There are two types of effects: the technological change effect (dark shaded upper-trapezoid) and the allocative efficiency (light shaded lower-trapezoid).

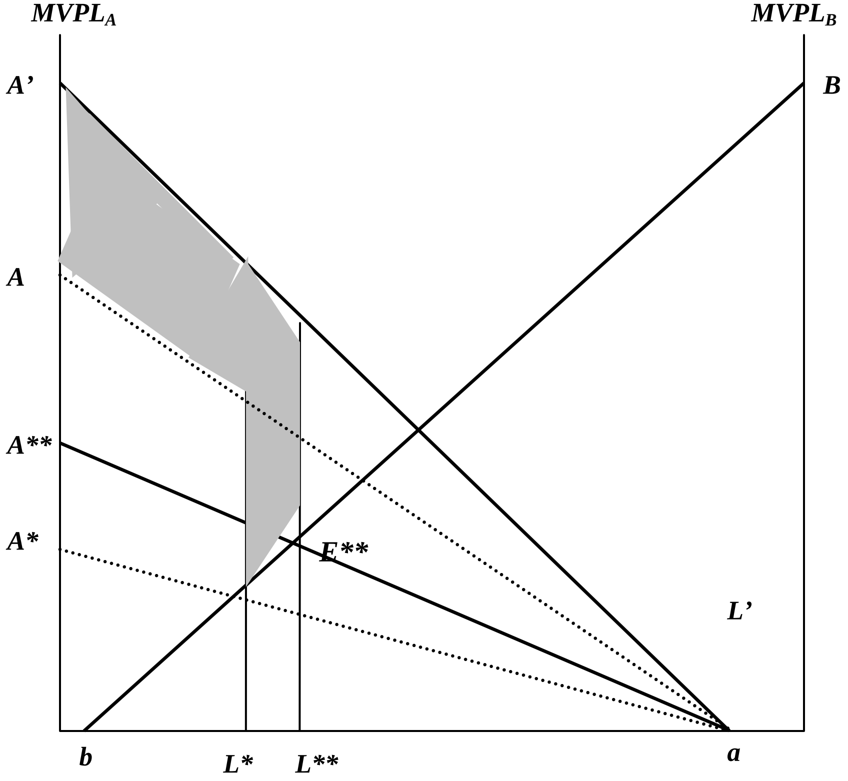

Figure 3.4. Welfare effects of technical change in the GTAP model in the presence of distortions (Source: Huff and Hertel, 2001).

Huff and Hertel (2001) draw some important conclusions from the welfare decomposition theory in the GTAP model:

- Increasing the use of a highly taxed activity is welfare-improving.
- If the activity is not taxed in the initial equilibrium, a technical change shock will not produce allocative efficiency effects.
- If a technological change shock increases the use of an input that is highly taxed, then this will contribute positively to the overall welfare change.

Hanslow (2000) generalizes the welfare decomposition presented before for any general equilibrium model. Amongst several additional features in Hanslow's decomposition is the computation of separate welfare contributions from foreign income flows and from non-competitive pricing behavior by firms (called *profits effect*). These profits effects are computed as the product of the market power measure in a particular input or output market and the usage change of the input or output[22].

The welfare decomposition theory has important implications for analyzing and interpreting results obtained with the GTAP model, and therefore for the study simulations. The next section describes the assumptions and data used in building the empirical GTAP model to carry out these simulations.

3.3. Empirical model

The GTAP model is particularly suitable to the present analysis for several reasons. First, it is an applied model built under a common theoretical framework that allows for direct calculation of welfare measures and accounts for a variety of general equilibrium effects. Second, the unified database and the applied model provide a common framework for policy analysis and comparison between studies, particularly when multiple regions are considered simultaneously and compatibility of data becomes an issue. Third, unlike for other agricultural crops (except wheat), the database identifies rice and processed rice as separate sectors, allowing for direct analysis of linkages between them and between rice and other agricultural activities. Fourth, the countries of interest for the study are identified as single regions and therefore effects on each country can be computed directly. Finally, the model is flexible enough to permit aggregations of regions and sectors such that the analysis can concentrate on the more relevant results in the regions and sectors under scrutiny without loosing the information about secondary effects in other areas.

The following sections explain in detail the model adjustments needed to accurately represent the issues under investigation. The empirical model must represent different rice environments (favorable and non-favorable) and must be able to model monopoly power in the market for the transgenic seed. These features of the empirical model necessitate changes to both the original database and the theoretical model (the model code).

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[22] The author notes that profits effects have similar structure than allocative efficiency effects due to the fact that markups are distortions “just like taxes”.

3.3.1. Modeling the rice environments

The first step in building the empirical model is to identify the world's rice production regions from the original database. Greenland (1997) disaggregates the rice area, yield and production for Asia and the rest of the world by ecosystem. Asia is further disaggregated in Southeast Asia, South Asia, and East Asia[23]. However, this regionalization includes in the same region countries with highly disparate production conditions and policies, and a more detailed description of rice ecosystems by country is needed. In 2000, more than 85 percent of the world's rice production occurred in nine Asian countries, and it is appropriate to represent each of them individually. Aggregation of the GTAP database in this study includes then eight of these individual countries: China, India, Indonesia, Bangladesh, Vietnam, Thailand, Philippines and Japan. Myanmar, the ninth country, representing 3.3 percent of the world rice production, is included in an aggregate region (Rest of Asia) with the rest of Asian countries. The rest of the rice producing countries are aggregated in the following regions: Africa, USA, Latin America and Rest of the World[24].

The economic sectors in the aggregated version of the model must also represent the main linkages between rice and other economic activities. Production substitution possibilities in agriculture must be identified, as well as transactions with specific manufacturing sectors. The first sector to focus on for production substitution possibilities is the rice sector, which is identified as a single sector in the original database. Other crops are aggregated into a single sector because they include crops which directly substitute or complement rice production, such as wheat. In many Asian regions, rice-wheat rotations are the most important cropping system. Other agriculture activities are aggregated as a single sector because they compete with rice for farm land and may also represent complements to rice production. Processed rice and other processed foods are also selected as specific sectors. The linkage of the former with rice production is evident. Processed rice uses rice as a major input, and changes in rice production and prices have direct impacts on the processed rice sector. The other processed foods sector is

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[23] Countries included in each sub-region identified by Greenland (1997) are: China, Japan, North Korea and South Korea (East Asia); Myanmar, Cambodia, Indonesia, Laos, Malaysia, Philippines, Thailand and Vietnam (Southeast Asia); Bangladesh, India, Nepal, Pakistan and Sri Lanka (South Asia).

[24] The justification for this aggregation is as follows: Myanmar is not identified as an individual country in the GTAP database and therefore has to be included in the Rest of Asia; Africa includes Egypt, the country with the highest annual yield in the world; Brazil (included in Latin America) and USA are the largest non-Asian countries in terms of world rice production. The Rest of the World includes all other countries.

identified because changes in rice production affect production of alternative agricultural activities, which in turn are major inputs of the other processed foods sector. Rice production and providers of fertilizers and pesticides form another important linkage, and the latter are therefore included in the chemicals sector. All other non-agricultural activities are aggregated into manufactures, which represent all manufacturing sectors not included in the sectors described before, and services. The final sectors in the aggregated database are then as follows: paddy rice, other crops, other agriculture, processed rice, other processed food, chemicals, manufactures and services. Table 3.1 presents the mapping of original regions and sectors in the GTAP 5.0 database with the aggregated version developed for the present study.

Furthermore, to account for different rice ecosystems and monopoly power in the transgenic seed, the paddy rice sector is disaggregated into irrigated and non-irrigated paddy rice, and irrigated and non-irrigated rice seed. The data and procedure to disaggregate the original paddy rice sector into these new four sectors is described next.

The original GTAP database is constructed from SAMs for each of the regions in the model. The first step was then to reconstruct the SAMs for each of the aggregated regions of the current study (table 3.1). The advantage of recovering the SAMs is that the data is readily available for analysis using methods derived from economic theory and that the SAM structure provides a description of underlying technologies in the economy. In a second step, secondary data was used to modify the SAM and transform the original paddy rice into two new sectors, representing the favorable and unfavorable environments of rice. The third step consisted in transforming these modified SAMs back into GTAP database format.

The secondary data needed to modify the SAM (second step) was obtained from two basic sources:

1) Area, yield and production statistics for each region and for favorable and unfavorable environments (table 2.1 and appendix A), defined based on Huke and Huke (1997), IRRI (1993 and 2002a) and Greenland (1997). Combining information from these sources, table 2.1 and appendix A present the most accurate data available on rice production by region and ecosystems for the year 2000.

2) Country studies included in David and Otsuka (1994). This reference provides basic data on input use and factor returns for rice production in both favorable and unfavorable environments. The data were collected using village surveys in both environments and analyzed

using a common economic framework for all countries, reducing the potential for model and data incompatibility.

3) Other references used included updates by Tran et al. (2000) of country studies in David and Otsuka (1994).

The procedure to modify the SAM structure and to obtain irrigated and non-irrigated rice sectors was as follows. First, per-hectare factor returns and input use information for each country and each environment were used to calculate totals per region, using area statistics given in appendix A. The resulting input use and factor returns proportions for each region and environment were then applied to split the paddy rice sector (in the original SAM) into irrigated and non-irrigated paddy rice. Information on fertilizer use by environment was applied to modify the chemicals sector. The production proportions by ecosystem in table 2.1 provided target values for aggregate totals for each production technology. In constructing the SAMs, it was also assumed that most international trade in rice involves rice grown in irrigated ecosystems, and therefore non-irrigated rice exports and imports are minimal. Appendix B includes the final structure for each regional SAM in the model after this first step towards disaggregation[25].

In a second step, the irrigated and non-irrigated rice sectors were each further disaggregated into paddy rice and rice seed sectors. The split procedure was performed with the SplitCom utility program described in Horridge (2005). The criteria for disaggregating each rice sector were as follows:

- Most of the income of the new seed sectors should come from sales to the corresponding paddy rice sector. Income from sectors other than the paddy rice was distributed 99 percent to the paddy sector and 1 percent to the seed sector.
- Seed purchases by the paddy rice sector must represent approximate budget shares for seed in rice production (around 10 percent).
- Own use of rice by the paddy sector in the database was assumed to correspond 80 percent to seeds for all regions except for China, where the proportion was 50 percent (due to the original high proportion of own use of rice in this region). For the seed sector, it was assumed no purchase of paddy rice.

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[25] McDonald and Thierfelder (2004) developed the theory and a software program to recover SAMs from the GTAP database.

- The cost structure of the seed sector should differ from that of the paddy rice sector, and therefore proportions of chemicals and capital use by the seed sector are double those of paddy rice sector.
- Cross sector exchange between different rice environments was minimized (i.e., no sales of irrigated seed to the non-irrigated sector and vice versa).

The final database (after all modifications were introduced) can be used to analyze the resulting cost structure of paddy rice and rice seed sectors in each region. This information is useful to assess the efficacy of the criteria in reproducing realistic data, and to understand the origin and implications of the results. The cost structure of paddy rice and rice seed firms for each region, as represented in the database used in the current study, is given in appendix C.

Table 3.1. Mapping of regions and sectors in the study version with original GTAP database.

Regions		**Sectors**	
Study Version	*Original Database*	*Study Version*	*Original Database*
China (CHN)	China	Irrigated and Non-Irrigated Paddy Rice, Irrigated and Non-Irrigated Seed	Rice
India (IND)	India	Other Crops	Wheat and Cereal grains nec.
Indonesia (IDN)	Indonesia	Other Agriculture	Sectors 4 to 14 in GTAP 5.0 database
Bangladesh (BGD)	Bangladesh		
Vietnam (VNM)	Vietnam		
Thailand (THA)	Thailand	Processed Rice	Processed Rice
Philippines (PHI)	Philippines	Other Processed Foods	Bovine meat products, Meat products nec., Vegetable oils and fats, Dairy products, Sugar, Food products nec.
Japan (JPN)	Japan		
Rest of Asia (ROA)	Hong Kong, Korea, Taiwan, Malaysia, Singapore, Sri Lanka, Rest of South Asia	Chemicals	Chemical, rubber and plastic products (sector 33)
USA (USA)	USA		
Latin America (LAM)	Mexico, Central America and the Caribbean, Colombia, Peru, Venezuela, Rest of Andean Pact, Argentina, Brazil, Chile, Uruguay, Rest of South America	Other Manufactures	Sectors 15 to 17, 26 to 32, and 34 to 42 in GTAP 5.0 database
Africa (AFR)	Morocco, Rest of North Africa, Botswana, Rest of South African Customs Union, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, Other South African, Uganda, Rest of Sub Saharan Africa	Services	Sectors 43 to 57 in GTAP 5.0 database
Rest of the World (ROW)	All other sectors in GTAP 5.0 database		

Modifying the database to represent the rice environments also required changes to the model theory in the code. Since now there are two sectors (irrigated and non-irrigated paddy rice) producing an homogenous output, rice, an assumption was made that paddy rice output from any environment in each region receives the same market price. This assumption is supported by empirical analysis (e.g., David and Otsuka, 1994). Although potential price differentials between environments may exist empirically, they have been related to spatial differentiation and transportation costs and these are not captured in the model. The assumption is modeled by including the following price linkage equation:

$$pm_{ir} = pm_{jr}\,, \qquad (41)$$

$$\forall i \in irri\_comm, \forall j \in nonirri\_comm, \forall r \in reg2\,.$$

Here pm_{ir} is the market price of commodity i (or j) in region r. *Irri_comm* is a set containing the irrigated paddy rice sector and *nonirri_comm* is a set containing the non-irrigated paddy rice sector. *Reg2* is a set defined by all regions where production in both environments takes place (all regions except USA and Japan). The same assumption about homogenous rice output entails the following modification of market clearing conditions:

$$\sum_j VOMPDR_{jr} qo_{jr} = \sum_k SHRDMPDR_{kr} qds_{kr} + \sum_s \sum_i SHRXMDRI_{irs} qxs_{irs}\,, \qquad (42)$$

$$\forall j,k,s,l \in paddy\_comm, \forall r \in reg2, \forall s \in reg\,.$$

Equation (42) expresses that the value of total paddy rice output j in region r ($VOMPDR_{jr}$) must equal the sum of the share values of rice traded domestically ($SHRDMPDR_{kr}$) and to international markets ($SHRXMDRI_{irs}$)[26]. *Paddy_comm* is a set containing irrigated and non-irrigated paddy rice sectors. The equation solves for the changes in the model multiplying the coefficient variables by the percentage change in paddy output (qo_{jr}), in domestically sold output (qds_{kr}) and in exported output (qxs_{irs}). As before, the equation applies only to the regions where both types of production ecosystems exist.

On a final note, there are no changes to the original parameter specification of the GTAP model. This implies that land, defined as a specific endowment, is not mobile between production sectors, even between irrigated and non-irrigated rice production. Therefore, there is

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[26] Value variables (upper-case) represent coefficients in the GTAP model.

not a unique market price for land across sectors (i.e., land prices between irrigated and non-irrigated sector are not equal). The assumption can be sustained because transforming non-irrigated land into irrigated is constrained by availability of water sources, appropriate soil conditions and financial resources for irrigation investments.

3.3.2. Monopoly power in the GTAP model

Following the theoretical approach discussed in section 3.1.2.iii, the present study models monopoly power as a markup tax on inputs purchased by firms, with a share of tax revenues accruing to the region where the tax is collected and the remaining share being transferred to the United States. This modeling framework represents the transfer of monopoly profits from the domestic region where transgenic seeds are sold to the region where transgenic seed owners are assumed to be based[27]. The rent transfer increases income in the United States and decreases that of the region where the markup tax is originally collected. The new tax instrument ($tmono_{ijr}$) adds a tax on domestic purchases of input i by industry j in region r to the equation linking domestic market prices and input prices paid by firms (pfd_{ijr}):

$$pfd_{ijr} = tfd_{ijr} + pm_{ir} + tmono_{ijr}, \tag{43}$$

$$\forall i \in trad\_comm, \forall j \in prod\_comm, \forall r \in reg\ .$$

Equation (43) includes the original GTAP model's tax on domestic input purchases by firms (tfd_{ijr}). The presence of an additional tax instrument implies changes on the formulae to update the levels variables (coefficients) and also provides a mechanism to calculate monopoly rents in the model. This procedure is explained next in more detail. The model begins by defining the total value of purchases of input i by industry j in region r as:

$$VDFA_{ijr} = PFD_{ijr} QFD_{ijr}, \tag{44}$$

$$\forall i \in trad\_comm, \forall j \in prod\_comm, \forall r \in reg\ .$$

$VDFA_{ijr}$ is initially read from the database as a total value in the initial equilibrium. PFD_{ijr} and QFD_{ijr} are the initial level values for the price and quantity of input purchases. After the policy

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[27] Selecting the United States as the recipient of the rent transfer is a simplifying assumption, since many multinational firms have merged and are owned by shareholders around the world, including the European Union.

experiments, $VDFA_{ijr}$ is updated according to the percentage changes in input prices and quantities. Recalling for the moment the updated value as $VDFA_{ijr}{}^{u}$, the formula is:

$$VDFA_{ijr}^{u} = VDFA_{ijr}(1+pfd_{ijr})(1+qfd_{ijr})\,. \tag{45}$$

Note that pfd_{ijr} includes changes in the market price of the input and changes in any domestic input tax, including the monopoly tax (see equation 43). To isolate the effect of the monopoly tax, a new variable $VCOMP_{ijr}$ is created, representing the value of total input *i* purchased by firm *j* in region *r* at *competitive* prices (without monopoly tax):

$$VCOMP_{ijr} = PM_{ir}TFD_{ijr}QFD_{ijr}\,. \tag{46}$$

Equation (46) assumes that all bio-tech seeds are purchased from a domestic supplier. Updating $VCOMP_{ijr}$ must exclude the monopoly tax:

$$VCOMP_{ijr}^{u} = VCOMP_{ijr}(1+pm_{ir})(1+tfd_{ijr})(1+qfd_{ijr})\,. \tag{47}$$

Originally, when no monopoly taxes are present at the pre-existent equilibrium, $VCOMP_{ijr}$ is a clone of $VDFA_{ijr}$. However, after the exogenous monopoly tax is assigned a non-zero value for a policy experiment, the updated levels $VDFA^{u}$ and $VCOMP^{u}$ take different values. The difference is the value of monopoly rents generated on purchases of domestic intermediate input *i* by *j* in *r* ($VRENT_{ijr}$):

$$VRENT_{ijr} = VDFA_{ijr} - VCOMP_{ijr}\,, \tag{48}$$

$$\forall i \in trad\_comm, \forall j \in prod\_comm, \forall r \in reg\,.$$

The monopoly tax revenue (rents) affects income computation in the model. Regional income in GTAP is defined as the sum of factor payments at market prices, net of depreciation plus tax revenues. Factor income (FY) in region *r* is defined as:

$$FY_{r} = \sum_{i} VOM_{ir} - VDEP_{r}\,, \tag{49}$$

for all $i \in endw\_comm$ (endowment commodities), where *VOM* is the value of factor payments at market prices and *VDEP* is the value of depreciation. Note that *VDEP* is defined as:

$$VDEP_{r} = DEPRATE_{r} * KB_{r} * PCGDS_{r}\,, \tag{50}$$

where *DEPRATE* is a constant rate of depreciation, *KB* is the beginning stock of capital, and *PCGDS* is the price of capital goods. Total differential of equation (49) yields:

$$dFY_r = \sum_i \left[QO_{ir} dPM_{ir} + PM_{ir} dQO_{ir} \right] - DEPRATE_r \left[PCGDS_r dKB_r + KB_r dPCGDS_r \right]. \quad (51)$$

Converting equation (51) to percentage change:

$$FY_r fincome_r = \sum_i \left[VOM_{ir} \left(pm_{ir} + qo_{ir} \right) \right] - VDEP_r \left[kb_r + pcgds_r \right]. \quad (52)$$

Equation (52) is equation FACTORINCOME in the model code. Regional income (*INCOME*) can then be defined as:

$$INCOME_r = FY_r + INDTAX_r, \quad (53)$$

where *INDTAX* is total tax revenues and is defined as:

$$INDTAX_r = TPC_r + TGC_r + TIU_r + TFU_r + TOUT_r + TEX_r + TIM_r. \quad (54)$$

The components of equation (54) are the tax payments on private consumption, government consumption, intermediate inputs, primary factors, production taxes, exports, and imports, respectively. Total differential of equation (53) yields:

$$dINCOME_r = dFY_r + dINDTAX_r. \quad (55)$$

Since *dFY* was defined in equations (51) and (52) above, let's now focus on *dINDTAX*. First, let the ratio of taxes to income (*R*) be defined as:

$$R = T/Y,$$

where *T* is the value of the tax and *Y* is total income. Totally differentiating this equation yields:

$$dR = \frac{1}{Y} dT - \frac{R}{Y^2} dY.$$

Rearranging terms yields:

$$dT = YdR + Ty/100 \rightarrow 100dT = 100YdR + Ty,$$

where *y* is the percentage change in income which is equal to *(dY/Y)*100.* The percentage change in income can then be used to determine *dINDTAX* in equation (55):

$$dINDTAX_r = 100 INCOME_r del\_indtaxr_r + INDTAX_r y_r \,, \tag{56}$$

where *del_indtaxr_r* is the sum of the percentage changes in several indirect tax components:

$$\begin{aligned} del\_indtaxr_r = {} & del\_taxrpc_r + del\_taxrgc_r + del\_taxriu_r + del\_taxrfu_r + del\_taxrout_r + \\ & del\_taxr\exp_r + del\_taxrimp_r \,, \end{aligned}$$

as defined by equation DINDTAXRATIO in the model code. Substituting equation (56) into equation (55) yields:

$$INCOME_r y_r = FY_r fincome_r + 100 INCOME_r del\_indtax_r + INDTAX_r y_r \,, \tag{57}$$

which is equation REGIONALINCOME in the code. Equation (57) states that the change in regional income is equal to the change in net factor payments plus the change in income and indirect tax payments.

In the presence of a monopolist, the definition of regional income must include the rents generated by the monopolist. The assumption that some of the monopoly rents may remain in the domestic market (for example, as licensing of seed sales to domestic firms) calls for a new variable in the model, the markup share in each region (*MKPSHR_r*). This new variable is defined as a model parameter (which is constant and not updated like coefficients) and included in the parameters set of the database. Modifying equation (53) to include the monopoly rents (*VRENT*) yields:

$$INCOME_r = FY_r + INDTAX_r + MKPSHR_r \sum_{i \in trad} \sum_{j \in prod} VRENT_{ijr} \,, \tag{58}$$

$$\forall r \in regnonusa.$$

In equation (58) *regnonusa* is a set of all regions but the United States. Combining the definition of *VRENT* and *VCOMP* yields:

$$\begin{aligned} VRENT_{ijs} &= VDFA_{ijs} - VCOMP_{ijs} \\ &= PM_{is} TFD_{ijs} TMONO_{ijs} QFD_{ijs} - PM_{is} TFD_{ijs} QFD_{ijs} \\ &= \left[TMONO_{ijs} - 1 \right] PM_{is} TFD_{ijs} QFD_{ijs} . \end{aligned} \tag{59}$$

Total differentiation of equation (59) yields:

$$\begin{aligned}dVRENT_{ijs} &= PM_{is}TFD_{ijs}TMONO_{ijs}QFD_{ijs}\frac{dTMONO_{ijs}}{TMONO_{ijs}} + \\ &\left[TMONO_{ijs} - 1\right]PM_{is}TFD_{ijs}QFD_{ijs}\left[\frac{dPM_{is}}{PM_{is}} + \frac{dTFD_{ijs}}{TFD_{ijs}} + \frac{dQFD_{ijs}}{QFD_{ijs}}\right] \\ &= \left\{VDFA_{ijs}tmono_{ijs} + VRENT_{ijs}\left[pm_{is} + tfd_{ijs} + qfd_{ijs}\right]\right\}/100.\end{aligned} \tag{60}$$

Using equations (57) and (60), the total differential of equation (58) can be expressed as:

$$\begin{aligned}INCOME_r y_r &= FY_r fincome_r + 100INCOME_r del\_indtaxr_r + INDTAX_r y_r + \\ &MKPSHR_r \sum_i \sum_j \left\{VDFA_{ijr}tmono_{ijr} + VRENT_{ijr}\left[pm_{ir} + tfd_{ijr} + qfd_{ijr}\right]\right\},\end{aligned} \tag{61}$$

$\forall i \in trad\_comm, \forall j \in prod\_comm, \forall r \in regnonusa$.

Equation (61) computes income for all regions except for the United States. The rent share remaining in the region is given by the parameter $MKPSHR_r$ in the last right hand side term. For the USA, income also includes rents that are collected and transferred from abroad:

$$\begin{aligned}INCOME_r y_r &= FY_r fincome_r + 100INCOME_r del\_indtaxr_r + INDTAX_r y_r + \\ &MKPSHR_r \sum_i \sum_j \left\{VDFA_{ijr}tmono_{ijr} + VRENT_{ijr}\left[pm_{ir} + tfd_{ijr} + qfd_{ijr}\right]\right\} + \\ &\sum_s \left\{(1 - MKPSHR_s)\sum_i \sum_j \left\{VDFA_{ijs}tmono_{ijs} + VRENT_{ijs}\left[pm_{is} + tfd_{ijs} + qfd_{ijs}\right]\right\}\right\},\end{aligned} \tag{62}$$

$\forall i \in trad\_comm, \forall j \in prod\_comm, \forall r \in regusa, \forall s \in regnonusa$.

Equations (61) and (62) replace the original equation REGIONALINCOME in the model. An additional change needs to be made in the computation of taxes in the original model to avoid double counting of rents. First, taxes on domestic purchases $DFTAX_{ijr}$ are redefined as:

$$DFTAX_{ijr} = VCOMP_{ijr} - VDFM_{ijr}, \tag{63}$$

$\forall i \in trad\_comm, \forall j \in prod\_comm, \forall r \in reg$.

Then the equation computing the ratio of tax payments to regional income ($TIURATIO_r$) is redefined as:

$$100INCOME_r del\_taxriu_r + TIU_r y_r = \sum_i \sum_j \left(VCOMP_{ijr} tfd_{ijr} + DFTAX_{ijr}\left[pm_{ir} + qfd_{ijr}\right]\right) + \sum_i \sum_j \left(VIFA_{ijr} tfm_{ijr} + IFTAX_{ijr}\left[pim_{ir} + qfm_{ijr}\right]\right), \qquad (64)$$

$\forall i \in trad\_comm, \forall j \in prod\_comm, \forall r \in reg$.

In summary, the major additions of this empirical model to the basic GTAP model are:

a) The original rice sector in the GTAP database was decomposed to represent favorable and unfavorable rice environments and paddy rice and rice seed sectors.

b) New price linkage and market clearing equations were introduced to represent equal behavior of paddy rice prices in both environments.

c) A new tax instrument ($tmono_{ijr}$) was created to model monopoly markups on purchases of domestic inputs. Markup taxes collected through this tax instrument are defined as rents.

d) The computation of regional income was modified to include the monopoly rents collected through the markup tax instrument.

e) A share parameter was introduced to allow for partial transfer of monopoly rents from the region where they are originally collected to the United States, effectively representing an income transfer.

The final structure of the empirical model deserves further clarification because some behavioral issues are not considered. First, modeling monopoly power as a tax instrument is a simplification of a more complex interaction between the monopolist's pricing strategy and producers' response. This interaction is represented by the perceived elasticity of demand for transgenic seed that monopolists' face and determines, in theory, the optimal markup. In turn, since supply of transgenic seed is fixed by monopolist's maximizing rule, adoption of the transgenic technology is determined by the availability of the input. The elasticity of demand indicates that while markups for transgenic seed increase, the endogenous adoption rate (which represents demand) of transgenic technologies is reduced, *ceteris paribus*. Welfare would in theory be reduced because the Pareto-efficient allocation would not be achieved as a monopoly creates deadweight losses in the economy. This behavior is not modeled in the empirical model, and adoption is an exogenous variable embedded in the technological shocks. To account for this behavior in the model, potential adoption is exogenously reduced in the simulations under monopoly power.

Second, and in relation to the previous issue, the magnitude of markups applied as a tax instrument (*tmono*) are not calculated according to the demand elasticity for transgenic seed. The model is not built to specifically represent rice farmers' response to changes in relative returns, and therefore using the elasticity of demand to calculate optimal markups is not necessarily consistent with model behavior. The markup values selected for the simulations under monopoly power are therefore based on theory only.

Finally, it is possible that based on the modeling framework, applying markups to transgenic seed use increases regional income, since taxes in the GTAP model are a component of regional income. As explained in sections 3.2.3. and 3.2.4, although demand for transgenic seed might be reduced due to higher prices, net technology benefits improve aggregate demand for transgenic seed. Since the input is taxed, tax revenues are also larger and increase regional income.

The next chapter proceeds with the simulation experiments of the study and the discussion and interpretation of the results.

Chapter 4. Potential benefits of transgenic rice technologies: Model simulations and results

This chapter presents and discusses the technology shocks and results of simulations carried out with the GTAP model described in chapter 3. The chapter proceeds as follows. First, current rice production constraints are described together with the transgenic technology targeted to address them. Based on this information, section 4.2 introduces the technological shocks applied to the model. Results under perfect competition assumptions are presented and discussed in section 4.3. Section 4.4 presents the model results when technology producers have monopoly power for some innovations. In this case, herbicide-resistance is the only transgenic technology expected to be developed by the private sector, therefore monopoly power is simulated only for this technology. Section 4.5 presents the sensitivity analyses for the perfectly competitive results. Section 4.6 draws conclusions from the simulations by comparing and contrasting the results obtained under both market structures.

4.1. Rice production constraints and biotechnology solutions

The study results are obtained by simulating three different transgenic rice technologies: stemborer resistant rice for stemborer control, mostly targeted toward favorable environments; drought resistant rice, for unfavorable environments; and herbicide resistant rice, which is for both environments but is only adopted by growers in areas using direct seeding instead of transplanting. The next sections describe the impact of constraints on rice production that these technologies address.

4.1.1. Stemborers and stemborer resistant rice

Insect pests cause estimated average rice losses of 18.5 percent in Asia (Pathak and Khan, 1994). The humid and warm environment in which rice is grown provides excellent growth conditions for a wide range of insects. For years, the stemborers species *Chilo suppressalis* (temperate Asia) and *Scirpophaga incertulas* (tropical Asia) have been considered the most destructive rice insect pest, but recent data suggests that their incidence is decreasing while that of other insects such as the brown plant hopper and the rice leaf folder is increasing[28].

Insects can cause direct damage during their adult stage by feeding, or they can be vectors for viral diseases. Damage caused by stemborers, however, occurs during the larval stage. *Dead hearts* are produced at the vegetative stage of the plant when stemborer larvae feed on the plant tillers. *White heads* are caused by the larvae feeding after panicle initiation and can cause complete drying of the panicle. While the rice plant can compensate for low levels of dead heart damage, white head damage is mostly irreversible, and a one percent incidence of white heads can reduce yield by one to three percent. Other damage to the rice crop includes reduced plant vigor, fewer tillers and unfilled spikelets (Pathak and Khan, 1994). Stemborer incidence increases with crop productivity (due to a larger biomass), and also varies across years and regions.

Chemical control of stemborers can be ineffective because the larvae locate deeply inside the plant, and thus are not easily reached by insecticides. High volume applications are recommended to increase the control's effectiveness. Japan is one of the few countries where successful control of stemborers using insecticides has been reported. A number of cultural practices can also reduce stemborers' damage. Clipping rice seedlings before transplanting is popular and effective in eliminating eggs that lay on the tip of the leaf blade. Since vigorous plants enhance larvae growth, split fertilization has been found to reduce damage. Low harvesting and removal of the rice stubble also helps remove larvae and prevent future damage. Sequential planting is another cultural measure applied by farmers to reduce insect damage. Biological control by natural predators is also possible, but this practice has been thwarted by the overuse of insecticides. Efforts in creating insect resistant rice varieties have not had great success because high levels of natural resistance have not been found in rice breeding lines. As such, traditional breeding has not been able to provide more than moderate resistance. However, stemborer resistance is high in some wild rice species and is associated with an array of genes. Plant characteristics which increase resistance include high proportions of lignified tissues and silica cells, and the presence of a Compound A (pentadecanal) substance (Pathak and Khan, 1994). Although genetic variability has not been a significant source of resistance to stemborers,

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[28] Other rice insect pests include gall midge, green leafhopper, grain-sucking bugs, hispa, water weevil, armyworms, thrips, caseworms, mealy bugs and whorl maggots. The rice water weevil, for example, is one of the most damaging insect pests in Japan.

artificial resistance was successfully created by introducing genes from *Bacillus thuringiensis* (*Bt*), a bacteria found in most soils. The *Bt* genes produce toxins that reduce growth or kill the larvae feeding in the rice plant.

Uncontrolled, the stemborer larvae can cause average annual yield losses between 5 and 10 percent, with occasional severe outbreaks causing yield losses as high as 60 percent (Pathak and Khan, 1994; Ye et al., 2001). *Bt* hybrid rice was found to increase yields in outbreak years, up to 28.9 percent yield improvement as compared to non-*Bt* hybrid varieties (Tu et al., 2000). Traditionally, insecticides have been used to control stemborers and represent a significant source of costs in rice production. Huang et al. (2003) report rice pesticide costs in China of 25 dollars per hectare, representing 7 to 8 percent of the total variable costs for the crop. Their study also showed that large benefits from the adoption of *Bt* cotton by Chinese farmers were due to the reduction in insecticide costs. Heong et al. (1994) report that insecticides represent 89 to 92 percent of all pesticide applications in rice in Vietnam and Philippines, and that stemborer control represents 8.1 to 10.3 percent of the total number of applications. Therefore, *Bt* rice could eventually lead to a substantial reduction in the use of pesticides.

4.1.2. Drought stress and drought resistant rice

Drought is a severe constraint to rice production because the rice crop requires more water per unit of biomass than any other commercial crop. Drought affects the rain-fed ecosystems, where regularity and amount of precipitation are highly uncertain, but drought also negatively impacts irrigated areas, creating shortages in water sources and reducing control of irrigation systems. Average rice crop losses from drought have been estimated between 3 percent for favorable irrigated environments and 17 percent for upland rice (Dey and Upadhyaya, 1996). Drought not only causes productivity losses but also significantly reduces grain quality. Drought is becoming a particular concern in Asia because increasing water scarcity limits the option of investing in irrigation systems for rice production.

The critical stages at which water stress affects rice production are seedling, vegetative growth, flowering and grain-filling. At the seedling and vegetative growth stages, lack of water reduces plant emergence and root development, and severe droughts can result in complete crop failure. At the reproductive stage, drought stress reduces the production of hormones that control panicle emergence from the sheath leaf (gibberellins), and increases production of abscisic acid, which inhibits panicle emergence (Barclay, 2005).

The unpredictability of drought stresses and its impact at different plant stages creates a complex problem for rice research. Dominated by multiple traits and with low heritability, traditional breeding has made slow progress in developing drought tolerant varieties. In addition, the mechanisms to cope with drought stress are not similar across rice sub-species. For example, *Japonica* varieties develop better root systems and are able to extract water at deeper soil layers, while *Indica* varieties respond by osmotic adjustment reducing plant transpiration (Robin et al., 2002). One of the problems traditional breeding has also encountered is that several wild rice species are drought tolerant, but the traits that govern tolerance expression do not combine well with those that govern high yield.

Rice research tackles drought constraints in farmers' fields under different approaches, including traditional breeding, crop management techniques, and biotechnology. In recent years, however, molecular biology has improved the chances of making faster progress towards developing successful drought resistant rice varieties by identifying, for instance, genes that are responsible for the production of gibberellins (Barclay, 2005).

4.1.3. Weeds and herbicide resistant rice

Estimates of average crop losses caused by weeds are higher than for any other production constraint due to the "omnipresence" of weeds in rice fields (Savary et al., 2000a). The potential for weed infestation is high in every year and in every production condition, while outbreaks of pests and diseases or even drought, although sometimes more damaging than weeds, are less frequent. Savary et al. (2000b) report that average crop losses due to weeds in tropical Asia are between 21 and 23 percent. Weeds compete with the crop for nutrients and water absorption and for light capture, and also reduce the grain quality when weed biomass mixes with rice harvests.

Unlike with pests and some abiotic stresses such as drought, yield losses due to weed infestation remain stable with changes in attainable yield and cannot be linked to specific environments. Rather, weed incidence is correlated with cropping practices that may vary within the same rice ecosystem. For instance, intensive hand weeding in upland rice reduces yield losses due to weeds. In contrast, in some rainfed ecosystems a combination of direct seeding practices and low use of herbicides yields sub-optimal weed control. Uncontrolled weeds, however, are a greater problem in unfavorable environments than in favorable irrigated environments, where water immersion partially suppresses weed growth.

The two mainstream rice crop establishment techniques in Asia (transplanting and direct seeding) interact with weed control practices. For example, transplanting and hand weeding are more frequently used in flood and drought-prone areas and contribute to better weed control in these environments. In fact, the main reason for transplanting is weed control (Barclay, 2006). Direct seeding and herbicides, on the other hand, are used primarily in favorable rainfed and irrigated environments. However, use of direct seeding (and herbicides) or transplanting (and hand weeding) is also associated to the relative scarcity of water and labor and therefore to relative prices. Where wages are low, hand weeding is more common, but water and labor scarcity in some areas are pushing farmers into direct seeding practices despite the higher complexity of this cropping system. Interaction between irrigated ecosystems and adoption of modern varieties also increase labor demand for crop care and weeding (David et al., 1994; Barker and Herdt, 1985).

Herbicide resistance in rice opens the possibility of using broad-spectrum herbicides with minimal damage to the rice plant and increased farming efficiency. Improved weed control is expected to reduce yield losses and herbicide costs, and in most Asian rice production conditions would also reduce labor costs. Adoption is likely to occur only in production systems using direct seeding instead of the more common transplanting technology (S.K. De Datta, pers. com. 2004).

4.2. Expected impacts of transgenic rice technologies: Model shocks

In ex-ante evaluations, estimates of average annual yield losses are frequently used as an indicator of potential output impacts of new agricultural technologies. The yield crop losses measure constraints to higher productivity in farmers' fields. The difference between actual farm yields and potential on-farm and experimental yields are defined as *yield gaps* and are a consequence of technical and socioeconomic constraints. *Yield gap I* is the difference between experimental yields and on-farm potential yields, while *yield gap II* is the difference between actual and on-farm potential yields. New agricultural technologies help to reduce losses caused by technical constraints in yield gap II. The remainder of yield gap II (an estimated average of 50 percent of the total gap range) and the totality of yield gap I represent socio-economic constraints and heterogeneity in production conditions between experimental plots and farms (Evenson et al., 1996). New agricultural technologies also impact the optimal input mix, the production cost structure and the output price. The combined change in all components is measured as a change in the unit-cost of production. Assuming full adoption of the technology when appropriate, the use of crop loss estimates is a conservative approximation to the expected yield impact of transgenic rice varieties and is the approach taken to assess impacts in the current study. In addition, changes in input use are also estimated when sufficient evidence exists (i.e., for herbicide resistance rice).

4.2.1. Stemborer resistant rice

For stemborers, Savary et al. (2000a) found average annual yield losses of 2.3 percent accross lowland areas of tropical Asia. To account for the larger incidence of stemborers in favorable environments, the yield change applied to unfavorable environments is assumed to be only 1.0 percent in the current study. More specific information exists for some countries. Widawsky and O'Toole (1996) estimated average annual crop losses for favorable and unfavorable (rain-fed) ecosystems in Eastern India of 2.15 and 1.65 percent, respectively. In Bangladesh, the losses were estimated at 2.76 and 1.43 percent for favorable and unfavorable environments, respectively (Dey et al., 1996). Losses in the favorable environment of Indonesia were estimated at 3.16 percent (Jatileksono, 1996). In China, Lin and Shen (1996) 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 (Widawsky et al., 1998). For the current simulations, the shock for unfavorable environments in China is therefore set at 1.0 percent.

No changes in input costs are assumed, although insecticide use may decline after the adoption of stemborer resistant technology, as it has been the case with *Bt* Cotton (Huang et al., 2003; Qaim and De Janvry, 2003; Elbehri and MacDonald, 2004). For purposes of exploring potential impacts of the stemborer resistant technology, full adoption is assumed in Asia.

Stemborer is not much of a problem outside the region and therefore no adoption of stemborer resistant rice is assumed in countries outside of Asia.

4.2.2. Drought resistant rice

Drought is a severe constraint to rice production, especially in rain-fed ecosystems. Average annual yield losses have been estimated at 3 percent for favorable environments and 7, 17 and 1 percent for rain-fed lowlands, uplands and deepwater ecosystems of unfavorable environments, respectively (Dey and Upadhyaya, 1996). The yield changes applied to the model in the present study weight these estimates for each country using the production proportions in table 2.3. Estimates of yield increases also assume that drought resistant varieties recover 50 percent of the losses in favorable environments and 60 percent in unfavorable environments. Similar to stemborer resistance, full adoption of the drought resistant rice variety is only assumed in Asian regions, given the large proportion of irrigated rice in the United States, the likely delay of adoption of any genetically modified rice in Africa, and limited information on drought losses in Latin America[29]. Assumed drought losses may be underestimated as well because farmers may adjust their cropping systems in ways that reduce risk to drought but lower rice production. The impacts of such coping mechanisms are not considered in the model.

4.2.3. Herbicide resistant rice

Modeling the herbicide resistant technology differs from the previous technologies in two areas. First, output and optimal input mix changes are assumed, due to increased costs of herbicides and seeds, and reduced costs of labor. Second, the presence of the private seed sector is acknowledged and will be discussed in section 4.4.

Average annual yield losses due to weeds at the farm level are estimated at 7 to 26 percent, with an average of 16 percent, despite efforts to manually or chemically control them (Oerke et al., 1994; Savary et al., 2000a). In fact, improved weed control with herbicide resistant rice varieties has increased yields between 5 and 10 percent in the United States (Oard et al., 1996; Bond et al., 2003). Moody (1996) reports that hand-weeding efficacy is about 70 percent, with

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[29] Implications of these assumptions are discussed later with the results.

residual weeds left in the field interfering with plant growth at different stages. An herbicide resistant technology is unlikely to eliminate all losses caused by weeds, although its efficacy is likely to be much greater than hand-weeding or conventional chemical use (Giannessi et al., 2002). The present study assumes a recovery rate of 90 percent of the losses reported by Oerke et al. (1996) for farmers who adopt the new technology.

In the current model, the cost of seed and herbicides is assumed to increase by 15 percent, the former due to a price mark-up for the improved technology and the latter to increased use. Labor costs are reduced by 15 percent in favorable environments and 30 percent in unfavorable environments. Further, adoption of the herbicide resistant technology is assumed to occur in favorable environments and rain-fed lowland eco-systems of the unfavorable environments, but not in upland or flood-prone eco-systems. Thus, for the herbicide resistant technology the yield increases presented for the unfavorable environments in table 4.2 are for the rain-fed lowland eco-systems only, weighted by the respective production proportions[30].

The shocks applied to the different environments in each Asian country also reflect the extent of adoption of direct seeding technologies reported in Pandey and Velasco (2002) and assume full adoption in those areas (table 4.1). For the non-Asian regions, adoption is assumed to be proportional to the adoption of modern rice varieties reported in Evenson (2000) and Maredia et al. (1998), with the shares increasing with economic development and for irrigated environments. The following adoption rates are assumed for the herbicide resistant technology in non-Asian regions: United States, 42.5 percent; Latin America, 23.5 percent in favorable environments and 6.5 percent in unfavorable environments; Africa, 10 percent in favorable environments only; and the Rest of the World, 30 percent in favorable environments.

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[30] To apply the biased shocks in the GTAP model, the magnitudes are further adjusted by the input and factor cost shares in each region (Frisvold, 1997).

Table 4.1. Direct seeding adoption in Asian regions (% of total rice area).

Regions	Irrigated	Rainfed Lowland
China	5.54	0.00
India	4.00	22.65
Indonesia	0.00	15.72
Bangladesh	3.82	0.00
Vietnam	35.89	34.69
Thailand	36.00	29.06
Philippines	35.00	33.58
Japan	0.01	NA
Rest of Asia	6.89	8.51

Source: Study estimates based on Pandey and Velasco (2002).

The current state of weed control technologies for rice production in the developed regions (Japan, United States and Rest of the World) and in Latin America indicates that herbicide resistant varieties are expected to cause a substitution among herbicides with little impact on labor use. Drawing from the adoption of herbicide-resistant technologies such as Round Ready® soybeans suggests that some cost savings can also be expected (Moschini et al., 2000; Penna and Lema, 2003). Ex-ante analyses of transgenic rice in the United States assume cost reductions in the use of chemicals of more than 15 percent with respect to the conventional technology (Annou et al., 2000; Bond et al., 2003). In some states, however, small cost increases with respect to the current technology may be possible (Giannessi et al., 2002). Cost reductions or increases will depend on the relative prices and amounts of herbicides used with the new and the old technologies and on labor and machinery cost differences. The present study assumes that no changes in labor, machinery, and chemical use occur in the developed regions and Latin America. Because this simplifying assumption may need to be adjusted in the future when more specific field data are available, an alternative scenario incorporating herbicide related input cost reductions is also discussed in the results.

Assumed output increases for country-specific environments under the three rice technologies are presented in table 4.2. Simulations of output increases are obtained by shocking the output technical change variable *aoall* in the GTAP model. Input changes are modeled by shocking the variable *afall* for herbicides (chemicals) and seed, and *afeall* for labor (unskilled). The next section presents the results obtained with the simulation experiments applying the model shocks described above.

Table 4.2. Assumed output increases from transgenic rice technologies in the model (%).

	Stemborer resistance		Drought resistance		Herbicide resistance	
Country	Favorable	Unfavorable	Favorable	Unfavorable	Favorable	Unfavorable*
China	2.30	1.00	1.50	5.09	0.73	0.00
India	2.15	1.65	1.50	4.55	0.72	3.58
Indonesia	3.16	1.00	1.50	5.00	0.00	1.96
Bangladesh	2.76	1.43	1.50	4.01	0.84	0.00
Vietnam	2.30	1.00	1.50	4.34	6.04	5.33
Thailand	2.30	1.00	1.50	4.16	7.43	5.64
Philippines	2.30	1.00	1.50	4.54	7.22	6.53
Japan	1.50	0.00	1.50	0.00	0.003	NA
Rest of Asia	2.30	1.00	1.50	4.38	1.08	1.19
USA	0.00	0.00	0.00	0.00	2.85	NA
Latin Amer.	0.00	0.00	0.00	0.00	4.99	0.02
Africa	0.00	0.00	0.00	0.00	2.26	0.00
ROW	0.00	0.00	0.00	0.00	4.68	0.00

Source: Model assumptions (note: * indicates yield increase for the lowland rain-fed eco-system area only).

4.3. Results under perfect competition

This section presents the results obtained with the simulation experiments under perfect competition (no seed sector rents with the herbicide resistant technology). The welfare impacts are expressed as an equivalent variation (EV) measure, both at the global and the regional level. Implications of changes in production, prices and trade due to the model shocks are discussed. Changes in demand due to population increases are also investigated, and compared to the scenario when no demand shifts are assumed.

4.3.1. Welfare impacts

Preliminary estimates of welfare gains are presented for all three rice technologies in table 4.3[31]. Associated changes in rice production, rice and processed rice prices, and rice exports and imports are presented in appendix D for each country and for each environment. Overall, welfare gains from the three technologies are similar in magnitude, with gains from rice technologies with stemborer resistance, drought resistance, and herbicide resistance estimated at 2.3 billion, 2.5 billion, and 2.2 billion dollars, respectively[32]. For specific countries, the greatest gains from stemborer resistant and drought resistant transgenic rice technologies would be realized by China, India, Indonesia, Japan, and to a lesser extent Bangladesh. Countries such as Thailand and Vietnam that are leading rice exporters will experience declining terms of trade that will offset about half of their potential gains. In fact, Thailand may experience little increase in welfare from stemborer resistant rice, both because of the terms of trade effect and because the country produces a significant proportion of its rice in unfavorable rainfed ecosystems. Thailand does experience larger gains for drought resistant and especially herbicide resistant rice, technologies more applicable to production constraints experienced in rainfed lowland ecosystems.

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[31] Welfare effects represent the total change in EV in moving from the initial equilibrium to the new, post technical change equilibrium. They are not the total discounted benefits over time from the change in technology, but the result of moving from one annual snapshot to another where all markets have adjusted in the new equilibrium.
[32] If complete adoption is assumed, the largest gains are for the herbicide-resistance technology with a total equivalent variation ($13.6 billion) that is more than five times greater than for the other two technologies.

Table 4.3. Welfare effects of three types of transgenic rice.

	Equivalent variation (EV, $ million dollars) for resistance to:		
	Stemborer	Drought	Herbicide
China	440.6	228.1	189.3
India	521.3	671.8	484.1
Indonesia	257.6	280.9	94.8
Bangladesh	98.4	162.8	16.9
Vietnam	23.9	26.2	72.9
Thailand	15.4	55.0	124.4
Philippines	76.3	98.2	303.3
Japan	403.4	431.3	115.1
Rest of Asia	427.9	600.9	338.4
USA	-21.5	-58.6	4.3
Latin America	-11.6	-26.2	39.3
Africa	1.8	-1.1	-109.3
ROW	44.6	49.6	492.9
Total	2,278.1	2,518.8	2,166.5

Source: Simulation results.

China receives the largest gains of any country for the stemborer resistance technology, and the second largest for the herbicide and drought resistant technologies. Some of these gains are derived from changes in technical efficiency that reduce the demand for own-seed production and, in the case of herbicide tolerant rice, the cost of labor. The United States, Latin America, Africa, and the Rest of the World are assumed not to adopt the stemborer resistant and drought resistant technologies and thus experience terms of trade and welfare losses. Stemborer is almost non-existent outside of Asia, and drought is also not 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.

A separate run including adoption of drought resistance in Africa was made and indicates that the region would experience significant welfare losses that would reduce global benefits from drought resistance to 2.3 billion. The source for these losses is an output subsidy to the rice sector that creates large allocative efficiency losses that more than offset technology gains (appendix D.1). Thus, the protectionist policy impedes the African region from realizing the full potential benefits from the technology. This result implies that elimination of protection for the rice sector would be valuable if the region is to face large technological changes in rice production, as it may be expected with the recent developments of a new rice variety for Africa (NERICA) and its potential widespread adoption (WARDA, 2006).

Herbicide resistant rice is assumed to impact all regions (the United States, Latin America, Africa, and the Rest of the World) in addition to Asia, with each region except for Africa, gaining from the technology. In the United States, potential gains are offset by negative terms of trade effects. Implications of private sector participation as a provider of the herbicide resistant technology are presented in section 4.4, and therefore are not discussed here.

Japan is an interesting case. First, it produces primarily *Japonica* rice, which has less of a yellow stemborer problem than the *Indica* rice found in more tropical areas. Second, it produces mostly irrigated rice, which reduces its gains from drought resistant and herbicide resistant rice, but Japan still receives a significant gain from each of these technologies. The reason for these gains is the high support price for rice (roughly ten times the world price). In the database, rice and processed rice sectors in Japan are protected by import tariffs of more than 400 percent[33]. In a separate analysis, Japan is found to gain more if it removes its paddy and processed rice tariffs than if it adopts the new transgenic technologies. It is possible that Japan will be slow to adopt transgenic technologies because of strong opposition to transgenic rice in the country. This reluctance to allow genetically modified (GM) rice may also lead to trade problems for countries exporting GM rice to Japan if they adopt the GM technologies, and potentially change the results for those countries (Nielsen et al., 2001). Some also suggest that, together with direct seeding practices, adoption of herbicide resistant rice in Japan could help to address high labor costs and the issue of an aging rural population in the country (Barry, 2005).

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[33] In contrast to Africa, where protection comes from an output subsidy and results in welfare losses, Japan's tariff policy does not create negative allocative efficiency effects in the region as measured by GTAP.

Focusing on increased stemborer and drought resistance, total projected gains for the world are similar. The latter is more suited to upland areas where 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 an argument could be made for the public sector to focus on drought resistance for the fragile upland area. However, stemborer resistant rice is closer to market than drought resistant rice, and the gains to stemborer resistant rice may be understated because the model was not adjusted to reflect possible reduced insecticide use. Additional analysis when field data becomes available would help to identify if insecticide cost reductions with the stemborer technology are attained to support this conclusion. Moreover, an additional expected benefit from drought resistance is to reduce yield variability and risk in rice production. These benefits are not accounted for in the model, but might be large considering that farmers in less-favored areas are in general the most risk-averse.

Turning to herbicide resistance, India receives the largest gains because of the size of the output changes, and because the technology is suitable for rain-fed areas, which represent a large share of the total rice area in the country. In fact, India is the only region gaining significantly from all three technologies. The Rest of Asia and the Philippines are also major beneficiaries of herbicide resistance, followed by China, Japan, the Rest of the World and Indonesia. All regions gain except Africa, as noted above. The Philippines, Thailand, and Vietnam experience significant benefits from herbicide resistance compared to stemborer and drought resistance because of their large areas of direct seeding (between 31 and 41 percent of total area). In terms of the welfare decomposition, the largest contribution to welfare gains (85 percent) comes from yield losses avoided as opposed to changes in input use.

Additional runs of the model explored an alternative assumption of reduction between 15 and 45 percent in herbicides use. Results show that, given the larger share of the output effect compared to the input use effect, marginal gains are small with total EV increasing to a maximum 2.22 billion dollars. Distribution of benefits remains similar, with Vietnam showing larger increases than any other region due to the larger share of its chemicals sector in the original data (22 percent). For all regions, the most relevant change is that the sign of the herbicide effect turns positive.

4.3.2. *Welfare decomposition: Sources of welfare*

The welfare results presented in the previous section can be decomposed into distinct sources: technical change, allocative efficiency and terms of trade effects. Investment-savings balance is another source of welfare but its effects in all cases are very small, so it will not be discussed here. Other welfare sources have a value of zero in the current simulations. Tables 4.4, 4.5 and 4.6 present the decomposition of welfare for the three transgenic technologies. In all adopting regions and for all three technologies, the largest contribution to welfare is from technical change effects, which outweighs all other effects. The magnitude of the technical change effects is related to the technology shocks in table 4.2.

Table 4.4. Welfare decomposition: Stemborer resistance ($ million).

	Alloc.	Tech.	TOT	IS	Total
China	-38.2	488.7	-9.9	0.0	440.6
India	28.2	517.4	-24.6	0.4	521.3
Indonesia	-7.0	262.9	1.6	0.0	257.6
Bangladesh	-2.1	93.9	4.5	2.1	98.4
Vietnam	-1.0	30.1	-5.4	0.3	23.9
Thailand	1.6	36.6	-22.7	-0.1	15.4
Philippines	-1.3	68.6	7.8	1.2	76.3
Japan	27.9	346.4	33.5	-4.3	403.4
Rest of Asia	10.5	390.0	26.8	0.5	427.9
USA	1.5	0	-24.5	1.5	-21.4
Latin America	-2.0	0	-9.4	-0.3	-11.6
Africa	1.2	0	0.7	0.0	1.8
ROW	24.2	0	21.7	-1.3	44.6
Total	43.5	2,234.6	0.0	0.0	2,278.1

Source: Simulation results (Alloc: allocative efficiency; Tech: technical change; TOT: terms of trade; IS: investment-savings balance).

Drought and herbicide resistance, with 2.7 and 2.56 billion dollars respectively, produce larger technical change effects on aggregate than stemborer resistance, but these gains are partially offset by larger negative allocative efficiency effects of 182 and 391 million dollars, respectively. China for drought resistance and Africa and Latin America for herbicide resistance are the individual regions with the largest negative allocative efficiency effects. On the other hand, with stemborer resistance the positive allocative efficiency effects of 43 million dollars add to technical change effects of 2.28 billion dollars and explain why global welfare with stemborer is larger than with herbicide resistance.

For all three technologies, technical change effects are positive in all adopting regions and zero in non-adopting ones. For stemborer resistance, there are no technical change effects in the United States, Latin America, Africa and the Rest of the World. The Rest of the World is the only one of these regions with positive global welfare due to positive allocative efficiency and terms of trade effects. Africa's gains are small, and negative terms of trade effects result in negative welfare for the United States and Latin America. For most of the adopting regions, gains from technology are much larger than other welfare effects. In China, allocative efficiency and terms of trade are negative and reduce the gains from technological change (488 million dollars) by 48 million dollars. In India, allocative efficiency and terms of trade are of opposite sign and nearly offset one another, and therefore the aggregate gains are similar to the gains from technical change. In Japan and the Rest of Asia, both allocative efficiency and terms of trade are positive and contribute to increase regional welfare. Relative to other Asian regions, Vietnam and Thailand experience little gains from the technology, and negative terms of trade effects further reduce these gains.

The decomposition pattern from drought resistance in China shows that the technical change effect is smaller than for stemborer resistance because most of rice production in the country is under irrigation, although the large rice sector still creates sizable benefits compared to other regions. However, technical change gains in China are reduced to almost half by a large negative allocative efficiency of 190 million dollars. India has the largest gains because of its large proportion of unfavorable environments suitable to drought resistance technology. Thailand again reduces technical change gains because of negative terms of trade effects, although the overall gains are larger than with stemborer resistance because most rice production in the country is in unfavorable environments. Impacts in the rest of the regions are similar to results reported for the stemborer resistance technology. The Rest of Asia enjoys larger technical change effects because this region includes several countries with unfavorable production conditions (notably Myanmar, one of the ten largest rice producers and consumers).

Table 4.5. Welfare decomposition: Drought resistance ($ million).

	Alloc.	Tech.	TOT	IS	Total
China	-191.7	390.7	35.9	-6.8	228.1
India	-44.2	741.7	-27.5	1.8	671.8
Indonesia	-13.5	284.7	9.6	0.1	280.9
Bangladesh	-12.1	165.8	6.3	2.7	162.8
Vietnam	-1.2	34.7	-11.9	4.5	26.2
Thailand	2.3	101.9	-48.8	-0.4	55.0
Philippines	-4.2	85.0	15.8	1.6	98.2
Japan	48.8	346.2	41.0	-4.7	431.3
Rest of Asia	0.7	550.5	48.7	1.1	600.9
USA	-0.1	0	-60.6	2.1	-58.6
Latin America	-5.2	0	-20.2	-0.7	-26.2
Africa	0.6	0	-1.7	-0.1	-1.1
ROW	37.3	0	13.4	-1.2	49.6
Total	-182.5	2,701.2	0.0	0.0	2,518.7

Source: Simulation results (Alloc: allocative efficiency; Tech: technical change; TOT: terms of trade; IS: investment-savings balance).

As mentioned before, the magnitude of technical change effects for the herbicide resistance technology is associated with the adoption of direct seeding technology (table 4.1). Technical change gains from herbicide resistance in China are smaller compared to stemborer and drought resistance, but allocative efficiency effects are positive (although small) and therefore the country's overall gains are comparable to those obtained with drought resistance. India again experiences large technical change effects with the herbicide resistance technology that counterweigh negative (but smaller) allocative efficiency and terms of trade, making India the largest single winner with this technology.

Table 4.6. Welfare decomposition: Herbicide resistance ($ million).

	Alloc.	Tech.	TOT	IS	Total
China	23.3	171.1	-5.2	0.1	189.3
India	-60.6	571.0	-27.6	1.3	484.1
Indonesia	-8.9	95.6	8.1	-0.1	94.8
Bangladesh	-0.1	13.4	3.4	0.2	16.9
Vietnam	1.8	85.4	-18.3	4.0	72.9
Thailand	8.0	191.8	-74.8	-0.6	124.4
Philippines	2.9	264.9	31.2	4.4	303.3
Japan	85.0	0.7	35.0	-5.6	115.1
Rest of Asia	26.6	267.0	44.7	0.1	338.4
USA	6.4	38.9	-44.2	3.2	4.3
Latin America	-242	292.3	-11.3	0.3	39.3
Africa	-237.4	123.9	4.3	-0.1	-109.3
ROW	3.7	441.7	54.9	-7.4	492.9
Total	-391.2	2,557.8	0.0	0.0	2,166.5

Source: Simulation results (Alloc: allocative efficiency; Tech: technical change; TOT: terms of trade; IS: investment-savings balance).

In contrast to stemborer and drought resistance, technology gains in Thailand and the Philippines are large with herbicide resistance because both countries have large areas under direct seeding. In Thailand, the export-oriented rice economy again hurts the technological change gains with negative terms of trade, although overall welfare is still positive. In Vietnam there is also a large proportion of direct seeding, but gains are smaller due to a smaller rice sector (approximately half that of Thailand). In Africa and Latin America, technology impacts are positive but significant negative allocative efficiency greatly reduces the gains. Rice is a protected sector in the aggregated African region of the model, with little trade with the rest of the world, and the negative allocative efficiency responds to a greater policy-induced loss.

Technical change effects can be further decomposed into other sources. In the case of stemborer and drought resistance technologies, the only sources for technical change are the output increases in table 4.2. In contrast, herbicide resistance technology also implies changes in input and factor use (seed, herbicide and labor costs). To analyze the contribution of each of these sources, technical change effects for this technology are decomposed in table 4.7.

Table 4.7. Herbicide resistance: Technical change decomposition ($ million).

	Output	Seed	Herbic.	Labor	Total
China	153.0	-5.4	-1.2	24.6	171.0
India	520.4	-5.9	-2.4	58.9	571.0
Indonesia	71.7	0	-0.9	24.8	95.6
Bangladesh	13.3	-0.1	-0.1	0.3	13.4
Vietnam	86.3	-0.5	-5.3	4.9	85.4
Thailand	166.8	-0.2	-0.2	25.5	191.9
Philippines	233.3	-1.8	-2.8	36.3	265.0
Japan	0.7	0	0	0	0.7
Rest of Asia	240.8	-0.6	-1.6	28.5	267.1
USA	39.1	-0.1	0	0	39.0
Latin America	292.3	-0.1	0	0	292.2
Africa	112.7	-0.5	-0.6	12.3	123.9
ROW	443.0	-1.4	0	0	441.6
Total	2,373.4	-16.6	-15.1	216.1	2,557.8

Source: Simulation results.

On aggregate, output augmentation explains the largest proportion (92.8 percent) of total technical change effects for the herbicide resistance technology. Most of the regions gain significantly from output increases except Japan, where adoption of herbicide resistant technology is assumed to be very low. Gains from labor savings are second to output gains (8.4 percent), an indication that the combined adoption of direct seeding and herbicide resistance technologies may indeed contribute to reducing production costs in labor scarce regions of Asia. Moreover, labor savings are almost seven times larger than increases in seed and herbicide costs. The greater the proportion of unfavorable environments (India, the Philippines, Indonesia, Rest of Asia, and Thailand), the larger the contribution of labor savings to technical change, due to the assumption that savings in these ecosystems are larger. In China, most labor savings are from favorable environments. Vietnam labor savings equal the increased costs of herbicides because their share in the country's cost structure is similar (appendix C).

In summary, the main contribution to technical change effects are the expected output increases. Labor savings contribute significantly, although in much smaller proportion than output increases. However, labor savings outweigh cost increases in seed and herbicides and play an important role in the relative returns that might be expected from the herbicide resistant technology.

4.3.3. Welfare decomposition: Environments

The previous section presented the welfare decomposition by source, concluding that the majority of welfare can be explained by output augmentation as a component of the technical change effect. This section presents the welfare contribution of each environment to the output augmentation effect, for each region and on aggregate. Such decomposition gives insights into the linkage between the proportion of each environment in each region, the magnitude of the technology shocks, and the benefits from each technology (table 4.8).

On aggregate, 82 percent of the output benefits from stemborer resistance are originated in favorable environments. On the other hand, most unfavorable environments contribute only marginally to output gains from stemborer resistance, except in India. China has the largest output from favorable environments with 477 million dollars, representing more than 21 percent of total global output effects from the technology. The large benefits obtained in China from stemborer resistance explain why this country is the first Asian region to adopt transgenic technologies containing the same trait, although for another crop (*Bt* cotton). In Bangladesh, which overall captures small benefits from stemborer resistance, benefits are equally shared between favorable and unfavorable environments. In Thailand, where unfavorable environments are predominant, total benefits from stemborer resistance are small.

Table 4.8. Decomposition of output effects: Environment contribution ($ million).

	Stemborer resistance		Drought resistance		Herbicide resistance	
Region	Favorable	Unfavorable	Favorable	Unfavorable	Favorable	Unfavorable*
China	477.3	11.4	301.6	89.1	153.0	0
India	335.1	182.3	223.8	517.9	107.8	412.6
Indonesia	228.7	34.3	105.3	179.4	0	71.7
Bangladesh	43.0	50.9	21.4	144.4	13.3	0
Vietnam	26.1	4.0	16.4	18.3	66.4	20.0
Thailand	13.9	22.6	8.6	93.2	43.4	123.4
Philippines	58.5	10.0	36.8	48.2	171.0	62.4
Japan	346.4	0	346.2	0	0.7	0
Rest of Asia	311.7	78.3	196.5	353.9	145.8	95.0
USA	0	0	0	0	39.0	0
Latin Amer.	0	0	0	0	291.8	0.5
Africa	0	0	0	0	112.8	0
ROW	0	0	0	0	443.0	0
Total	1,840.8	393.8	1,256.7	1,444.5	1,587.8	785.7

Source: Simulation results.

In contrast to the findings for stemborer resistance, marginal environments benefit greatly from the drought resistance technology, contributing to more than 53 percent of the total output augmentation. The unfavorable areas of India are the largest beneficiaries, with 518 million dollars, for all country environments and all three technologies. In Indonesia and the Rest of Asia, benefits from drought resistance are also large. Marginal environments in Bangladesh and

Thailand obtain significant benefits from drought resistance and advocate for strong support for this technology in these countries. Had Africa been assumed to adopt the technology, technology benefits to the region would have been positive and large (435 million), with more than 87 percent accruing to unfavorable environments. Regional welfare, however, would decrease due to larger negative allocative efficiency (appendix D.1). It is interesting to note that with drought resistance, favorable environments in most regions also contribute significantly to total output because the assumed output shocks in these areas (50 percent recovery of a three percent yield loss) are only slightly smaller than expected output shocks for stemborer resistance.

Output increases associated with herbicide resistance are larger in favorable environments than in unfavorable ones (1.58 billion and 786 million dollars, respectively). The latter, however, also benefit significantly and much more than with stemborer resistance, but not as much as with drought resistance. The unfavorable areas of India are again the largest winners in Asia with herbicide resistance technology, gaining 412 million dollars. These environments are large in India and direct seeding is adopted in 22 percent of the area. The favorable environments of Latin America, Africa and the Rest of the World enjoy output gains with herbicide resistance because many of these areas are under direct seeding technology. Favorable environments in the Philippines, Rest of Asia and India also increase output significantly, as do unfavorable environments in Thailand. Vietnam output increases more with this technology than with stemborer and drought resistance, mostly in favorable environments. A common view is that herbicide resistance technology benefits large, commercial farmers in favorable environments. However, the output gains associated with herbicide resistance are linked to adoption of direct seeding, and this production process can also be found in unfavorable areas. Therefore, based on the results in table 4.8, herbicide resistance is also beneficial for farmers in less favored environments, as long as they can overcome the complexity of the technology.

4.3.4. Production, price and trade impacts

Production response to the model shocks varies across regions and for each technology (appendix D.2). Aggregate paddy rice production response in irrigated and non-irrigated areas is given in table 4.9. All three technologies increase world paddy rice production by less than one percent. Irrigated paddy rice production increases 1.57 percent with stemborer resistance, while non-irrigated paddy rice production decreases 3.33 percent. On aggregate, paddy rice production increases 0.23 percent with stemborer resistance. With drought resistance, irrigated paddy rice production decreases 2.54 and production from non-irrigated areas increases 8.13 percent. World rice production increases 0.37 percent. Herbicide resistance technology provides the largest world production response with 0.57 percent, with 1.67 percent increase in irrigated and 2.34 percent decrease in non-irrigated areas.

Table 4.9. Paddy rice production response (%).

	Irrigated paddy rice	Non-irrigated paddy rice	World paddy rice
Stemborer	1.57	-3.33	0.23
Drought	-2.54	8.13	0.37
Herbicide	1.67	-2.34	0.57

Source: Simulation results.

The aggregated production gains produce a world decline in paddy and processed rice prices for all regions and all technologies, although adopting regions in general experience larger price reductions. Paddy price in adopting regions declines between 1.8 and 3.8 percent for stemborer resistance, between 1.8 and 5.4 percent for drought resistance, and between 0.1 and 11.2 percent for herbicide resistance. Although the model does not allow for separate estimates of consumer and producer gains, these price effects favor consumers in all countries.

With regard to trade, exports increase for regions adopting stemborer and drought resistance technologies, with non-adopting regions increasing imports. For the herbicide resistance technology, impacts vary across regions. Philippines, Thailand and Vietnam increase exports of paddy and processed rice between 3.9 and 42.7 percent, while other regions resort to increased imports to supply the domestic market.

4.3.5. Land and labor markets

Effects on the land market show mixed impacts, but in those environments where technologies have larger impacts land demand increases (appendix D.3). The overall effect, however, is to reduce the composite rental price of land in most countries. Labor demand also varies significantly across environments and across the three technologies. However, an interesting result is that wages remain stable and in some cases may even increase slightly (e.g., drought resistance), as a reflection of factor market adjustments that occur.

The welfare effects from technical change are shocks to the supply side of the economy. In the general equilibrium framework of the present study, it is interesting to analyze the welfare consequences of simultaneous demand shocks.

4.3.6. Summary of results under perfect competition

Global welfare impacts from adopting stemborer, drought or herbicide resistant rice in Asia are large and positive, although non-adopting regions may experience welfare losses. The output augmentation effects from technical change drive welfare gains in all cases. With herbicide resistant technology, labor savings prove to be significant and larger than increases in seed and herbicide costs, but do not hurt labor wages. An obvious implication is that labor scarcity in some regions may be an important motivation for adopting the labor-saving herbicide resistant technology. Favorable environments are large winners with stemborer resistance, while with drought resistance unfavorable environments experience large benefits without significantly reducing benefits accrued to favorable areas. Benefits from herbicide resistance increase with direct seeding adoption rates, regardless of the environment.

The results presented in the preceding section assumed that technologies are supplied as public goods. In the next section this assumption is changed by considering that herbicide resistance is supplied by a private firm.

4.4. Results under monopoly power

This section presents the results for herbicide resistance technology delivered by private firms with monopoly power in the market for transgenic seed. Data and justification for markup levels and domestic markup shares used in the simulation are presented first. Welfare impacts under monopoly power assumptions are then discussed. The results for the herbicide resistance technology are compared with those under perfect competition, and conclusions from the analysis are drawn in the last section.

4.4.1. Markup levels and domestic shares

The simulation of monopoly power in the study requires data on markups to shock the exogenous monopoly tax variable (*tmono*), and on domestic profit shares for the markup share parameter ($MKPSHR_r$). Markup values estimates for transgenic crops in developing countries are available mostly for *Bt* cotton and herbicide resistant soybeans, the two most widely adopted transgenic crops. From 1999 to 2001, *Bt* cotton seed costs per hectare in China ranged from slightly less than five percent higher to three hundred percent higher compared to their non-*Bt* counterpart (Pray et al., 2002). In India, *Bt* cotton seed costs for the 2002/2003 season were estimated to be two hundred percent higher than those of conventional cotton varieties (Qaim et al., 2006; Bennett et al., 2006). An ex-ante study by Huang et al. (2004) estimated markups of 120 percent for *Bt* cotton and 50 percent for transgenic rice. The authors mention that surveyed markups tend to decline over time. Markup in developed countries might be higher but studies have used a range of values. Bond et al. (2003), for instance, apply seed markups between 30 and 60 percent to evaluate the economic impacts of herbicide resistant rice in California.

The markup levels noted above are relatively high. They may reveal what companies are able to extract from early adopters of the technology. High initial markups may also be a financial strategy intended to obtain early returns to cover development costs. Equilibrium markup levels depend on the degree of market power that monopolists enjoy and the elasticity of demand. In turn, market power depends on the status of intellectual property rights in each country and the ability to enforce them. Observed markups may not be consistent with equilibrium, optimal monopoly profits and adoption rates. It has been shown, for instance, that sub-optimal pricing strategies for *Bt* cotton seed in Argentina decreased adoption of *Bt* varieties and company's profits. The *Bt* cotton seed markup was almost 3 times higher than farmers' willingness to pay, resulting in lower adoption rates, increased illegal planting, and reduced monopoly profits (Qaim and de Janvry, 2003). In contrast, widespread adoption of herbicide resistant soybeans in Argentina could be linked to a low seed markup of 20 percent over conventional seed costs. The low markup level produced more than 80 million dollars in profits for the technology owner between 1996 and 2001, even though enforcement of property rights in Argentina is considered weak (Qaim and Traxler, 2005). The evidence suggests that in developing countries, with weaker IPR regimes and more elastic demand schedules, markups are smaller but potentially large seed markets still produce attractive profits for seed companies. Results for *Bt* cotton in Argentina also show room for price discrimination according to farm size, with lower optimal markups for small farms. In fact, given strong IPR settings, monopoly companies are willing to price discriminate. In South Africa, for instance, small farmers pay a technology fee for *Bt* cotton that is less than 40 percent the fee charged to large-scale farmers (Gouse et al., 2004).

Early work on monopoly power theory suggests that equilibrium markup levels range from zero to 20 percent. Higher markups are challenged by the existence of relatively close substitutes for the input (in this case, conventional seeds) and the threat of entry or imitation (Harberger, 1962). In the case of transgenic seeds, and particularly in developing countries, farmers can also reduce seed density and resort to farm saved seed with open-pollinated varieties, effectively reducing seed costs per hectare. The current simulation applies a benchmark markup value of 30 percent for rice seeds in USA and Japan. The markup is reduced to 20 percent for rice seed in favorable environments of the remaining regions. To represent some degree of price discrimination, markups for rice seed in unfavorable environments are 50 percent those of favorable areas. The values are applied to the monopoly tax instrument (*tmono*) and the final shocks include adjustments by direct seeding areas.

The simulation also requires selecting a parameter value for domestic profit shares (parameter $MKPSHR_r$). In several developing countries, multinational firms have contracted with local seed companies to produce and distribute transgenic seeds through licensing. Therefore, a proportion of the monopoly profits remain locally instead of being transferred to the multinationals' original region. The $MKPSHR_r$ parameter can also represent other situations. For example, publicly developed transgenic varieties of *Bt* cotton already exist in China and successfully compete (or even partner) with Monsanto's products. The public varieties have been capturing an increasing share of the *Bt* cotton planted area, with local companies keeping some claim on private profits. Upper-bound estimates of Monsanto's markup share in China are in the order of 40 percent (Pray et al., 2001)[34].

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[34] The study by Pray et al. (2001) provides a hint to explain the high transgenic seed costs reported in other studies. According to the authors, a large proportion of the seed costs paid to government seed companies in China are just returns to factors of production in the transgenic seed sector, with no private rents created. Therefore, the high seed costs do not reflect actual true markup values. Following Falck-Zepeda et al. (2000), the assumption in the current model is that production costs for transgenic and conventional seeds are similar. Thus, the use of a smaller markup value is justified.

Not every developing country has China's capacity in biotechnology to compete for the production and commercialization of transgenic crops. Within the developing world, only China, India and Brazil seem to be able to develop a biotechnology sector capable of producing commercial transgenic crops (Pray, 2001). These countries can eventually claim a larger domestic share of profits than the rest of the regions. The domestic markup share used in the current study for China and India is therefore set at 60 percent. Because Brazil is part of an aggregated region where other countries have smaller biotech capacity, the domestic markup share is set at 50 percent for Latin America. The markup share parameter assumes a value of 100 percent in the United States and Japan. For all other regions, domestic markup share is set at 40 percent. Table 4.10 presents the final values for the monopoly tax shock (*tmono*) and for domestic profit shares ($MKPSHR_r$) applied in the simulation.

Table 4.10. Monopoly tax shocks and domestic profits shares under imperfect competition.

	Markup Shock (%)		Profits domestic share (%)
	Favorable	Unfavorable	
China	1.00	0.00	60
India	0.72	2.04	60
Indonesia	0.00	1.41	40
Bangladesh	0.69	0.00	40
Vietnam	6.46	3.12	40
Thailand	6.48	2.62	40
Philippines	6.30	3.02	40
Japan	0.00	0.00	100
Rest of Asia	1.24	0.77	40
USA	11.48	0.00	100
Latin America	4.28	0.06	50
Africa	1.75	0.00	40
ROW	5.40	0.00	40

Source: Model assumptions.

One additional assumption is made for the simulation under monopoly power. To account for the impact of increased seed costs in reducing the relative profitability of the technology, adoption rates are assumed to decline to 90 percent with respect to those assumed in the simulation under perfect competition. All shocks are adjusted according to this assumption, included in the values reported in table 4.10. For example, in Vietnam the markup tax of 20 percent for favorable environments is adjusted by direct seeding adoption rates of 35.89 percent in table 4.1 and then further reduced to 90 percent, to give the final value for the markup shock of 6.46 percent in table 4.10. In the case of unfavorable environments, the assumed base markup for the shock calculation is half that of favorable environments (10 percent).

4.4.2. Welfare impacts and monopoly rents

Welfare impacts (EV) and private rents generated by the monopoly power model are presented in table 4.11. The results also include the rents that are transferred to the USA region as multinational firms' profits. Moreover, the rents are sourced to the environment in which they are created.

Table 4.11. Welfare impacts and rents for herbicide resistance under monopoly power ($ million dollars).

		Private sector rents			
	EV	Favorable	Unfavorable	Total rents	Rents transfer
China	169.6	19.0	0.0	19.0	7.6
India	434.4	9.7	22.3	32.0	12.8
Indonesia	86.3	0.0	0.1	0.1	0.06
Bangladesh	14.6	0.9	0.0	0.9	0.54
Vietnam	62.7	4.7	0.8	5.5	3.3
Thailand	111.8	1.2	2.2	3.4	2.04
Philippines	263.7	12.0	2.3	14.3	8.6
Japan	102.2	0.0	0	0.0	0.0
Rest of Asia	297.9	7.9	3.0	10.9	6.54
USA	77.6	4.9	0	4.9	4.9
Latin America	57.8	4.0	0.0	4.0	2.0
Africa	-64.1	6.6	0.0	6.6	3.96
ROW	434.1	20.4	0.0	20.4	12.24
Total	2,048.4	91.3	30.7	122.0	64.56

Source: Simulation results.

Results show that adoption of herbicide resistant rice varieties supplied by private firms increases world equivalent variation by 2.05 billion dollars and leaves 122 million dollars in profits for the private sector. Thus, the technology's welfare impact is robust to model assumptions and is only 5.4 percent lower under monopoly power than under perfect competition. The regional distribution of welfare is also similar when compared to perfect competition. Equivalent variation in most of the regions is reduced between 9 and 14 percent but is still positive. Latin America increases welfare by 47 percent and Africa, the only region experiencing negative welfare with herbicide resistance, reduces its losses by 41 percent. Equivalent variation in the United States increases significantly from 4 million dollars under perfect competition to 77 million dollars under monopoly power. The large welfare increase in the United States is due to the transfer of almost 60 million dollars in rents from all other regions, which add to 5 million dollars of domestically generated rents. Therefore, the private rents boost welfare in the United States but do not significantly reduce the gains in each of the other regions individually. The largest transfers correspond to India and the Rest of the World with little more than 12 million dollars each. The Philippines, China and the Rest of Asia transfer between 6.5 and 8.6 million dollars each, and all other regions transfer less than 4 million dollars each.

Almost 75 percent (91 million dollars) of the rents are generated in favorable environments and the remainder (30.7 million dollars) in unfavorable environments. The favorable environments contribute more due to the larger economic size and also because a higher markup is assumed for these environments. Individually considered, the unfavorable environments in India are the largest rent creators with 22 million dollars, followed by the favorable environments in the Rest of the World and in China with 20 million and 19 million dollars respectively. The Rest of the World includes rice production areas in regions such as Australia and the European Union, where capture of rents by domestic firms is likely[35]. In China, although adoption of direct seeding is relatively low, the large rice economy still generates large profits compared to other regions (market size effect). The favorable environments in the Philippines and India also produce sizable profits between 9.7 and 12 million dollars. In the Philippines, adoption of direct seeding in favorable environments is assumed at 35 percent and therefore creates an attractive market size for firms. In India, adoption of direct seeding in favorable areas is much lower (four percent) but the larger size of the rice economy implies that the effective

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[35] As mentioned before, if these regions were assumed to be home for shareholders of multinational firms, then a share of the rent transfer would also accrue to the regions, adding to the rents captured by domestic firms.

market size is larger than that of the Philippines. The favorable environments in the Rest of Asia and Africa generate profits of 7.9 and 6.6 million dollars respectively. All other environments in all other regions generate less than 5 million dollars in profits each, given the assumptions about technology adoption.

Decomposition of technical change effects shows that output gains and labor savings are much larger than losses due to higher seed and herbicide costs (table 4.12)[36]. Consistent with the perfect competition case, output augmentation explains most of the technical change effect (92.8 percent). The absolute magnitude of the output effect is also similar (both on aggregate and for each region individually considered) to results generated by the model under perfect competition. Likewise, labor savings more than offset seed and herbicide costs. In China, India, Indonesia, Thailand, the Philippines and the Rest of Asia, labor savings obtained with herbicide resistance technology are enough to offset the private rents. In Vietnam and Bangladesh rents are slightly higher, and only in the Rest of the World rents are significantly higher because no labor savings were assumed in modeling herbicide resistance for this region.

The robustness of the results to alternative model assumptions is also explored. For example, assuming full adoption of herbicide resistant rice (as if all rice area was under direct seeding) increases rents but also technology gains proportionally. An interesting implication of this result is that private companies willing to increase their effective market size for the herbicide resistant technology could eventually partner with the public sector in campaigns promoting direct seeding, as a marketing strategy to indirectly induce an increased demand for the transgenic technology.

The study also explores an alternative markup specification of 100 percent for all regions. With no changes in adoption assumptions, rents increase to 588 million dollars, but technological change effects are still almost four times larger (2.3 billion dollars). Therefore, given the current cost structure of firms in the model data, benefits from technological change outweigh potentially large increases in seed costs. It is worth noting, however, that the model does not allow for producers to respond to seed cost increases (which reduce technology's profitability) by reducing technology adoption.

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[36] The seed costs in the decomposition of technical change are from the previous assumption of an increase in seed costs of 15 percent and not from the monopoly tax. The computation of rents in the model is done separately from the technical change calculations.

Finally, the current simulation assumes a share of profits remain domestically. Under the extreme assumption that all profits accrue to multinational firms and are transferred to the United States, global welfare remains almost unchanged. Changes to regional distribution are not large and most regions maintain similar levels of welfare impacts, except for the United States which increases equivalent variation from 77.6 million to 138 million dollars. Thus, the extreme assumption still produces large welfare gains globally and regionally and only welfare in the United States region is significantly altered.

Table 4.12. Herbicide resistance under monopoly power: Decomposition of technical change (EV, $ million dollars).

	Output	Seed	Herbic.	Labor	Total
China	138.3	-4.8	-1.1	22.2	154.6
India	468.4	-5.3	-2.2	52.9	513.8
Indonesia	64.7	0.0	-0.8	22.3	86.2
Bangladesh	11.8	-0.1	-0.1	0.3	11.9
Vietnam	78.0	-0.4	-4.8	4.4	77.2
Thailand	151.0	-0.2	-0.2	23.0	173.6
Philippines	212.1	-1.7	-2.5	32.9	240.7
Japan	0.7	0.0	0	0	0.7
Rest of Asia	216.8	-0.6	-1.4	25.7	240.5
USA	35.2	-0.1	0	0	35.1
Latin America	261.5	-0.1	0.0	0	261.4
Africa	99.5	-0.5	-0.5	10.8	109.4
ROW	400.4	-1.2	0	0	399.2
Total	2,138.6	-15.2	-13.5	194.4	2,304.3

Source: Simulation results.

4.4.3. Summary of results under monopoly power

The results of the simulation under monopoly power reveal that, at 2.05 million dollars, global welfare gains from herbicide resistance are close to those obtained under perfect competition, despite markups on seed costs. Output augmentation effects in the model are the largest welfare driver, and labor savings in many regions are enough to cover seed cost increases due to monopoly markups. The regional distribution of welfare is comparable to that of perfect competition for most of the regions, with no region significantly hurt by the higher seed costs and the rents transfer. The United States is the only region benefiting significantly more because it is the recipient of all seed rents from other regions. Total rents generated are estimated at 122 million dollars, with nearly 65 million dollars accruing to the United States. The results are robust to changing assumptions about markups, adoption rates and domestic shares of profits. A first conclusion is that, as long as markups are not excessively high, claims that monopoly pricing schemes extract most of the benefits from the technology are not warranted based on the current simulation. Rather, there seems to be interesting room for complementary strategies between public and private sectors to make the effective market for seed companies more attractive, for example by promoting direct seeding adoption in labor scarce areas.

4.5. Sensitivity Analysis

This section presents sensitivity analyses conducted to determine the robustness of results to changes in model assumptions. Simulation results are driven by assumed technology shocks, which represent unit-cost reductions achieved under production conditions. The aggregate effect of unit-cost reductions is to create a rice supply response that starts the general equilibrium effects in the model. The shift in the rice supply curve depends on the magnitude of expected unit-cost reductions and also on adoption assumptions, both of which are embedded in the technological change variables in the model. Thus, given the model structure, conducting sensitivity analyses on the expected technological change variable (*aoall*) is equivalent to changing assumptions on adoption rates and on the expected supply curve shift. Results for the sensitivity analyses are presented in equivalent variation measure and their values compared to those obtained in the original perfectly competitive simulations (as a percentage change in adjacent columns).

First, the sensitivity of welfare change to a 50 percent increase in the output augmenting technical change variable is examined in table 4.13. Global welfare increases for all three technologies, but more for stemborer resistance (44 percent) than for drought and herbicide resistance (39 and 24.5 percent respectively). In most of the regions and for all technologies, welfare changes less than the change in the technology variable, with some exceptions. For stemborer resistance, welfare change ranges between 42 and 49.2 percent, except for China, the United States, Latin America and Africa. In China, welfare increases by only 30 percent because technology gains are partially offset by negative allocative efficiency effects that increase more than three-fold. The allocative efficiency effects originate in the rice sector. In the United States and Latin America, changes in welfare are proportional but negative, because negative terms of trade for those regions also increase proportionally. In Africa, welfare increases by more than 50 percent but from a very small original value.

Global welfare from drought resistance also increases less than the increase in technological change, because negative allocative efficiency effects offset part of the technology gains. At the regional level, negative allocative efficiency effects increase in China, reducing welfare for this region compared with the base run simulation. Because of the large magnitude of welfare effects in China compared to other regions, this result explains a large proportion of the changes in global welfare. In Africa, changes are compared to a very small original value and therefore have little impact on global impact. Overall, sensitivity of results with drought resistance is larger than for stemborer resistance because of the response in China.

Regarding herbicide resistance, a 50 percent increase in technological change increases global welfare 24.5 percent. The result is due in part to the assumptions for herbicide resistance technology. Input changes (labor savings, chemicals and seed cost increases) are also assumed for herbicide resistance, but only the output augmenting technology variable is changed for the sensitivity analysis. A second cause is the large negative allocative efficiency effects that reduce welfare in Latin America and Africa, as output of a domestically protected sector increases with the adoption of the improved technology.

Table 4.13. Sensitivity analysis: 50 percent increase in output augmenting technical change variable ($ million).

	Stemborer resistance		Drought resistance		Herbicide resistance	
Region	Welfare	Change (%)	Welfare	Change (%)	Welfare	Change (%)
China	576.4	30.8	199.8	-12.4	251.5	32.8
India	769.3	47.6	951.2	41.6	655.4	35.4
Indonesia	374.3	45.3	404.9	44.2	126.5	33.4
Bangladesh	144.0	46.3	230.4	41.5	24.2	42.8
Vietnam	34.1	42.6	36.6	39.9	105.9	45.2
Thailand	22.9	48.4	80.2	46.0	171.3	37.6
Philippines	111.4	46.0	140.3	42.9	420.2	38.5
Japan	598.8	48.4	637.9	47.9	163.7	42.2
Rest of Asia	628.2	46.8	861.4	43.4	481.4	42.2
USA	-31.5	-46.8	-84.6	-44.4	6.6	54.4
Latin Amer.	-16.8	-44.7	-37.3	-42.3	-109.9	-379.7
Africa	2.9	57.6	-1.0	-6.4	-298.3	-172.9
ROW	65.6	47.0	72.3	45.8	698.5	41.7
Total	3,279.4	43.9	3,492.0	38.6	2,697.0	24.5

Source: Simulation results.

In summary, when the technological change variable increases by 50 percent, stemborer resistance results are more robust than drought and herbicide resistance. The latter is the least robust of all three technologies because input changes in the technology are not affected and allocative efficiency effects increase in regions were rice is a protected sector. Thus, after the sensitivity shock, global welfare changes with herbicide resistance are lower than for stemborer and drought resistance.

Next, a sensitivity analysis is conducted assuming a 50 percent reduction in the technological change variable (table 4.14). This analysis may also represent an equivalent reduction of adoption rates for the stemborer and drought resistance technologies, instead of full potential adoption assumed in the base simulations. Results are more robust for a reduction in expected technological shock than it was for an increase. This is explained because a smaller shock implies that marginal changes are smaller and the new equilibrium is closer to the initial situation. Global welfare changes for the stemborer and drought resistance decrease by 48 and 46 percent, respectively, while for herbicide resistance welfare is reduced by 38 percent compared to the base simulation. For stemborer and drought resistance, the change in welfare in most regions follows the magnitude of the shock reduction. In China, however, welfare decreases less for drought resistance because negative allocative efficiency effects originated in the non-irrigated rice sector are smaller. Thus, China is able to capture the technology gains while the negative allocative efficiency effects are reduced compared to the base simulation.

For herbicide resistance, since the output shock is smaller, allocative efficiency effects that drive some of the reductions in welfare are also smaller. Therefore, on aggregate results are more robust with a reduction in technical change than with an increase in the same variable.

In summary, the sensitivity analysis shows that when technical change increases, the contribution of increased output varies because additional general equilibrium effects, such as allocative efficiency losses, increase in magnitude. However, if technical change is reduced by 50 percent, there are still large global benefits to realize from the three technologies. This result would cover, for example, the case when stemborer and drought resistance are not fully adopted and their potential adoption rates reduced from 100 to 50 percent.

Table 4.14. Sensitivity analysis: 50 percent decrease in output augmenting technical change variable ($ million)

	Stemborer resistance		Drought resistance		Herbicide resistance	
Region	Welfare	Change (%)	Welfare	Change (%)	Welfare	Change (%)
China	248.9	-43.5	164.5	-27.9	114.9	-39.3
India	264.8	-49.2	355.0	-47.2	283.3	-41.5
Indonesia	132.8	-48.4	146.2	-48.0	60.6	-36.1
Bangladesh	50.7	-48.5	86.0	-47.2	9.0	-46.8
Vietnam	12.6	-47.4	13.9	-46.7	36.8	-49.5
Thailand	7.8	-49.5	28.3	-48.6	74.2	-40.4
Philippines	39.2	-48.6	51.5	-47.5	175.0	-42.3
Japan	203.9	-49.5	218.8	-49.3	63.0	-45.2
Rest of Asia	218.6	-48.9	314.5	-47.7	189.5	-44.0
USA	-11.0	48.8	-30.5	48.0	2.1	-52.1
Latin Amer.	-6.0	48.0	-13.8	47.3	76.9	95.6
Africa	0.9	-53.3	-0.8	29.1	-3.5	96.8
ROW	22.7	-49.0	25.4	-48.7	262.8	-46.7
Total	1,185.7	-48.0	1,359.0	-46.0	1,344.6	-37.9

Source: Simulation results.

4.6. Conclusions

The ex ante benefit estimates in the present study indicate that rice biotechnologies are expected to have significant cross-country and cross-sector effects, and the presence of favorable and unfavorable environments will influence the level and distribution of benefits from the technologies. The general-equilibrium-model results highlight the significance of gains from product and factor adjustments when technologies favor specific environments. It appears that a technology for unfavorable environments, such as drought resistance, may have as much economic impact as a technology for favorable environments such as stemborer resistant rice. Arguments about which type of technology the public sector should emphasize depend as well on how the private sector responds in the future as hybrid rice becomes more important in favorable environments 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. Benefits from the herbicide-resistant rice technology, although potentially much larger than those from the other two technologies, are reduced because expected adoption is limited under the current rice production systems in Asia. Aggregate expected benefits are therefore similar among all three technologies. Were the herbicide resistant technology provided by private firms, the technology would still produce large welfare gains with the markup specification used in the current study. The results of the study are, as noted, preliminary given the nature of the ex-ante analysis and the uncertainty surrounding many assumptions. Estimated impacts of each technology at the firm level can be improved when more field data by region become available as the technologies are released and adopted by farmers. At that time, adoption assumptions would become a more deterministic variable, as would the technology cost structure at the farmers' fields.

Chapter 5. Conclusions and policy implications

At the outset of the twenty-first century, lack of enough food to pursue a healthy and productive life is still a problem for a large share of world's population. Most chronically hungry people live in unfavorable rural areas where productive natural resources are scarce, basic infrastructure is inadequate and poverty is widespread. Such is the picture in many of the rice growing regions in Asia. The agricultural sector can play a critical role in improving their living conditions, both as a direct provider of cheap food and as the main income source for the rural population. Improved agricultural technologies are a primary source of growth in the agricultural sector, as demonstrated by the large reductions in poverty achieved through high-yielding varieties developed during the Green Revolution by the public sector. In this context, it has been debated whether biotechnology can provide the basis for a new revolution in agriculture. Concerns remain about the adaptability of transgenic crops to less favored lands and the perceived detrimental presence of multinational companies on crop returns. Previous studies show positive impacts from transgenic rice, but the topic deserves a deeper analysis in which the issues described above are more formally addressed.

This study investigated the potential economic impacts of three transgenic rice technologies: stemborer resistance, which is more suitable for favorable irrigated environments; drought resistance, which addresses a major constraint in unfavorable non-irrigated environments; and herbicide resistance, which can potentially benefit any of the environments but can only be adopted in areas under direct seeding. Equivalent variation welfare measures obtained from simulating the impacts of the three technologies are fairly similar at 2.3 billion, 2.5 billion and 2.2 billion dollars for stemborer, drought and herbicide resistance respectively. As expected, most of the benefits from stemborer resistance are captured in favorable environments, while drought resistance produces larger welfare gains in unfavorable environments. With herbicide resistance, benefits are distributed according to adoption of direct seeding. All three technologies are expected to increase global rice output and to reduce rice prices while keeping labor wages at stable levels. Private provision of herbicide resistance rice keeps global welfare at comparable levels (2.05 billion dollars) while creating 122 million dollars in private profits. Although profits increase in the model if companies decide to charge higher markups, there are still large social benefits to realize from herbicide resistance technology.

The methods employed in this investigation are innovative in several respects. First, the specification of each of the technology impacts was based on extensive literature review and expert opinion. The use of average values for the expected impact instead of potential maximum losses is better suited to the static general equilibrium model developed for the study. Unlike previous studies, the approach permits comparison between individual transgenic rice technologies and identifies single regions as principal beneficiaries. Second, taking into account the rice production ecosystems adds an extra dimension to the analysis that proves to be important in the results obtained. Indeed, the environments imply two distinct production systems in which each technology has unique impacts. Future studies on rice technology impacts should consider this modeling framework in their analysis. Third and last, the empirical simulations introduced new features to the applied GTAP model used in the study. The GTAP database was decomposed to represent the rice environments and the paddy rice and rice seed sectors. The resulting data structure provides valuable input for similar analysis and for use as benchmark information for future adjustments to the database. Furthermore, the GTAP model code was also modified to correctly represent the rice environments, and to include the presence of monopoly power in the supply of the seed input. The latter implies changes in the income computation of the model to include monopoly rents. The model also allows for the transfer of monopoly rents between regions. This novel model design applied theoretically sound methods and can be used for similar analysis with other versions of the GTAP model.

The empirical model adopts a simplified structure for the monopoly power that introduces some rigidity to the behavior of agents. Producers do not respond to an increased markup by reducing adoption of transgenic technology, and therefore adoption is an exogenous variable in the model. This is because the monopoly maximizing rule is not modeled and therefore results are not related to the elasticity of demand for transgenic seed. For the same reason, markup values do not represent optimal markups for the monopolists. Introducing the monopoly rule framework would likely result in a reduction of welfare due to increased deadweight losses created by the monopolist presence.

The findings from the present study lead to important policy implications. The expected benefits from stemborer, drought and herbicide resistance rice technologies are similar and of large magnitude, although smaller than previous estimates that used more generous technology shocks. If these benefits are a close measure of social returns, then all technologies are attractive enough to encourage public research investments on biotechnology, and the decision of which technology to develop first should be made on grounds other than potential benefits. Stemborer resistance is a technology that has already been developed, which reduces development costs and increases marginal returns to investment compared to drought resistance. Therefore, the initial decision of the public research system to concentrate research efforts on *Bt* rice seems reasonable. Since stemborer resistance is a trait governed by only one gene, it was a strategic decision to choose it over the multi-gene drought resistance trait. Ultimately, the stemborer resistance technology was acquired from the private sector and helped the public sector gain critical knowledge and experience in biotechnology research. The public sector strategy was therefore not unfounded and, if *Bt* rice makes its way to farmers fields in Asia, the study results suggest it will have a high payoff.

What is next then for rice biotechnology research? Both drought and herbicide resistance are potential candidates for research efforts, and research is underway on both of them. A similar line of reasoning as for *Bt* rice, however, may not be sound. Herbicide resistance is less costly, has higher probability of research success and in fact the technology is ready for commercial release, barring regulatory and commercial constraints. The results of this study suggest that despite higher costs farmers may have to pay for improved seeds, herbicide resistance technology output gains still create large benefits for those who adopt it. Moreover, monopoly profits for the private sector are, on a global basis, probably just enough to encourage companies to participate in the market. Imposing further restrictions would only deter private firms from offering the technology (and indeed firms have been doing so owing to commercial uncertainty).

Drought resistance technology combines several positive impacts that have been the concern and the topic of debate for diverse interest groups: large economic benefits for farmers in unfavorable environments; no additional investments or expenditures on inputs would be required, in principle, to adopt the technology; less dependence on irrigation, saving increasingly scarce water resources; and minimal consumer and environmental safety concerns arising from the biotechnology procedures. Developing a drought resistance rice variety would provide large benefits to rice farmers in marginal lands. Focusing on constraints in less favored environments creates the opportunity to put rice biotechnology at the service of those who received fewer benefits from the Green Revolution. These benefits to marginal areas might boost the image of biotechnology in the eyes of those who claim that it only benefits farmers in favorable environments. Furthermore, although the biological pathways to develop drought resistance are not known with precision, the technology should raise fewer environmental concerns than insect and herbicide resistance. Once ready for commercial release, drought resistant rice should be granted official approval relatively fast. Delays in obtaining governments' authorization in several countries, including China, have imposed significant costs to the stemborer resistance technology and have reduced potential benefits. Pressure from consumers' groups and non-governmental organizations have discouraged the public and private sectors from pushing the research agenda on biotechnology forward. Investing on research for drought resistance, while more challenging and risky, may help to overcome such delays and opposition.

Currently, there is little concerted effort in the private research sector to develop drought resistant varieties. However, such investments would be desirable on several grounds. First, it would increase the financial and intellectual resources allocated to solve a complex problem. More resources increase the probability of research success and reduce development lags. Second, private and public research working on similar problems could eventually increase efficiency because research groups might be compelled to coordinate their actions, while at the same time create a sense of competition for success. Third, the private sector's involvement in developing a technology suitable for the poorest farmers would help to cleanse the image of biotechnology firms, tarnished by allegations that their profit-driven research targets commercial crops with little concern for the needy and the environment. However, private firms require a return on their investment, and a mechanism to ensure that they obtain reasonable profits must be developed. Patenting of drought resistance technology is probably not a viable option because target farmers could eventually escape buying seed every year and enforcement costs would be high. But the public sector can play a role in providing appropriate incentives for private sector participation in the research endeavor, while keeping the final outcome in the public domain. The question is therefore how private firms can be providers of public goods. One option is the "pull" program suggested to develop vaccines for some basic maladies and diseases in developing countries (Kremer, 2002). Under the "pull" approach, the public sector commits to purchase the development of a public good under certain eligibility rules. The commitment rewards the actual delivery of the public good, acting as an incentive for the private sector to invest in its development. One of the attractiveness of such a scheme for the private sector is that, if successful, returns are guaranteed by the purchase commitment[37]. The "pull" approach could be implemented to promote private participation in research to develop drought resistant rice. The specific program design could involve the international and national research systems establishing purchase commitments for specific traits that could later be used by the public research system to develop the desired varieties. Drawing on the "pull" approach, similar strategies have been suggested to involve private capacity in biotechnology towards the goal of developing transgenic varieties that target the poor. For instance, one suggestion is to establish a competition to develop the transgenic variety in which the prize would cover the research costs and a premium equal to normal returns to research (Pinstrup-Andersen and Schiøler, 2000, p.143).

The mechanisms to encourage private sector research in drought resistant rice recognize the potential market failures that prevent biotechnology firms from engaging in such an enterprise. However, private research has been successful in developing herbicide resistance, even though in rice the varieties have not yet reached the market (an indication that other types of market failures also exist). In the context of scarce resources, public involvement in research on herbicide resistance is hardly justified. But concerns that, by setting high seed prices, private suppliers would reap most of the benefits that would otherwise accrue to producers, have cast a doubt that influences public research priorities. Results in the present study show that, under acceptable ranges and the assumptions of the study, higher seed costs still leave large benefits for producers from herbicide resistance, while keeping the magnitude of rents attractive to the private sector. Rather than opposing the private sector, the public sector would do better trying to increase the effective market size for biotechnology firms by correcting some of the market failures that arise with herbicide resistance technology. Clear intellectual property rights regulation is the key that opens the door for private firms, but other not so obvious constraints may also need to be addressed. For instance, public institutions could involve private firms in campaigns where all parties are interested, such as the promotion of direct seeding. These campaigns are needed because moving from transplanting to direct seeding implies fundamental changes in the production process and in the cultural background of rice farmers in Asia. On the

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[37] In addition to the public goods problem, another potential market failure that the "purchase commitment" approach addresses is that of time inconsistency, since governments would not be willing to recognize fixed research investments and would rather put pressure for the good to be sold at the lowest possible cost. "Neglected" human diseases that have been identified as targets for this type of program are HIV/AIDS, malaria and tuberculosis (Barder et al., 2006).

other hand, social benefits and private profits from herbicide resistance are proportional to the area under direct seeding. Meanwhile, mutual recognition from both private and public sector that proper attitudes can lead to a win-win situation should be built. Private firms have much to gain from increased technology adoption and from partnerships with the public sector. The present study shows that output effects (or yield effects) are in general large, and raising yield potential continues to be a central focus of public research. If the public sector develops superior germplasm with higher yields, the private sector would benefit from increased adoption rates. Therefore, it is also in the firms' interest that public institutions concentrate on what they do best.

The study assumes that consideration of the rice environments is crucial for the assessment of rice technologies, and that in fact the same technology applied to two environments behaves as two distinct technologies. This assumption gives some insight into why potential tensions may arise between national research systems and the international research system at the priority setting process. While countries with large proportions of unfavorable environments press for more research on technologies such as drought resistance, those with larger favorable lands are arguably more interested in technologies such as stemborer resistance. The economic rationale behind each argument differs: supporters of research for favorable environments would probably stress the spillover effects of market adjustments and the higher returns from research for those environments; supporters of research for unfavorable environments, on the other hand, would highlight the urgent need the poor have for technologies that address their specific constraints. Both arguments are valid according to the results of the study and the final research portfolio, rather than choosing between options, should weigh impacts and costs and the likelihood of a final product reaching the market. However, the study results have implications for where the public sector should be involved, and suggest drought resistance as the main focus of public research. On the other hand, findings in the present study highlight the importance of approaching the analysis of impacts from transgenic crops on a case by case basis.

Finally, there is promising hope that all the technologies evaluated in the study will provide abundant and affordable food for the population in Asia. The magnitude of potential benefits is large, and changes in input use or rents to the private sector do not reduce those benefits. This result demonstrates the importance that policy makers establish appropriate policies to facilitate the development and commercialization of transgenic varieties, including recommended environmental safeguards and other science-based regulations.

Several additional issues are left for further research. There are other transgenic rice technologies being developed whose potential impacts would be interesting to compare with the ones analyzed in the present study. These include resistance to bacterial blight (*Xa21* gene), Golden rice (provitamin A enriched) and C_4 rice (increased photosynthesis). Regarding the rice environments, and in particular the unfavorable ones, additional heterogeneity could be worth modeling. For instance, unfavorable environments include rainfed ecosystems whose yield is sometimes closer to that of irrigated ecosystems than to that of other rainfed or upland areas. Geographic information systems data could be used to identify these regions and more accurately represent the large heterogeneity of rice production. With respect to methods, alternative representations of monopoly power, such as including Lerner's rule in the model and fixing supply for the imperfectly competitive good according to its demand elasticity are interesting. This in turn could lead to reduced adoption of the technology, and coexistence of improved and conventional technologies. The basic theory for this framework is sketched in section *3.1.2.ii*.

References

Ahmed, A.U., and R.K. Sampath, 1992. Effects of Irrigation-Induced Technological Change in Bangladesh Rice Production. *American Journal of Agricultural Economics,* vol. 74(1): 144 - 157.

Alston, J.M., P.G. Pardey, and M.J. Taylor, 2001. Changing Contexts for Agricultural Research and Development. In: J.M. Alston, P.G. Pardey and M.J. Taylor (editors). *Agricultural Science Policy: Changing Global Agendas*. International Food Policy Research Institute (IFPRI). Johns Hopkins University Press.

Anderson, K., L.A. Jackson, and C.P. Nielsen, 2004. Genetically Modified Rice Adoption: Implications for Welfare and Poverty Alleviation. World Bank Policy Research Working Paper Nº 3380. The World Bank, Washington, D.C.

Anderson, K., C.P. Nielsen, and S. Robinson, 2002. Estimating the Economic Effects of GMOs: the Importance of Policy Choices and Preferences. In: Evenson R.E., V. Santaniello, and D. Zilberman (editors). *Economic and Social Issues in Agricultural Biotechnology*. CAB International Publishing, New York, NY.

Annou, M., E. Wailes, and G. Cramer, 2000. Economic Analysis of Adopting Liberty Link Rice. Special Report RCS 2000, Rice Situation and Outlook. Economic Research Service, United States Department of Agriculture, Washington, D.C.

Barclay, A., 2005. Dreams Beyond Drought. International Rice Research Institute (IRRI). *Rice Today*, vol. 4(2): 14 – 21.

Barclay, A., 2006. The Direct Approach. International Rice Research Institute (IRRI). *Rice Today*, vol. 5(2): 13 – 18.

Barder, O., M. Kremer, and H. Williams, 2006. Advance Market Commitments: A Policy to Stimulate Investments in Vaccines for Neglected Diseases. *The Economists's Voice*, vol. 3(3): 1 – 6. Available at: http://www.bepress.com/ev/vol3/iss3/art1.

Barker, R., and R.W. Herdt, 1985. *The Rice Economy of Asia*. Resources for the Future: Washington, D.C.

Barry, G., 2005. Ups and Downs: Private- Sector Investment in rice Research. International Rice Research Institute (IRRI). *Rice Today*, vol. 4(1): 38.

Blackorby, C., and R.R. Russell, 1989. Will the Real Elasticity of Substitution Please Stand Up? (A Comparison of the Allen/Uzawa and Morishima Elasticities). *The American Economic Review*, vol.79 (4): 882 – 888.

Bennett, R., U. Kambhampati, S. Morse, and Y. Ismael, 2006. Farm-level Economic Performance of Genetically Modified Cotton in Maharashtra, India. *Review of Agricultural Economics*, vol. 28(1): 59 – 71.

Bond, C.A., C.A. Carter and Y.H. Farzin, 2003. Medium Grains and High Stakes: Economics of Genetically Modified Rice in California. *AgBioForum*, vol. 6(4): 146 – 154.

Bourguignon, F., and C. Morrison, 2002. Inequality among World Citizens: 1820 – 1992. *The American Economic Review*, vol. 92(4): 727 – 744.

Byerlee, D., G. Alex, and R.G. Echeverria, 2002. The Evolution of Public Research Systems in Developing Countries: Facing New Challenges. In: Byerlee, D., and R. Echeverría (editors), *Agricultural Research in an Era of Privatization*. CABI Publishing, New York, NY: 19 - 34.

CGIAR, 2002. Biofortified Crops for Improved Human Nutrition: A Challenge Program Proposal. CGIAR discussion documents, September 2002. Consultative Group on International Agricultural Research, http://www.cgiar.org (Accessed October 2002).

______, 2004. CGIAR on line. Consultative Group on International Agricultural Research, http://www.cgiar.org (accessed March 2004).

Cohen, J.I., 2005. Poorer Nations Turn to Publicly Developed GM Crops. *Nature Biotechnology*, vol. 23(1): 27 – 33.

Coxhead, I.A., and P.G. Warr, 1991. Technical Change, Land Quality, and Income Distribution: A General Equilibrium Analysis. *American Journal of Agricultural Economics*, vol. 73(2): 345 – 360.

Datta, S.K., 2004. Rice Biotechnology: a Need for Developing Countries. *AgBioForum*, vol. 7(1&2): 31 – 35.

David, C.C., V.G. Cordova, and K. Otsuka, 1994. "Technological Change, Land Reform and Income Distribution in the Philippines". In: David, C.C. and K. Otsuka (editors). *Modern Rice Technology and Income Distribution in Asia*. Lynne Rienner Publishers, Boulder, CO & London, and the International Rice Research Institute (IRRI), Manila, Philippines: 51 – 106.

David, C.C., and K. Otsuka, 1994. "Modern Rice Technology: Emerging Views and Policy Implications". In: David, C.C., and K. Otsuka (editors). *Modern Rice Technology and*

Income Distribution in Asia. Lynne Rienner Publishers, Boulder, CO & London, and the International Rice Research Institute (IRRI), Manila, Philippines: 411 – 449.

Deaton, A., 2002. Is World Poverty Falling? *Finance & Development*, vol. 39(2): 4 – 7.

De Datta, S.K., 2004 (July). Personal Communication. Virginia Polytechnic Institute and State University. Blacksburg, VA.

de Kathen, A., 2000. Managing Biosafety Capacity Development: Technical and Political Aspects. In: Qaim, M., A.F. Krattiger, and J. von Braun, (editors). *Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor*. Kluwer Academic Publishers, Boston, MA: 39 – 67.

Dervis, K., J. De Melo, and S. Robinson, 1982. *General Equilibrium Models for Development Policy*. Cambridge University Press: New York, NY.

Dey, M.M., M.N.I. Miah, B.A.A. Mustsfi, and M. Hossain, 1996. "Rice Production Constraints in Bangladesh: Implications for Further Research Priorities". In: Evenson, R.E., R.W. Herdt, and M. Hossain (editors). *Rice Research in Asia: Progress and Priorities*. CAB International in association with the International Rice Research Institute (IRRI), Manila, Philippines: 179 – 191.

Dey, M.M., and H.K. Upadhyaya, 1996. "Yield Loss Due to Drought, Cold and Submergence in Asia". In: Evenson, R.E., R.W. Herdt, and M. Hossain (editors). *Rice Research in Asia: Progress and Priorities*. CAB International in association with the International Rice Research Institute (IRRI), Manila, Philippines: 291 – 303.

Dollar, D., and P. Collier, 2002. *Globalization, Growth and Poverty: Building an Inclusive World Economy.* World Bank Policy Research Report. The World Bank and Oxford University Press, Washington, D.C., and New York, NY.

Dollar, D., and A. Kraay, 2002. Growth is Good for the Poor. *Journal of Economic Growth*, vol. 7(3): 195 – 225.

Elbehri, A., and S. MacDonald, 2004. Estimating the Impact of Transgenic *Bt* Cotton on West and Central Africa: a General Equilibrium Approach. *World Development,* vol. 32(12): 2049 – 2064.

Estudillo, J.P., A.R. Quisumbing and K. Otsuka, 2001. Income Distribution in Rice-growing Villages During the Post-Green Revolution Periods: the Philippine Case, 1985 and 1998. *Agricultural Economics,* vol. 25(1): 71 - 84.

Evenson, R.E., 2000. Crop Genetic Improvement and Agricultural Development. Doc. SDR/TAC/IAR/00/17. Consultative Group for International Agricultural Research (CGIAR), Rome, Italy.

Evenson. R.E., 2002. From the Green Revolution to the Gene Revolution. In: Evenson R.E., V. Santaniello, and D. Zilberman (editors). *Economic and Social Issues in Agricultural Biotechnology*. CABI Publishing, New York, NY: 1 – 16.

Evenson, R.E., and D. Gollin, 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*, vol. 300(5620): 758 - 762.

Evenson, R.E., R.W. Herdt, and M. Hossain, 1996. "Priorities for Rice Research: Introduction". In: Evenson, R.E., R.W. Herdt, and M. Hossain (editors). *Rice Research in Asia: Progress and Priorities*. CAB International in association with the International Rice Research Institute (IRRI), Manila, Philippines: 3 – 15.

Falck-Zepeda, J.B., G. Traxler, and R.G. Nelson, 2000. Surplus Distribution from the Introduction of a Biotechnology Innovation. *American Journal of Agricultural Economics*, vol. 82(2): 360 – 369.

FAOSTAT, 2004. FAO Statistical Database. Food and Agricultural Organization (FAO), Rome, Italy. Available at <http://faostat.fao.org> (accessed October 2004).

FAOSTAT, 2006. Food Security Statistics. Food and Agricultural Organization (FAO): Rome, Italy. Available at <http://www.fao.org/es/ess/faostat/foodsecurity/index_en.htm>

Fan, S., and P. Hazell, 2000. Should Developing Countries Invest more in Less-Developed Areas? An Empirical Analysis of Rural India. *Economic and Political Weekly*, vol. 35(17): 1455 – 1464.

Fischer, S., 2003. Globalization and its Challenges. *The American Economic Review*, vol. 93(2): 1 - 30.

François, J.F., and D.W. Roland-Holst, 1997. "Scale Economies and Imperfect Competition". Chapter 11 in: François, J.F., and K.A. Reinert (editors). *Applied Methods for Trade Policy Analysis: A Handbook*. Cambridge University Press, Cambridge, United Kingdom: 331 – 363.

Frisvold, G.B., 1997. "Multimarket Effects of Agricultural Research with Technological Spillovers". In: Hertel, T.W. (editor). *Global Trade Analysis: Modeling and Applications*. Cambridge University Press, New York, NY: 321 – 346.

Gianessi, L.P., C.S. Silvers, S. Sankula, and J.E. Carpenter, 2002. "Plant Biotechnology: Current and Potential Impact for Improving Pest Management in U.S. Agriculture. An Analysis of 40 Case Studies". National Center for Food and Agricultural Policy, Washington, D.C.

Ginsburgh, V., and M. Keyzer, 1997. *The Structure of Applied General Equilibrium Models.* The MIT Press: Cambridge, Massachusetts.

Gouse, M., C. Pray, and D. Schimmelpfennig, 2004. The Distribution of Benefits from *Bt* Cotton Adoption in South Africa. *AgBioForum*, vol. 7(4): 187 – 194.

Greenland, D.J., 1997. *The Sustainability of Rice Farming*. International Rice Research Institute (IRRI). CAB International, Wallingford, U.K.

GTAP, 2006. Global Trade Analysis Project. Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University. https://www.gtap.agecon.purdue.edu/default.asp

Hanslow, K.J., 2000. A General Welfare Decomposition for CGE Models. GTAP Technical Paper Nº 19. Center for Global Trade Analysis, Purdue University: West Lafayette, IN.

Harberger, A.C., 1962. The Incidence of the Corporation Income Tax. *The Journal of Political Economy,* vol. 70(3): 215 – 240.

Harris, R., 1984. Applied General Equilibrium Analysis of Small Open Economies with Scale Economies and Imperfect Competition. *The American Economic Review*, vol. 74(5): 1016 – 1032.

Harvestplus, 2006. Breeding Crops for Better Nutrition. <www.harvestplus.org> (Accessed April 2006).

Hayami, Y., and R.W. Herdt, 1997. Market Price Effects of Technological Change on Income Distribution in Semisubsistence Agriculture. *American Journal of Agricultural Economics,* vol. 59(2): 245 - 256.

Hazell, P.B., and C. Ramasamy, 1991. *The Green Revolution Reconsidered: the Impact of High-Yielding Varieties in South India*. International Food Policy Research Institute. The John Hopkins University Press: Baltimore and London.

Heong, K.L., M.M. Escalada, and V. Mai, 1994. An Analysis of Insecticide Use in Rice: Case Studies in the Philippines and Vietnam. *International Journal of Pest Management*, vol. 40: 173 – 178.

Hertel, T.W. (editor), 1997. *Global Trade Analysis: Modeling and Applications*. Cambridge University Press, New York, NY.

Horridge, M., 2005. SplitCom: Programs to Disaggregate a GTAP Sector (Preliminary Draft). Centre of Policy Studies, Monash University, Melbourne, Australia.

Hossain, M., 1996. “Recent Developments in the Asian Rice Economy: Challenges for Rice Research”. In: Evenson, R.E., R.W. Herdt and M. Hossain (editors). *Rice Research in Asia: Progress and Priorities*. CAB International, in association with the International Rice Research Institute (IRRI), Manila, Philippines: 17 – 33.

Hossain, M., 2001. “Opening Address: The Challenge to Feed the World’s Poor”. In: Goode, J. and D. Chadwick (editors). *Rice Biotechnology: Improving Yield, Stress Tolerance and Grain Quality*. Novartis Foundation Symposium (Laguna, Philippines, 2000). John Wiley & Sons Ltd, England: 1 - 10.

Hossain, M., J. Bennett, S. Datta, H. Leung, and G. Khush, 2000. “Biotechnology Research in Rice for Asia: Priorities, Focus and Directions”. In: Qaim, M., A.F. Krattiger, and J. von Braun (editors). *Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor*. Kluwer Academic Publishers, Boston, MA: 99 – 120.

Huang, J., R. Hu, C. Pray, F. Qiao, and S. Rozelle, 2003. Biotechnology as an Alternative to Chemical Pesticides: a Case Study of *Bt* Cotton in China. *Agricultural Economics*, vol. 29(1): 55 – 67.

Huang, J., R. Hu, S. Rozelle, and C. Pray, 2005. Insect-Resistant GM Rice in Farmers’ Fields: Assessing Productivity and Health Effects in China. *Science,* vol. 308(5722): 688 – 690.

Huang, J., R. Hu, H. van Meijl, and F. van Tongeren, 2004. Biotechnology Boosts to Crop Productivity in China: Trade and Welfare Implications. *Journal of Development Economics*, vol. 75(1): 27 – 54.

Huff, K.M., and T.W. Hertel, 2001. Decomposing Welfare Changes in the GTAP Model. GTAP Technical Paper Nº 5. Center for Global Trade Analysis, Purdue University: West Lafayette, IN.

Huke, R.E., and E.H. Huke, 1997. *Rice Area by Type of Culture: a Revised and Updated Database.* International Rice Research Institute (IRRI), Manila, Philippines.

IRGSP (International Rice Genome Sequencing Project), 2005. The Map-Based Sequence of the Rice Genome. *Nature*, vol. 436(7052): 793 – 800.

IRRI, 1993. *1993-1995 IRRI Rice Almanac*. International Rice Research Institute (IRRI), Manila, Philippines.

____, 1997. *Bt Rice: Research and Policy Issues*. IRRI Information Series Nº 5, revised June 1997. International Rice Research Institute (IRRI), Manila, Philippines.

____, 2002a. Rice Facts. International Rice Research Institute (IRRI), Manila, Philippines, http://www.irri.org/Facts.htm (Accessed October 2002).

____, 2002b. Medium Term Plan 2003-2005. International Rice Research Institute (IRRI), Manila, Philippines, (available a <www.irri.org>).

____, 2005. Medium Term Plan 2006-2008. Achieving the UN Millennium Development Goals begins with Rice Research. International Rice Research Institute (IRRI), Manila, Philippines, (available a <www.irri.org>).

____, 2006. World Rice Statistics. International Rice Research Institute (IRRI), Manila, Philippines, http://www.irri.org (Accessed 2006).

James, C., 2005. Preview: Global Status of Commercialized Biotech/GM Crops: 2005. Executive Summary. ISAAA Briefs Nº 34. International Service for the Acquisition of Agri-biotech Applications (ISAAA), Ithaca, NY.

Jatileksono, T., 1996. “Rice Production Losses from Pests in Indonesia”. In: Evenson, R.E., R.W. Herdt, and M. Hossain (editors). *Rice Research in Asia: Progress and Priorities*. CAB International in association with the International Rice Research Institute (IRRI), Manila, Philippines: 251 – 257.

Jirström, M., 1996. *In the Wake of the Green Revolution. Environmental and Socio-Economic Consequences of Intensive Rice Agriculture: the Problem of Weeds in Muda, Malaysia*. Lund University Press, Lund, Sweden.

Keller, W.J., 1980. *Tax Incidence: a General Equilibrium Approach*. North Holland Publishing Company: Amsterdam, The Netherlands.

Khush, G., 2001. “Chair’s Introduction”. In: Goode, J. and D. Chadwick (editors). *Rice Biotechnology: Improving Yield, Stress Tolerance and Grain Quality*. Novartis Foundation Symposium (Laguna, Philippines, 2000). John Wiley & Sons Ltd., England: 11 – 12.

Kremer, M., 2002. A Purchase Commitment for Vaccines. In: Kaul, I., Le Goulven, K., and Schnupf, M. (editors). *Global Public Goods Financing: New Tools for New Challenges, a Policy Dialogue.* United Nations Development Program (UNDP). Available at http://www.undp.org/ods/ffd-monterrey.html

Lin, J.Y., and M. Shen, 1996. "Rice Production Constraints in China". In: Evenson, R.E., R.W. Herdt, and M. Hossain (editors). *Rice Research in Asia: Progress and Priorities*. CAB International in association with the International Rice Research Institute (IRRI), Manila, Philippines: 161 – 178.

Maclean, J.L., D.C. Dawe, B. Hardy, and G.P. Hettel (editors), 2002. *Rice Almanac: Source Book for the Most Important Economic Activity on Earth*. Third Edition. Published by the International Rice Research Institute (IRRI) in association with the International Center for Tropical Agriculture (CIAT), the West Africa Development Association (WARDA) and the Food and Agriculture Organization (FAO). CAB International, Wallingford, UK.

Maredia, M., D. Byerlee, and P. Pee, 1998. Impacts of Food Crop Improvement Research in Africa. Special Program for African Agricultural Research (SPAAR), Occasional Papers Series Nº 1. The World Bank, Washington, D.C. Available at <http://www.worldbank.org/afr/aftsr/impaper.pdf>

McDonald, S., and K. Thierfelder, 2004. Deriving a Global Social Accounting Matrix from GTAP Versions 5 and 6 Data. GTAP Technical Paper Nº 22. Center for Global Trade Analysis, Purdue University, West Lafayette, IN.

Mellor, J.W. (editor), 1995. *Agriculture on the Road to Industrialization*. Published for the International Food Policy Research Institute (IFPRI) by The John Hopkins University Press, Baltimore, Maryland.

Mills, B.F., 1997. Ex-ante Research Evaluation with Site Specific Technology Generation: the Case of Sorghum in Kenya. *Agricultural Economics,* vol. 16(2): 125 – 138.

Moody, K., 1996. "Priorities for Weed Science Research". In: Evenson, R.E., R.W. Herdt, and M. Hossain (editors). *Rice Research in Asia: Progress and Priorities*. CAB International in association with the International Rice Research Institute (IRRI), Manila, Philippines: 277 – 290.

Moschini, G., H. Lapan, and A. Sobolevsky, 2000. Roundup Ready® Soybeans and Welfare Effects in the Soybeans Complex. *Agribusiness*, vol. 16(1): 33 – 55.

Nielsen, C.P., S. Robinson, and K. Thierfelder, 2001. Genetic Engineering and Trade: Panacea or Dilemma for Developing Countries. *World Development*, vol. 29(8): 1307 – 1324.

Normile, D., and E. Pennisi, 2002. Rice: Boiled Down to the Bare Essentials. *Science*, vol. 296(5565): 32 – 36.

Oard, J.H., S.D. Linscombe, M.P. Braverman, F. Jodari, D.C. Blouin, M. Leech, A. Kohle, P. Vain, J.C. Cooley, and P. Christou, 1996. Development, Field Evaluation and Agronomic Performance of Transgenic Herbicide Resistant Rice. *Molecular Breeding*, vol. 2(4): 359 – 368.

Oerke, E.C., H.W. Dehne, F. Schonbeck, and A. Weber, 1994. *Crop Production and Crop Protection: Estimated Losses in Major Food and Cash Crops*. Elsevier Science, Amsterdam, The Netherlands.

Paine, J.A., C.A. Shipton, S. Chaggar, R.M. Howells, M.J. Kennedy, G. Vernon, S.Y. Wright, E. Hinchliffe, J.L. Adams, A.L. Silverstone, and R. Drake, 2005. Improving the Nutritional Value of Golden Rice through Increased Pro-Vitamin A Content. *Nature Biotechnology*, vol. 23(4): 482 – 487.

Pandey, S., and L. Velasco, 2002. "Economics of Direct Seeding in Asia: Patterns of Adoption and Research Priorities". In: Pandey, S., M. Mortimer, L. Wade, T.P. Tuong, K. Lopez, and B. Hardy (editors). *Direct Seeding: Research Issues and Opportunities*. Proceedings of the International Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities (Bangkok, Thailand, 2000). International Rice Research Institute (IRRI), Los Baños, Philippines: 3 – 14.

Pathak, M.D., and Z.R. Khan, 1994. *Insect Pests of Rice*. International Rice Research Institute (IRRI), Manila, Philippines.

Paul, H., and R. Steinbrecher (with D. Kuyek and L. Michaels), 2003. *Hungry Corporations: Transnational Biotech Companies Colonise the Food Chain*. Zed Books, London & New York.

Penna, J.A., and D. Lema, 2003. Adoption of Herbicide Tolerant Soybeans in Argentina: an Economic Analysis. In: Kalaitzandonakes, N.G. (editor), *The Economic and Environmental Impacts of Agbiotech: a Global Perspective*. Kluwer Academic/Plenum Publishers, New York, NY: 203 – 220.

Pingali, P.L., M. Hossain, and R.V. Gerpacio, 1997. *Asian Rice Bowls: the Returning Crisis?*. International Rice Research Institute, Manila, Philippines, and CAB International, New York, NY.

Pinstrup-Andersen, P., and E. Schiøler, 2000. *Seeds of Contention. World Hunger and the Global Controversy over GM Crops.* The John Hopkins University Press, Baltimore & London.

Pinstrup-Andersen, P., 2005. "Food Security in South Asia: a 2020 Perspective". In: Babu, S. C. and A. Gulati (editors). *Economic Reforms and Food Security: the Impact of Trade and Technology in South Asia.* A selection of the presentations made at the South Asia Regional Conference held in New Delhi, April 2002. The Haworth Press, New York, NY: 41 - 60.

Pray, C.E., 2001. Public-private Sector Linkages in Research and Development: Biotechnology and the Seed Industry in Brazil, China and India. *American Journal of Agricultural Economics*, vol. 83(3): 742 – 747.

Pray, C., 2002. The Growing Role of the Private Sector in Agricultural Research. In: Byerlee, D., and R. Echeverría (editors). *Agricultural Research in an Era of Privatization*. CABI Publishing, New York, NY: 35 - 50.

Pray, C.E., J. Huang, R. Hu, and S. Rozelle, 2002. Five Years of *Bt* Cotton in China – the Benefits Continue. *The Plant Journal*, vol. 31(4): 423 – 430.

Pray, C.E., J. Huang, D. Ma, and F. Qiao, 2001. Impact of *Bt* Cotton in China. *World Development*, vol. 29(5): 813 – 825.

Pray, C.E., and A. Nasseem, 2003. Biotechnology R&D: Policy Options to Ensure Access and Benefits for the Poor. Agriculture and Economic Development Analysis Division (ESA) Working Paper Nº 03-08. The Food and Agriculture Organization (FAO), Rome, Italy.

Qaim, M., and A. de Janvry, 2003. Genetically Modified Crops, Corporate Pricing Strategies and Farmers' Adoption: the Case of *Bt* Cotton in Argentina. *American Journal of Agricultural Economics*, vol. 85(4): 814 – 828.

Qaim, M., and I. Matuschke, 2005. Impacts of Genetically Modified Crops in Developing Countries: a Survey. *Quarterly Journal of International Agriculture*, vol. 44(3): 207 – 227.

Qaim, M., A. Subramanian, G. Naik, and D. Zilberman, 2006. Adoption of *Bt* Cotton and Impact Variability: Insights from India. *Review of Agricultural Economics*, vol. 28(1): 48 – 58.

Qaim, M., and G. Traxler, 2005. Roundup Ready Soybeans in Argentina: Farm Level and Aggregate Welfare Effects. *Agricultural Economics*, vol. 32(1): 73 – 86.

Rao, C.H.H., 2005. *Agriculture, Food Security, Poverty and Environment. Essays on Post-reform India*. Oxford University Press, New Delhi, India.

Rapp, R.T., and R.P. Rozek, 1990. Benefits and Costs of Intellectual Property Protection in Developing Countries. *Journal of World Trade*, vol. 24(5): 75 – 102.

Renkow, M., 1993. Differential Technology Adoption and Income Distribution in Pakistan: Implications for Research Resource Allocation. *American Journal of Agricultural Economics*, vol. 75(1): 33 – 43.

Robin, S., B. Courtois, M.S. Pathan, P. Jeyaprakash, R. Lafitte, G. Atlin, H.T. Nguyen, and Z. Li, 2002. Marker Assisted Back Cross Breeding for Improvement of Drought Tolerance in *Indica* and *Japonica* Rice. Progress Toward Developing Resilient Crops for Drought-prone Areas. Abstracts of an International Workshop. International Rice Research Institute (IRRI), Manila, Philippines.

Robinson, S., 1989. "Multisectoral Models". In: Chenery, H., and T.N. Srinivasan (editors). *Handbook of Development Economics.* Volume 2. Elsevier Science Publishers B.V.: 886 – 947.

Robinson, G.M., and F. Harris., 2004. "Food Production and Supply". In: Harris, F. (editor). *Global Environmental Issues*. John Wiley & Sons, Ltd., England: 117 – 153.

Rosegrant, M.W., and P.B. Hazell, 2000. *Transforming the Rural Asian Economy: the Unfinished Revolution*. Oxford, University Press, New York, NY.

Sadoulet, E., and de Janvry, A., 1995. *Quantitative Development Policy Analysis*. Johns Hopkins University Press: Baltimore, MD.

Savary, S., L. Willocquet, F.A. Elazegui, P.S. Teng, P.V. Du, D. Zhu, Q. Tang, S. Huang, X. Lin, H.M. Singh, and R.K. Srivastava, 2000a. Rice Pest Constraints in Tropical Asia: Characterization of Injury Profiles in Relation to Production Situations. *Plant Disease*, vol. 84(3): 341 – 356.

Savary, S., L. Willocquet, F.A. Elazegui, N. P. Castilla, and P.S. Teng, 2000b. Rice Pest Constraints in Tropical Asia: Quantification of Yield Losses Due to Rice Pests in a Range of Production Situations. *Plant Disease*, vol. 84(3): 357 – 369.

Science Letters, 2005. Debate Over a GM Rice Trail in China. *Science*, vol. 310(5746): 231 – 233.

Scobie, G.M., and R. Posada, 1978. The Impact of Technical Change on Income Distribution: The Case of Rice in Colombia. *American Journal of Agricultural Economics*, vol. 60(1): 85 – 92.

Shiva, V., 1991. *The Violence of the Green Revolution. Third World Agriculture, Ecology and Politics.* Zed Book Ltd. and Third World Network: London, UK, and Penang, Malaysia.

Shoven, J.B., and J. Whalley, 1992. *Applying General Equilibrium.* Cambridge University Press, New York, NY.

Smith, P.J., 1999. Are Weak Patent Rights a Barrier to U.S. Exports? *Journal of International Economics*, vol. 48(1): 151 – 177.

Spielman, D.J., and K. von Grebmer, 2004. Public-Private Partnerships in Agricultural Research: An Analysis of Challenges Facing Industry and the Consultative Group on International Agricultural Research. Environment and Production Technology Division, Discussion Paper Nº 113. International Food Policy Research Institute (IFPRI), Washington, D.C.

The World Bank, 1986. Poverty and Hunger: Issues and Options for Food Security in Developing Countries. World Bank Policy Paper N° 9275. The World Bank, Washington, D.C.

The World Bank, 2005. India: Re-energizing the Agricultural Sector to Sustain Growth and Reduce Poverty. Agriculture and Rural Development Unit, South Asia Region, The World Bank. Oxford University Press, New Delhi, India.

Tran, T.U., M. Hossain, and A. Janaiah, 2000. Modern Farm Technology and Infrastructure in Vietnam. *Economic and Political Weekly*, vol. 35(52): 4638 – 4643.

Tu, J., G. Zhang, K. Datta, C. Xu, Y. He, Q. Zhang, G. S. Khush, and S.K. Datta, 2000. Field Performance of Transgenic Elite Commercial Hybrid Rice Expressing *Bacillus thuringiensis* δ–endotoxin. *Nature Biotechnology*, vol. 18(10): 1101 – 1104.

United Nations, 2000. United Nations Millennium Declaration. Resolution of the General Assembly A/RES/55/2, September 18th 2000. United Nations: New York, NY.

United Nations, 2005. The Millennium Development Goals Report 2005. United Nations: New York, NY.

USA Rice Federation, 2006. Biotechnology. Government Affairs Policies of the USA Rice Federation. <http://www.usarice.com/industry/gov/affairs.html> (Accessed May 2006).

van Meijl, H., and F. van Tongeren, 2004. International Diffusion of Gains from Biotechnology and the European Union's Common Agricultural Policy. *Agricultural Economics*, vol. 31(2&3): 307 – 316.

Varian, H.R., 1992. *Microeconomic Analysis*. Third Edition. W.W. Norton & Company: New York, NY.

Verdurme, A., X. Gellynck, J. Viaene, and W. Verbeke, 2002. "Differences in Public Acceptance Between Generic and Premium Branded GM Food Products: an Analytical Model". In: Santaniello, V., R.E. Evenson, and D. Zilberman (editors). *Market Development for Genetically Modified Foods*. CAB International, Wallingford, U.K.

Vyas, V.S., 2005. "Food Security in South Asia: Issues, Options and Opportunities". In: Babu, S. C. and A. Gulati (editors). *Economic Reforms and Food Security: the Impact of Trade and Technology in South Asia.* A selection of the presentations made at the South Asia Regional Conference held in New Delhi, April 2002. The Haworth Press, New York, NY: 61 -86.

WARDA, 2006. Upland NERICA. Africa Rice Center (WARDA). Available at http://www.warda.org/warda/uplandnerica.asp (Accessed June 2006).

Widawsky, D.A., and J.C. O'Toole, 1996. "Prioritizing the Rice Research Agenda for Eastern India". In: Evenson, R.E., R.W. Herdt, and M. Hossain (editors). *Rice Research in Asia: Progress and Priorities*. CAB International in association with the International Rice Research Institute (IRRI), Manila, Philippines: 109 – 129.

Widawsky, D., S. Rozelle, S. Jin and J. Huang, 1998. Pesticide Productivity, Host-Plant Resistance and Productivity in China. *Agricultural Economics*, vol. 19(1&2): 203 – 217.

Wu, F., and W.P. Butz, 2004. *The Future of Genetically Modified Crops: Lessons from the Green Revolution.* RAND Corporation, Santa Monica, CA.

Ye, G., Q. Shu, H. Yao, H. Cui, X. Cheng, C. Hu, Y. Xia, M. Gao, and I. Altosaar, 2001. Field Evaluation of Resistance of Transgenic Rice Containing a Synthetic *cry1Ab* Gene from *Bacillus thuringiensis* Berliner to Two Stem Borers. *Journal of Economic Entomology*, vol. 94(1): 271 – 276.

Appendix A

Area, average yield and total rice production per region in the model

Table A.1. Area (000’ ha), average yield (tons per ha) and total rice production (000’ tons) per region in the model.

	China	India	Indonesia	Bangladesh	Vietnam	Thailand	Philippines	Japan	Rest of Asia	USA	Lat. America	Africa	ROW
Irrigated													
Area	28,159	20,624	6,199	2,623	3,916	978	2,457	1,770	9,265	1,232	2,081	1,303	666
Av. Yield	6.5	3.8	5.5	5.6	6.0	4.1	3.6	6.7	3.7	7.0	7.1	5.6	6.6
Production	182,273	77,639	34,213	14,648	23,611	3,973	8,875	11,863	33,880	8,669	14,874	7,251	4,401
Rainfed													
Area	1,874	17,237	4,057	6,156	3,140	8,502	1,396	0	6,085	0	435	1,616	0
Yield	3.6	2.9	3.6	3.0	2.6	2.2	2.4	0	3.0	0	2.9	2.5	0
Production	6,720	49,449	14,547	18,396	8,164	18,292	3,337	0	18,182	0	1,249	4,056	0
Upland													
Area	470	5,308	1,265	698	387	212	184	0	743	0	3,757	3,295	93
Yield	2.5	0.9	1.8	0.9	1.1	1.7	1.1	0	1.5	0	1.8	1.1	1.1
Production	1,175	4,691	2,235	617	427	350	203	0	1,149	0	6,640	3,640	102
Flood-prone													
Area	0	1,431	2	1,222	213	356	0	0	673	0	114	1,562	0
Yield	0	1.7	1.9	1.8	1.7	2.2	1.4	0.0	1.3	0	2.0	1.4	0.0
Production	0	2,371	4	2,160	352	787	0	0	892	0	227	2,243	0
TOTAL													
Area	30,503	44,600	11,523	10,700	7,655	10,048	4,037	1,770	16,765	1,232	6,388	7,776	759
Yield	6.2	3.0	4.4	3.3	4.3	2.3	3.1	6.7	3.2	7.0	3.6	2.2	5.9
Production	190,168	134,150	51,000	35,821	32,554	23,403	12,415	11,863	54,103	8,669	22,990	17,190	4,503

Source: Maclean et al. (2002) for totals per region. Study calculations for figures for each ecosystem in each region, based on Maclean et al., Huke and Huke (1997), IRRI (1993) and Greenland (1997).

Appendix B

Model database and rice environments: Social Accounting Matrices (SAMs) for each region with the rice sector disaggregated in irrigated and non-irrigated rice

The following tables are included in separate .pdf file:

Appendix C

Model database: final cost structure of firms for irrigated and non-irrigated paddy rice sectors

Table C.1. Irrigated paddy rice sector: cost structure of firms (%).

IRRICE	CHN	IND	IDN	BGD	VNM	THA	PHL	JPN	RASIA	USA	LATAM	AFRICA	ROW
Land	20.1	32.3	46.8	21.7	32.3	52.2	33.3	12.0	34.9	16.4	13.0	7.0	20.5
UnSkLab	37.5	18.6	33.5	17.8	19.2	23.0	37.9	33.6	29.6	20.6	20.2	41.3	33.5
SkLab	0.3	0.0	0.0	0.2	0.1	0.0	0.7	0.5	0.3	1.6	0.5	0.3	0.7
Capital	7.0	8.3	5.5	7.5	3.1	4.6	2.8	20.6	7.3	18.9	27.9	8.8	9.1
NatRes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
irrice	9.2	2.4	0.0	1.8	1.2	0.3	2.0	0.0	0.6	0.3	0.1	1.2	0.7
iseed	10.0	10.4	0.2	9.2	7.3	3.3	9.4	0.8	5.0	3.4	1.8	7.6	5.2
nonrice	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nonseed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ocrp	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	2.4	0.0	0.1
oagr	0.3	5.0	0.8	8.4	0.1	5.9	0.0	7.2	2.6	0.0	7.7	8.6	2.7
pcr	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
opcf	0.9	0.0	0.0	0.0	0.1	0.0	0.0	1.5	0.0	0.0	3.0	0.0	0.2
chem	7.5	8.9	9.4	9.4	21.6	5.3	10.1	7.2	9.0	7.3	10.2	8.8	9.1
mman	2.6	1.1	0.3	2.2	2.8	1.4	0.4	2.6	1.9	6.7	3.1	1.3	5.6
serv	4.3	13.0	3.5	21.9	12.0	3.8	3.4	13.9	8.7	24.6	10.0	14.8	12.5
Total (US$ ‘000)	19,084	14,255	7,352	1,432	1,065	583	2,357	23,261	13,088	1,355	5,463	4,140	9,458

Source: model database.

Table C.2. Non-irrigated paddy rice sector: cost structure of firms (%).

NONRICE	CHN	IND	IDN	BGD	VNM	THA	PHL	JPN	RASIA	USA	LATAM	AFRICA	ROW
Land	4.9	18.4	37.2	25.9	9.3	37.7	22.5	0.0	35.4	0.0	13.0	7.0	20.5
UnSkLab	54.2	28.7	40.8	22.5	27.4	36.2	43.9	0.0	29.9	0.0	20.2	41.3	33.5
SkLab	0.4	0.0	0.0	0.2	0.2	0.0	0.9	0.0	0.3	0.0	0.5	0.3	0.7
Capital	8.9	11.7	6.9	10.2	3.8	5.5	2.4	0.0	7.4	0.0	28.0	8.8	9.2
NatRes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
irrice	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	1.0
iseed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nonrice	1.0	2.4	0.0	0.7	1.2	0.4	1.8	0.0	0.6	0.0	0.1	1.2	0.4
nonseed	7.0	10.5	0.2	5.8	7.6	4.3	9.2	0.0	5.1	0.0	1.6	7.6	4.4
ocrp	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	2.4	0.0	0.1
oagr	8.9	7.9	0.2	10.0	0.4	7.6	0.1	0.0	4.5	0.0	7.7	8.6	2.7
pcr	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
opcf	0.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.2
chem	9.4	6.2	10.8	9.7	34.4	4.0	15.5	0.0	6.1	0.0	10.2	8.8	9.1
mman	1.7	1.1	0.3	1.4	3.0	1.2	0.4	0.0	1.9	0.0	3.1	1.3	5.6
serv	2.8	13.1	3.5	13.4	12.5	3.1	3.3	0.0	8.8	0.0	10.0	14.8	12.5
Total (US$ ‘000)	1,311	10,296	3,610	3,481	388	2,212	969	0	7,710	0	2,989	5,675	221

Source: model database.

Appendix D

Model simulations: Additional results

Table D.1. Drought resistance: Results and welfare decomposition assuming adoption in Africa (EV, $ million).

	Alloc.	Tech.	TOT	IS	Total
China	-191.4	390.7	35.0	-6.7	227.5
India	-43.6	741.5	-28.9	1.8	670.9
Indonesia	-13.5	284.7	9.5	0.1	280.8
Bangladesh	-12.1	165.8	6.3	2.7	162.8
Vietnam	-1.1	34.7	-12.2	4.4	25.8
Thailand	2.3	101.9	-49.2	-0.4	54.6
Philippines	-4.2	85.0	15.8	1.6	98.2
Japan	49.6	346.2	39.9	-4.5	431.1
Rest of Asia	0.6	550.4	46.4	1.0	598.3
USA	-0.8	0.0	-60.2	1.7	-59.3
Latin America	-5.0	0.0	-19.2	-0.7	-24.9
Africa	-644.7	434.9	8.2	0.1	-201.6
ROW	32.6	0.0	8.6	-1.0	40.2
Total	-831.3	3,135.7	0.0	0.0	2,304.5

Source: Simulation results.

Table D.2. Production, price, and export - import changes for the three rice technologies

	Production (% change)			Domestic price (% change)		Exports (% change)		Imports (% change)	
	Favorable	Unfavorable	Processed	Paddy	Processed	Paddy	Processed	Paddy	Processed
Stemborer resistance									
China	2.93	-33.04	0.09	-2.62	-0.92	6.43	0.33	-1.21	1.07
India	2.20	-2.22	4.87	-2.66	-2.04	7.28	4.89	-2.21	-0.42
Indonesia	3.42	-5.71	0.32	-3.75	-2.35	11.71	7.38	0.25	-1.56
Bangladesh	5.66	-2.00	0.17	-3.43	-2.14	10.58	6.11	-2.19	-0.20
Vietnam	3.74	-8.62	0.33	-1.87	-1.66	0.83	1.18	1.16	-0.52
Thailand	4.03	-0.73	0.19	-1.96	-1.57	2.44	0.45	-0.05	-0.77
Philippines	2.77	-5.69	0.27	-2.75	-2.13	7.68	6.31	-0.94	-1.57
Japan	0.13	0	0.11	-1.84	-1.39	5.75	2.88	-1.16	-1.44
Rest of Asia	2.40	-3.01	0.49	-2.91	-2.37	7.46	6.56	-1.86	-1.87
USA	-0.60	0	-1.22	-0.11	-0.01	-1.67	-2.37	4.77	2.46
Latin America	-0.06	-0.06	-0.09	-0.02	-0.01	-1.19	-1.26	0.25	0.45
Africa	-0.11	-0.11	-0.13	-0.02	-0.01	-2.67	-2.82	0.73	2.64
ROW	-0.57	-0.57	-0.50	-0.14	-0.09	-3.49	-2.66	1.73	1.47
Drought resistance									
China	-3.63	64.43	0.06	-3.17	-1.12	6.46	-1.38	0.49	5.01
India	-5.29	9.32	8.65	-4.58	-3.50	13.1	8.70	-4.36	-1.33
Indonesia	-3.36	8.48	0.38	-4.69	-2.93	13.65	7.48	0.46	0.69
Bangladesh	-10.72	5.08	0.26	-5.35	-3.34	16.52	9.09	-1.86	0.33
Vietnam	-2.75	12.48	1.21	-4.16	-3.66	2.33	5.16	-1.09	-3.03
Thailand	-3.88	3.77	1.99	-4.96	-3.96	10.05	5.69	-2.79	-5.20
Philippines	-3.83	10.82	0.28	-4.23	-3.28	12.06	9.14	-0.70	-0.66
Japan	0.06	0	0.05	-1.87	-1.41	4.14	0.33	-0.61	-0.12
Rest of Asia	-4.01	8.34	0.51	-4.04	-3.29	8.52	8.04	-2.40	0.01
USA	-0.94	0	-2.21	-0.18	-0.02	-2.56	-3.88	7.26	5.33
Latin America	-0.10	-0.10	-0.16	-0.03	-0.01	-1.97	-2.23	0.39	0.89
Africa	-0.19	-0.19	-0.21	-0.03	-0.02	-4.56	-4.83	1.29	4.32
ROW	-0.99	-0.97	-0.85	-0.25	-0.15	-5.72	-4.49	3.03	2.51
Herbicide resistance									
China	1.37	-18.94	-0.14	-0.85	-0.33	-10.46	-9.02	6.48	11.19
India	-6.25	9.97	2.97	-3.77	-2.88	-3.38	2.98	-1.23	-1.18
Indonesia	-2.81	6.21	0.08	-1.66	-1.04	-8.58	-4.87	0.57	7.56
Bangladesh	3.52	-1.49	-0.06	-0.65	-0.41	-14.91	-7.77	8.67	5.34
Vietnam	5.79	-8.47	2.01	-6.77	-5.97	3.78	8.44	-9.01	-7.52
Thailand	8.05	3.59	4.53	-7.91	-6.33	12.07	13.14	-7.77	-10.63
Philippines	2.45	-1.87	1.31	-11.15	-8.64	42.81	35.28	-9.17	-8.23
Japan	-0.30	0	-0.22	-0.09	-0.08	-10.44	-8.92	4.52	4.58
Rest of Asia	-0.48	0.46	-0.27	-2.23	-1.82	-8.86	-1.94	0.15	6.87
USA	-0.46	0	-3.41	-3.37	-0.16	-1.33	-6.39	-1.45	7.59
Latin America	20.26	-28.60	-0.14	-3.34	-0.63	-1.82	-2.87	-0.76	0.85
Africa	28.81	-17.03	-0.10	-1.07	-0.66	-9.23	-6.36	1.53	2.53
ROW	1.46	-27.36	0.26	-5.35	-2.34	4.73	0.27	-2.10	-0.23

Source: Simulations results.

Table D.3. Land demand, labor demand and prices for the three rice technologies (% change).

	Stemborer resistance					
	Land demand			Labor demand		
Country	Irrigated	Non-irrigated	Land Price*	Irrigated	Non-irrigated	Labor price
China	0.51	-28.58	0.13	0.67	-34.04	-0.02
India	0.12	-3.18	-0.77	-0.03	-4.09	-0.01
Indonesia	0.42	-5.65	-1.92	0.06	-7.37	0
Bangladesh	3.10	-2.39	-4.86	2.60	-4.13	0.14
Vietnam	1.22	-8.20	0.61	1.67	-9.90	-0.06
Thailand	1.62	-1.44	-0.83	1.82	-1.96	-0.05
Philippines	0.53	-5.59	-1.04	0.41	-7.10	-0.01
Japan	-0.78	-2.97	-2.14	-1.47	-4.16	0.01
Rest of Asia	0.28	-3.36	-1.69	-0.07	-4.54	0.02
USA	-0.49	-3.34	-0.16	-0.65	-4.16	0
Latin America	-0.04	-0.04	-0.07	-0.07	-0.07	0
Africa	-0.08	-0.08	-0.10	-0.12	-0.12	0
ROW	-0.47	-0.47	-0.15	-0.62	-0.62	0

	Drought resistance					
	Land demand			Labor demand		
	Irrigated	Non-irrigated	Land Price	Irrigated	Non-irrigated	Labor price
China	-4.09	44.92	-1.84	-5.48	57.52	0.10
India	-5.79	4.31	-2.52	-7.71	4.68	0.17
Indonesia	-4.02	3.31	-3.10	-5.68	3.32	0.07
Bangladesh	-10.01	1.70	-6.27	-13.61	0.51	0.19
Vietnam	-3.41	7.34	-4.33	-5.27	7.94	0.30
Thailand	-4.77	-0.13	-1.75	-6.27	-0.59	0.01
Philippines	-4.31	5.59	-2.83	-5.97	6.21	0.08
Japan	-0.81	-4.33	-2.32	-1.55	-5.86	0.01
Rest of Asia	-4.60	3.64	-2.30	-6.19	3.94	0.04
USA	-0.76	-4.69	-0.32	-1.01	-5.84	0
Latin America	-0.06	-0.07	-0.14	-0.11	-0.11	0
Africa	-0.12	-0.12	-0.21	-0.20	-0.20	0
ROW	-0.81	-0.79	-0.30	-1.07	-1.05	0.01

	Herbicide Resistance					
	Land demand			Labor demand		
	Irrigated	Non-irrigated	Land Price	Irrigated	Non-irrigated	Labor price
China	0.49	-15.82	0.14	0.40	-19.16	-0.02
India	-6.04	5.48	-2.32	-8.03	4.85	0.12
Indonesia	-2.42	3.65	-1.17	-3.26	2.93	0.02
Bangladesh	2.48	-1.17	-1.18	2.71	-1.73	0.02
Vietnam	-0.11	-11.20	-1.89	-1.39	-15.74	0.08
Thailand	0.55	-1.86	-1.38	-0.56	-4.74	-0.11
Philippines	-3.55	-6.64	-5.04	-6.95	-12.05	-0.01
Japan	-0.16	-2.77	-0.56	-0.33	-3.54	0.01
Rest of Asia	-1.23	-0.53	-1.55	-2.12	-1.54	0.02
USA	-2.71	-2.79	-0.31	-3.42	-3.51	0
Latin America	12.13	-24.64	0.03	15.23	-29.53	0
Africa	20.83	-14.41	0.74	26.03	-17.37	0
ROW	-2.59	-23.92	-0.44	-3.30	-28.77	0.01

Source: Simulations results (* Note: land prices refer to the composite price for land).

Vita

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Guy G. Hareau was born in Montevideo, Uruguay, in 1961. In 1987 he graduated as an Agricultural Engineer from the School of Agriculture, University of the Republic (Uruguay). He is a researcher at the National Agricultural Research Institute (INIA) of Uruguay since 1991. After obtaining a grant from the Fulbright Commission, in August 1999 he began his graduate studies in Agriculture and Applied Economics at Virginia Tech, where he first earned a Master of Science degree in 2002. He is married to Elena D’Alessandro and they have three children, Sylvie, Chantal and Etienne.