Table of Contents

List of Tables

List of Figures

Transgenic Pest-resistant Rice: An Ex-ante Economic Evaluation of an Adoption Impact Pathway in the Philippines and Vietnam for *Bt* Rice

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CHAPTER I. INTRODUCTION

This chapter contains the background and significance of the study along with an outline of the research problem area and statement of objectives. It begins with an overview of host plant resistance in rice research and its potential contribution to integrated pest management (IPM). This overview is followed by a discussion on how biotechnology is being used to enhance the host plant resistance of rice. A discussion then follows on how advances in rice biotechnology research have given plant breeders several tools by which to enhance the host plant resistance of rice (Khush and Bhar 1998). This study focuses on the use of genetic engineering to produce transgenic pest-resistant rice, specifically *Bt* rice. The research problem is identified and the objectives of the study are presented in the last part of the chapter.

IA. Biotechnology for host plant resistance in rice IPM

The introduction of new high yielding rice varieties by the International Rice Research Institute (IRRI) in the late 1960s helped revolutionize irrigated rice production in tropical Asia and marked the beginning of a phenomenon commonly referred to as the "green revolution". These genetically improved rice cultivars that were short, stiff-strawed, fertilizer responsive, and non-photoperiod sensitive allowed for the intensification of rice production in South and Southeast Asia (Evenson and David 1993). The first generation of modern rice varieties however were highly susceptible to pests and diseases (Alexandratos 1994, Ramasamay and Jatileksono 1996). This led to growing crop losses and infestation problems that were often addressed by an emphasis and unilateral reliance on pesticides (IRRI 1994, Rola and Pingali 1993). Widespread pesticide misuse persisted even after farmers adopted succeeding generations of modern varieties with improved pest resistance (Heong and Escalada 1997, K. Heong 2000 personal communication). Concern over the harmful effects to health and rice ecosystems from conventional chemical pest controls led to the development of Integrated Pest Management (IPM) to reduce dependence on chemical pesticides and make pest control more environmentally sustainable.

IPM in the last two decades has evolved into a widely accepted paradigm for pest control in tropical Asian irrigated rice. There may be no consensus on how tropical rice IPM should be implemented let alone defined (Pinstrup-Anderson 2001), but rice IPM research and extension efforts in irrigated tropical Asia are considered to be the largest and most innovative in the world (Matteson 2000). Yet for all the new strategies and concepts in today's rice IPM as reviewed in Way and Heong (1994) and Kogan (1998), its central element and foundation remains the development of host plant resistance and the dissemination of pest-resistant seed varieties (Panda and Khush 1994, Widawsky et al 1998, Teetes 1999). Seeds with improved host plant resistance represent the simplest, most economic and environmentally sustainable approach to protecting crops against insect damage (Panda and Khush 1995). According to Otsuka et al (1994), the green revolution in irrigated rice production in tropical Asia could not have been sustained without the development of modern rice varieties with multiple pest and disease resistance. IRRI studies show that if it were not for continuous improvement in host plant resistance in modern rice varieties, yield would have declined by an annual 1.3 percent or 2 tons per hectare per year (Cantrell 2001).

Advances in rice biotechnology research have provided breeders with several tools[1] that can further exploit and extend the capability of rice plants to withstand attacks or limit damage from pest and diseases (Portrykus et al 1995, Khush and Bhar 1997, Bennett 1999, Hossain et al 2000, Khush 2001, IRRI MTP 1998-2000). According to Pingali et al (1997), modern biotechnology enhances conventional breeding programs by: (1) reducing the trial and error of conventional screening techniques in identifying pest-resistant traits through the use of molecular marker technology, and (2) using genetic engineering to bring non-rice genes[2] into the rice gene pool. Fernandez-Cornejo and McBride (2000) add that genetic engineering allows for the precise manipulation of a plant's genes and the targeting of a single plant trait without the unintended characteristics that may occur with traditional breeding methods. More importantly, biotechnology can be used to address pest problems such as stemborer infestation for which pest control solutions cannot be obtained by a traditional or conventional breeding approach (Tu et al 1998).

The concept of integrating biotechnology into pest control systems is not new and has been examined in the literature by Brar 1993, Panda and Khush 1995, and Persley 1996. It is also a concept that is strongly endorsed (CGIAR 1998). The technical and management aspects for applying biotechnology to achieve pest control goals have also been considered (see Panda and Khush 1995, Whalon and Norris 1999). Despite all the exploratory research on integrating rice biotechnology research and host plant resistance into IPM, host plant resistance in itself as a

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[1] IRRI started applying biotechnology tools in its rice breeding program in 1985 with the advent of tissue culture (Khush and Bhar 1998, IRRI 2001c, see **Figure 1**). This was followed by DNA marker technology in 1988 and by 1991, IRRI had begun to apply genetic engineering techniques.

[2] In conventional breeding, the only method of introducing genes into a plant is by crossing it with another plant containing the desired gene or genes. Search for genes is also limited only to plants that can be crossed with rice (IRRI Riceweb 2000a). With advances in tissue culture and genetic engineering, genes of rice from wild relatives and non-rice genes can now be introduced into rice plants (IRRI Riceweb 2000a).

component of IPM remains underutilized (Widawsky et al 1998) and the actual integration of biotechnology into IPM has been limited (Waage 1996).

Among the several rice biotechnology applications currently in use (see **Figure 1**), one that has much appeal for rice pest management in tropical irrigated Asia is to genetically engineer *Indica* rice with novel genes that confer pest-resistant traits (Panda and Khush 1995). A rice plant is transgenic pest-resistant when its hereditary DNA has been modified by the addition of DNA from a source other than parental germplasm using recombinant DNA techniques so that the plant will exhibit a pest-resistant trait (definition derived from Evenson 1996, Cohen 1999, Fernandez-Cornejo and McBride 2000). Transgenic crops are also often referred to as genetically modified (GM) crops (James 2000).

Hossain et al (1999) highlights some of the agronomically valuable genes that have been incorporated into rice (**Table 1**). Perhaps the most widely cited transgenic pest-resistant application for rice is that of conferring host plant resistance to stemborers by incorporating synthetic *cry1A*[3] genes from the soil bacterium *Bacillus thuringiensis (Bt)* to produce *Bt* rice (e.g. Portrykus et al 1996, Khush and Bhar 1998, Bennett 1999, Matteson 2000, IRRI Riceweb 2000a). These *Bt* genes encode insecticidal proteins known as delta endotoxins lethal to *Lepidopteran* insects like stemborers but are not harmful to mammals (Krattiger 1999, Cohen et al 2000).

The development of *Bt* rice is significant for three primary reasons: (1) Stemborers are considered to be the most important insect pest[4] of rice in Asia (Herdt and Riely 1987, Khan et al 1991, Khush and Toenniessen 1991, Pathak and Khan 1994, Ramasamay and Jatileksono 1996, Evenson et al 1996). The importance of finding a breeding solution to stemborer infestation is cited in (Herdt 1991) and Evenson et al (1996) where it was highly prioritized in the research portfolios of IRRI and the Rockefeller Foundation funded International Rice Biotechnology Program. (2) Chemical control of stemborers is often ineffective (Bennett 1999, PhilRice 1999). This ineffectiveness occurs because stemborers are internal feeders[5] and are protected from both adverse biotic and abiotic conditions including non-systemic insecticides. As a result, there is no treatment once damage is evident (IRRI

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[3] CryI is one of 4 classes of *Bt* toxins and is active against *Lepidoptera* insects. "Cry" stands for "crystalline" reflecting the crystalline appearance of the delta endotoxin; "Cry" denotes the protein and "cry" denotes the specific gene (Krattiger 1999).

[4] These insect pests belong to the Lepidoptera families: Noctuidae and Pyralidae (Heinrichs 1999). The *IRRI Riceweb* list four rice stemborers of significance: (1) Yellow stemborer *Scirpophaga Incertulas* (Walker), (2) White stemborer *Scirpophaga innotata* (Walker), (3) Striped stemborer *Chilo suppressalis* (Walker), and (4) Dark-headed rice borer *Chilo polychrysus* (Meyrick). For most parts of tropical Asia, the Yellow stemborer is considered to be most damaging while the Striped stemborer is more endemic to temperate Asia (Ye et al 2000).

[5] As their names suggest, stemborer feed on the rice stems and infestation comes either in the form of larvae (see **Figure 2d**) or adult moths (see **Figures 2a,2b**, IRRI TropRice). Insecticide spraying is virtually ineffective once the larvae enter the rice tiller (PhilRice 1999). Symptoms of damage can occur during the vegetative growth phase and the reproductive phase of the rice plant. If the central shoot is damaged during the vegetative stage, the plant produces no panicles and therefore no grain. These damaged shoots are otherwise known as "*deadhearts*" (Heinrichs 1999). If stemborers feed during the reproductive phase, they can severe the developing panicle at the base and as a result, the panicle becomes unfilled and whitish in color rather than brownish and filled with grain (Heinrichs 1999). The empty panicles are commonly referred to as "*whiteheads*" (see **Figure 2c**).

TropRice). (3) More than 30,000 rice varieties have been screened with no sufficient levels of resistance to stemborers being found in the rice germplasm (Khan et al 1991, Jackson 1995, Teng and Revilla 1996, Cohen et al 2000, Tu et al 2000).

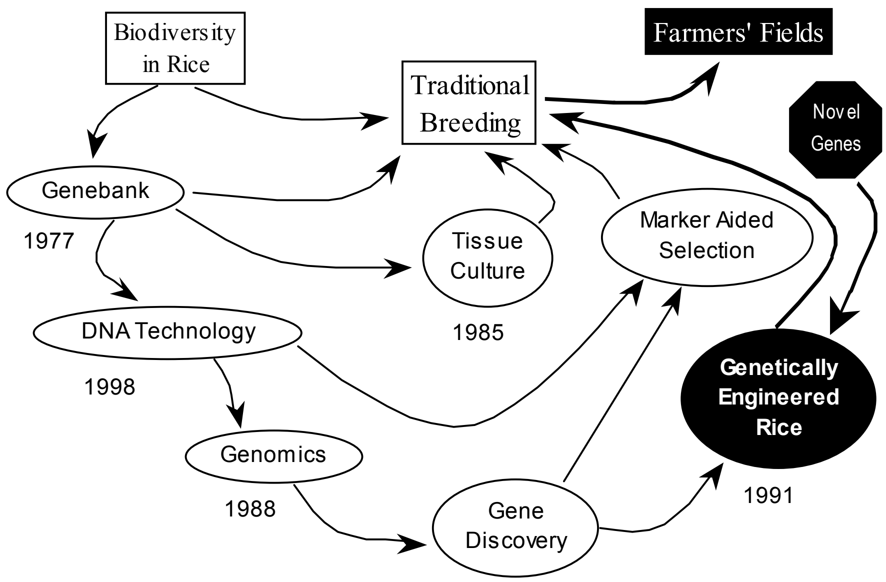

Figure 1. Biotechnological approaches to rice breeding at IRRI
(Source: IRRI 2001c, p15, Fig3)

Table 1. Genes of agronomic value introduced in rice

Rice Variety	Method Used	Gene Transferred	Trait
Indica / Japonica	Biolistic	bar/gus	Resistance to HERBICIDES
IR72	Protoplast	bar	Resistance to HERBICIDES
Japonica	Protoplast	CP-stripe virus	Resistance to STRIPE VIRUS
Indica	Protoplast	Chitinase chi11	Resistance to SHEATH BLIGHT (SB)
Japonica	Biolistic / Protoplast	pinII	Resistance to INSECT
Indica	Biolistic / Protoplast	Bt	STEMBORER Resistance
Japonica	Biolistic	HVA1	Osmoprotectant
Indica / Japonica	Biolistic / Protoplast	adh/pdc	Submergence tolerance
Indica	Biolistic	Bt	STEMBORER Multiple Resistance
Indica / Japonica	Biolistic / Protoplast	Bt	STEMBORER Resistance, tissue specific
Indica	Biolistic	Xa-21	Bacterial Leaf Blight (BLB) Resistance
Japonica	Agrobacterium	Ferritin	Iron Improvement
Japonica	Agrobacterium	psy, crt1, lyC	B-Carotene

Source: Hossain et al 1999 (p15, Table4)

Figure 2a. Stemborer adult

Figure 2b. Stemborer adult

Figure 2c. Dead heart symptoms

Figure 2d. Stemborer egg masses

Figure 2. Pictures of rice stemborers (source: IRRI TropRice[6])

In 1994, IRRI started growing *Bt* rice along with other transgenic rice lines in special containment greenhouses (IRRI 1997). Since then, several laboratories from around the world have grown and evaluated *Bt* rice under laboratory or greenhouse conditions (Cohen et al 2000). Research on *Bt* rice is now at a stage where field testing is needed in order for its development to move forward (CGIAR 1998, Bennett 1999, Datta personal communication, IRRI Rolling MTP 2001-2003). However, it is unclear why IRRI has yet to field test *Bt* rice in the Philippines where the institute is located. The reason could either be the lack of a regulatory framework for field testing *Bt* rice (CGIAR 1998, S. Datta 2000 personal communication) or the presence in the Philippines of significant public opposition to field testing transgenic crops lead by non-governmental organizations (NGOs) and environmentalist groups (Aerni et al 1997, CGIAR 1998, D. Ramirez 2000 personal communication).

[6] All photos from: Mueller, K.E. 1983. Field Problems of Tropical Rice. Revised. IRRI, Los Baños, Philippines

So far, China is the only country where field testing of *Bt* rice has taken place (Yu et al 2000, M. Cohen and S. Datta 2000 personal communication).

IB. The controversy of adopting transgenic pest-resistant crops

The current policy environment for agricultural biotechnology in the Philippines is polarized over field testing of transgenic rice (Aerni 1999). It is a similar situation in other Asian countries and reflects the contentious nature of the public debate over the benefits and risks of using agricultural biotechnology to improve the welfare and address food security concerns of less developed countries (Leisinger 1999, Tripp1999, Borlaug and Doswell 2000, Conway 2000). Due to a lack of empirical evidence of actual benefits and risks from adopting transgenic crops, the debate between critics and proponents of agricultural biotechnology has often been based on beliefs rather than facts (Quaim 2000a). According to McCalla and Brown 1999, much of the debate over biotechnology focuses on risks from the transfer of genes between species rather than genetic modifications within the same genotype[7]. Still, Conway (2000) argues that field testing is the only way to gain a better assessment of the actual benefits and risks from transgenic crops.

In the case of *Bt* rice, the actual performance of *Bt* rice under various environmental conditions in tropical Asia especially in terms of host-plant-pest interaction, yield stability and grain quality will remain uncertain if field testing is not carried out (Panda and Khush 1995, Bennett 1999). Field testing also provides the opportunity to improve field testing protocols and evaluate deployment strategies especially in view of indications that stemborers in Southeast Asia can develop resistance to *Bt* toxins under certain conditions (CGIAR 1998, Bentur et al 2000, Cohen et al 2000). Field testing is essential in the selection and improvement of valuable crop cultivars for release (PhilRice NCT Manual). In the case of *Bt* Rice, it represents the first step in getting the benefits of improved crop protection technology into the hands of farmers. Banning field testing of *Bt* rice effectively denies farmers and ultimately the rest of society the opportunity to reap the benefits that were originally intended for them[8]. By being able to provide empirical evidence on the potential economic benefits of *Bt* rice represents a positive contribution towards a constructive public debate on adopting agricultural biotechnology products in developing countries.

[7] One example of how this distinction applies to transgenic rice is the case of rice that is genetically engineered with *Xa21* a gene that confers bacterial blight resistance (BB) and comes from *O. longistamina,* a wild species of rice from Africa (Khush and Bhar 1998, Bennett 1999). It is thought that unlike *Bt* rice which contains genes alien to the rice germplasm, BB rice is expected to generate less controversy and gain more public acceptance for field testing since its trait is conferred by a rice gene under the control of a rice promoter (Bennett 1999).

[8] As much as the focus of this study is on the economic benefits of *Bt* rice adoption, it is recognized that the debate over transgenic crops is also about perceived risks and potential social costs. Conway (2000) outlines some of the major issues of contention, these are: (1) environmental issues, (2) health issues, (3) consumer/labelling issues, (4) ethical concerns, (5) concern targeted to the poor and excluded, (6) industry/science interests, and (7) sustainable versus industrial agricultural issues.

IC. Research problem

The literature has established the huge socioeconomic impact of modern rice technology and the tremendous returns from investments on rice R&D for Asia at both the regional and national levels (Evenson and David 1993, see **Table 2**). Rice biotechnology research for Asia is expected to be just as productive based on results from research prioritization studies in Herdt (1991) and Evenson et al (1996, see **Table 3**). Using inputs from rice scientists and biotechnologists from around the world, Herdt and Evenson assessed research priorities by type of research or plant breeding activity, rice ecosystem and production constraint. They estimated the potential value of desired traits in addressing specific production constraints and the probability that biotechnology would enable successful breeding of such traits into rice. Based on their results, Herdt and Evenson recommended that the bulk of research focus on problems in irrigated rice ecosystems (see **Table 4**) wherein biotic constraints would make up around 30 percent of the research investment allocated for that ecosystem. In terms of research approach by production constraint, transgenic research was expected to yield the most gains in addressing insect and disease constraints with almost 40 percent of the investment on transgenic research allocated to addressing biotic constraints (see **Table 5**).

There are some limitations though to the Herdt and Evenson studies: (1) the distribution of benefits and spillover effects are not determined and (2) their results are for Asia as a whole and would not be as useful at the national or local levels (Toenniessen, 1998, page 208). Even if their results do represent a good coverage of China and South Asia, Herdt (1996, page 403) admits that the omission of Vietnam and the Philippines along with other countries in Southeast Asia are a serious limitation to their study. Thus, further evaluation of biotechnology research priorities at the national level is encouraged using location specific objectives and detailed local information (Toenniessen 1998, page 208).

The results from Evenson and Herdt though are consistent in terms of actual biotechnology research efforts carried out to date. Hossain et al (1999) reports that the majority of rice biotechnology research has focused on traits related to pest resistance (see **Table 5**) that are expected to yield the most benefits as indicated in Evenson and Herdt (**Table 3**). Still, Yudelman et al (1998) foresees the potential benefits and actual impact of agricultural biotechnology on crop protection in developing countries to be limited. Hossain (2001, page 9) further adds that gains would be greater from rice biotechnology research if it were directed instead to addressing abiotic constraints in unfavorable rice growing ecosystems (e.g. drought tolerance).

For all the arguments on what the optimal research portfolio should be, the actual economic impact of rice biotechnology research is still unknown because no rice biotechnology product has yet been released (Wailes et al 2001). This deficiency is recognized in IRRI (2001) and the CGIAR (1998) where there is now an increased emphasis on product delivery. One way to addressing this deficiency is to evaluate potential impact pathways for rice biotechnology R&D output like *Bt* rice (CGIAR 1998). The information generated by such evaluations can be used in research prioritization and developing effective product deployment strategies.

ID. Objectives of the study

The main purpose of this study is to develop and test an ex-ante analytical framework that can be used as a template to evaluate the size and distribution of benefits from adopting a transgenic rice variety like *Bt* rice over a specified adoption impact pathway in Southeast Asia. In this study, the adoption impact pathway refers to relevant geographical and temporal dimensions of the welfare effect from *Bt* rice deployment. Specifically, the Philippines and Vietnam are targeted as the initial recipients for *Bt* rice deployment in Southeast Asia. In contrast to the existing socioeconomic literature on rice biotechnology evaluation (e.g. Herdt 1991, Evenson et al 1996, 1998) which have comprehensively evaluated returns to research from almost every type or area of rice biotechnology,

Table 2. A Summary of selected studies of returns to rice research in selected Asian countries

Study	Country	Time period	Estimated MIRR
Hayami and Akino, 1977	Japan	1915-1950	25-27
Hayami and Akino, 1977	Japan	1930-1961	73-75
Pray, 1979	Bangladesh	1961-1977	30-35
Evenson and Flores, 1978	Asia (NARS)	1950-1965	32-39
Evenson and Flores, 1978	Asia (NARS)	1966-1975	73-78
Evenson and Flores, 1978	Asia (IRRI)	1966-1975	74-108
Flores, Evenson & Hayami, 1978	Philippines	1966-1978	75
Flores, Evenson & Hayami, 1978	Tropics	1966-1975	46-71
McKinsey and Evenson, 1991	India	1954-1984	65
Evenson and David 1993	India	1954-1984	180
Evenson and David 1993	India (non-HYV)	1954-1984	80
Azam, *et al.,* 1991	Pakistan	1969-1988	84
Dey and Evenson, 1991	Bangladesh	1969-1989	165
Salmon, 1991	Indonesia	1969-1980	151
Setboonsarng & Evenson, 1991	Thailand	1967-1980	35

Source: Evenson and Pray 1991 as cited and compiled by Evenson and David 1993 (p138, Table 6.1)
Note: MIRR is marginal internal rate of return to investment

Table 3. Estimates of the effects of the Rockefeller Foundation International Program on Rice Biotechnology, 1994.

	Time to production (years)		Time to field trials (years)		Annual effect after realization				Present value of benefits (billion US$)			
					Area (million ha.)	Yield (%)	Quantity (million tons)	Value (in 1990 bil USD)	5% Discount		10% Discount	
	Optimistic	Conservative	Optimistic	Conservative					Optimistic	Conservative	Optimistic	Conservative
1. Multiple insect resistance	8	15	12	21	37.5	30	41	8	91	50	20	10.5
2. Multiple disease resistance	10	18	15	22	50	15	27	5.4	25	19	5.4	4
3. Hybrid rice enhancement	5	10	9	16	30	15	16	3.2	41	28	14	7
4. Stress tolerance	13	18	17	22	50	15	27	5.4	23	19	5.4	4
5. General yield enhancement	20	25	25	40	100	20	70	14	82	39	13	3
Total with yield enhancement							181	36	260	164	63.8	28.5
Total without yield enhancement							111	22	178	125	50.3	25.5

Source: Evenson 1996 (p343, Table 21.9)

Notes:

Time to field trials based an time assessment (section II).

Time to production based an 4-6 years diffusion.

Area estimates based an incremental areas to conventional breeding.

Yield estimates based an India-Indonesia studies.

Program costs discounted at 10%=US$ 1 billions; benefits/costs ratio ranges from 14 to 39.

Program costs discounted at 5%=2 billion; benefits/costs ratio ranges from 55 to 130.

Table 4. An optimal portfolio of Asian rice research investment based on conservative expectations of research success by rice agroecosystems.

Research problem area category	Annual research investment** for all research techniques by ecosystem***			
	Irrigated	Rainfed	Upland	Deepwater
	---------- *million USD* ----------			
Insects	58	15	8	6
Disease	31	14	9	5
Other pests	28	13	17	5
Abiotic stress	76	23	20	4
Bio-efficiency	178	31	9	2
Total	388	95	63	22

Source: Evenson, Herdt and Hossain 1996 (p402, Table23.4)

Notes: * Conservative expectations reflect the average number of years untill 25% of the remaining potential yield increase is obtained. ** Optimal investment based on allocation of 568 million USD that w ill generate an annual IRR of 25 percent. *** Rice production by agro-ecology is: irrigated, 352 million tons; rainfed, 74 million tons; upland, 34 million tons; deepw ater, 14 million tons. Rice is valued at US$ 200 per ton

Table 5. An optimal portfolio of Asian rice research investment based on conservative expectations of research success by rice research technique.

Research problem area category	Management	Conventional Breeding	Wide Crossing	Transgenics
	Annual research investment** for all rice agroecologies using			
		---------- *million USD* ----------		
Insects	28	17	6	36
Disease	15	10	12	20
Other pests	27	0	23	12
Abiotic stress	33	50	11	29
Bio-efficiency	0	126	33	77
Total	104	204	84	176

Source: Evenson, Herdt and Hossain 1996 (p403, Table23.5)

Notes: * Conservative expectations reflect the average number of years untill 25% of the remaining potential yield increase is obtained.

** Optimal investment based on allocation of 568 million USD that w ill generate an annual IRR of 25 percent

Table 6. Distribution of papers presented in Rockefeller Foundation Rice Biotech meetings by area of research.

Fields of Research	1994 No. of papers	1994 Percent	1997 No. of papers	1997 Percent	1999 No. of papers	1999 Percent
Biotic stresses	86	39.5	108	37.2	116	38.5
Insects	28	12.8	37	12.8	37	12.3
Diseases	58	26.6	71	24.5	79	26.2
Abiotic stresses	20	9.2	25	8.6	35	11.6
Drought	8	3.7	11	3.8	14	4.7
Submergence	5	2.3	7	2.4	8	2.7
Salinity/Cold	7	3.2	7	2.4	13	4.3
Human Nutrition	6	2.8	4	1.4	2	0.7
Yield/Quality	32	14.7	64	22.1	53	17.6
Transgenic / methodology	35	16.1	46	15.9	43	14.3
Genomics	39	17.9	43	14.8	54	17.9
TOTAL	218		290		301	

Source: Hossain et al 1999 (p12, Table2).

this study focuses on the size and distribution of economic benefits from the technology delivery phase. The welfare impact is expressed in terms of valuing the changes in economic surplus. Technology and price spillovers are examined since *Bt* rice is the product of a collaborative effort at the international and national levels and because the Philippines and Vietnam undertake international trade in rice. The value of the potential economic impact of *Bt* rice is also compared to other types of transgenic pest-resistant rice. Finally, we suggest modes of *Bt* rice deployment that would appear to yield favorable welfare benefits based on the results of the analysis.

IE. Statement of the hypothesis

Rice consumers may be the primary beneficiaries if prices in the market are freely allowed to reflect the reduction in unit costs generated by the improved rice technology. However, the initial adoption of *Bt* rice by a small open-economy rice importer like the Philippines does not necessarily benefit consumers since prices depend on the international market price. A market distortion such as a government imposed ad valorem tariff on rice imports result in a greater share of the benefits being absorbed by producers. Likewise, welfare effects from adopting *Bt* rice in the Philippines will depend on: (1) changes in the Philippine rice import tariff schedule (2) the nature and extent of farmer adoption, and (3) the effectiveness or durability of *Bt* rice technology.

Philippine consumers may eventually benefit if a technology spillover from the Philippines to a large open economy rice exporter such as Vietnam where to occur. When farmers in Vietnam's Mekong River Delta[9] region adopt *Bt* rice, it shifts Vietnam rice supply curve outward and increases its exportable surplus. Increased Vietnam rice exports cause the world price to fall and benefits are spread throughout the market especially for consumers in both the Philippines and Vietnam. Therefore, the central hypothesis is that the benefits of Bt rice will be positive for both producers and consumers in the Philippines and Vietnam.

IF. Organization of the Thesis

In chapter II, we develop the adoption impact pathway for *Bt* rice and present the conceptual framework and empirical model of this study. The results are reported and discussed in Chapter III, finally in chapter IV the results are summarized and conclusions are drawn on the potential economic benefits from adopting *Bt* rice.

[9] The Mekong River Delta is the most commercialized region in Vietnam and characterized as a fertile and mostly-irrigated area with rice surpluses up to over 4 million tons. In a country where up to 70 percent of the total harvested production is a marketable surplus (Ryan 1999), up to 95 percent of that surplus comes from the Mekong River Delta region which also accounts for over half of Vietnam's production. Hence, relatively small changes in the region's production and consumption level can result in large changes in exports (Minot and Goletti 1997).

CHAPTER II. BACKGROUND AND METHODS

This chapter presents a background about *Bt* rice and the methods used in this study to evaluate its economic benefits. The discussion is organized into four sections. In the first section, we develop a base adoption scenario from which to specify an adoption impact pathway for *Bt* rice. This is followed by a discussion of the economic surplus model used to assess the expected welfare effects from *Bt* rice deployment. Parameter values for initializing the empirical model are specified and a baseline projection of rice supply and demand without the adoption of *Bt* rice is presented. The last section of this chapter outlines the set of calculations to be carried out using the empirical model.

IIA. Base adoption scenario for *Bt* rice

This section examines the adoption impact pathway specified for *Bt* rice in Southeast Asia. The discussion focuses on assumptions about the impact pathway that are used to construct the base adoption scenario from which the welfare effects of deploying *Bt* rice can be evaluated. The discussion of the base adoption scenario is organized into three parts. First, an overview of the base adoption scenario is given. This is followed by a review of the assumptions on the product characteristics and efficacy of *Bt* rice. The last part of the section examines the assumptions on the geographical and temporal aspects of *Bt* rice deployment.

In this study, the term *adoption impact pathway* for *Bt* rice refers to the socioeconomic effects, product characteristics, geographical, and temporal aspects of deploying *Bt* rice. The adoption impact pathway for *Bt* rice is determined or modified by both the physical and socioeconomic environment in which the technology delivery process is carried out. To date there are no existing adoption impact pathways to identify and adapt for *Bt* rice evaluation since no rice biotechnology product has yet been released in Southeast Asia. This study therefore specifies an adoption impact pathway based on a series of assumptions that are used to construct a scenario of where, when and how *Bt* rice will likely be disseminated in Southeast Asia.

This study assumes that an effort is made to ensure consumer acceptance by incorporating the *Bt* gene into IR 64, the most widely grown and consumed *Indica* rice variety today in South and Southeast Asia (Khush 1995, Cantrell 2001, IRRI 2001b). Apart from its transgenic pest-resistant mechanism, a *Bt* IR 64 variety is expected to retain all the performance and quality characteristics of conventionally bred IR 64. In addition, the study assumes no technology fee or royalties are levied on producers who buy seed of *Bt* IR 64. Therefore, market prices of transgenic *Bt* IR 64 are not expected to differ from conventionally bred IR 64.

The study assumes that *Bt* rice is first field tested and commercially released in the Philippines and subsequently adopted in Vietnam. The International Rice Research Institute (IRRI) is identified as the lead institution for rice biotechnology research in Southeast Asia and is the initial source of *Bt* rice cultivars for field testing and release in Southeast Asia. Under the base adoption scenario, welfare benefits from *Bt* rice are evaluated for the years 2000 to 2020. The length of the evaluation period considers the time from field testing to commercial release of a *Bt* rice variety and its expected duration in the market.

The year 2000 is selected as the base year since that is the year that IRRI made the transition from conducting laboratory and greenhouse level research on *Bt* rice to preparing *Bt* rice lines for field testing. From 2001 to 2003, field testing of *Bt* rice is carried out in the Philippines within regulatory field testing guidelines for transgenic rice and closely supervised by IRRI. The multiplication and production of *Bt* rice seed runs through 2004 and is commercially released in the Philippines by the year 2005. Vietnam becomes the next country in Southeast Asia to adopt *Bt* rice and follows the same biosafety and field testing protocols for *Bt* rice developed in the Philippines. Field testing of *Bt* rice in Vietnam takes place from 2005 up to 2006, seed production through 2007 with commercial release of a *Bt* rice variety by 2008. Targeted recipients of *Bt* rice seed in the Philippines are farmers in irrigated regions. In Vietnam, targeted recipients for *Bt* rice are farmers from the Mekong River Delta (MRD) region. Equivalent annual adoption rates of *Bt* rice are assumed for both the Philippines and Vietnam. We assume released *Bt* rice varieties are completely resistant to stemborer infestation. No depreciation in the host plant resistance of *Bt* rice and no farmer disadoption are assumed throughout the evaluation period.

A1. Assumptions on the product and form of Bt rice deployment

Bt rice is deployed as seed of IR 64 - an *Indica* rice variety

Conventional breeding of host plant resistance involves the crossing of complete genomes of different lines to form a new variety. In contrast, genetic engineering allows for the introduction of a new resistance mechanism into varieties that are already established (Quaim 199b). This study assumes that an effort is made to increase the likelihood of public acceptance of *Bt* rice by genetically engineering the *Bt* gene into a well established variety like IR 64. Apart from having a transgenic pest-resistant mechanism, *Bt* IR 64 is expected to be no different from conventionally bred IR 64. This allows us to characterize the production and dissemination of *Bt* rice like that of a conventionally bred modern rice variety.

Selecting IR 64 as the model variety for *Bt* rice in Southeast Asia is significant for the following reasons: (1) its rice type is *Indica*[10] which is consumed by more than 2 billion people, mostly from countries in South and Southeast Asia (Portrykus et al 1995), (2) it is the most popular *Indica* variety in South and Southeast Asia[11], and (3) because IR 64 is so popular due to the valuable agronomic traits it carries, it has become an important reference variety in rice biotechnology research especially in the field of functional genomics (Leung et al 2001)[12].

Bt rice is completely resistant to stemborers

The assumption that *Bt* rice is completely resistant to stemborers is based on communication with IRRI scientists and reports by Khush and Bhar (1998) and Ye et al (2000) that indicate *Bt* rice lines tested in IRRI greenhouses and in the field in China have proven to be highly toxic if not completely resistant to stemborers.

Although past evidence has shown that host plant resistance in modern rice varieties is not permanent (Evenson et al 1996), the base adoption scenario assumes that planting *Bt* rice will yield the same benefit per hectare per year. At this point, not much is known about the durability of the plant resistance in current *Bt* rice lines. However, even if no technology depreciation is assumed for *Bt* rice in the base adoption scenario, just like all insect control technologies, stemborers can eventually evolve resistance to *Bt* rice (Cohen et al 2000). To ensure the durability of the plant resistance in *Bt* rice, the release of *Bt* rice follows the recommendations by Cohen et al (2000) that only *Bt* rice cultivars having a high level of toxin and containing two *Bt* toxin genes should be released.

Crop loss estimates as an indicator of potential gain

This study utilizes crop loss estimates on stemborer infestation as a way of estimating the size of the *Bt* rice adoption-induced supply shift[13]. Crop loss estimates have been extensively used in rice

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[10] Among the four major types of rice consumed in the world: *Indica*, *Japonica*, aromatic and glutinous *Indica* rice is the most widely grown, consumed and traded type of rice (Cramer et al 1993, Sombilla and Rosegrant 1994).

[11] Among *indica* rice varieties planted today in South and Southeast Asia, the most widely grown *indica* variety by far is IR 64 (IRRI 2001b). First released in 1985, IR 64 is planted on about 8 million hectares throughout the Philippines, Vietnam, Indonesia and India (Cantrell 2001, IRRI 2001b). Khush (1994) explains that IR 64 is so popular because it has a favorable combination of traits desired by both farmers and consumers in South and Southeast Asia. Those traits include a high yield potential, short growth duration, and long, slender and translucent grains of superior cooking quality (as characterized by a desirable combination of intermediate amylose content and intermediate gelatinazation temperature).

[12] In order to fully exploit the information generated from the sequencing of Rice DNA, the biological functions encoded in the sequenced DNA needs to be first understood. In line with this objective, Leung et al (2001) reports the large scale mutagensis of IR 64 which involves the creation of mutations in the gemone in order to faciliate the detection of phenotypic changes in important agronomic traits. The goal according to Leung et al, is to assign sequenced DNA to the biogical variation revealed by these mutations.

[13] Estimates of yield loss from stemborer infestation across Asia are reported in Khush and Toenniessen (1991), Pathak and Khan (1994), Teng and Revilla (1996), Ramasamy and Jatileksono (1996), and IRRI (1997). Figures cited vary considerably by agro-ecological region and for individual Asian countries can range anywhere from 3-10 percent to as much as 60-90 percent yield loss.

research prioritization studies as an indicator of potential gain from specific types of research or as a measurement for valuing genetic traits (e.g. Evenson et al 1996, 1997, 1998). However, some question the use of crop loss estimates for designing pest management strategies due to the inherent variability of pest infestation especially in tropical Asia[14]. Yudelman et al (1998) and Matteson (2000) suggest that crop loss estimates on rice pest infestation have often been unreliable and overstated. Crop loss assessments were usually based on single location, single season observations, and quantitative estimates were often derived from simple experiments on biocide efficiency (Oerke et al 1994, Savary et al 1998). Still, quantitative information on crop loss from pests is critical for developing sound pest management practices (Savary et al 2000b). A comprehensive survey begun in 1990 has been carried out by IRRI to develop an extensive crop loss database which would characterize and quantify the rice pest intensity and yield loss relationship over a range of production situations (CGIAR 1998, Cohen et al 1998, Savary et al 1997, 1998, 2000a, 2000b). Crop loss estimates were compiled for both disease and insect pests from multi-year, multi-location surveys of over 700 farmer fields in countries that included China, India and Southeast Asia and experimental data taken from more than 400 plots. Yield loss estimates derived from survey results are reported in Savary et al 2000b.

In this study, we adapt the estimates of Savary et al (2000b) of rice crop losses from stemborer infestation, and use a value of 2.4 percent yield loss based on a 5.5 MT/HA attainable yield, as an indicator of the potential gain from planting *Bt* rice. Some may consider this value to be a conservative estimate since the attainable yield in both the Philippines and Vietnam is higher than the 5.5 MT/HA attainable yield derived in Savary et al 2000b (Hossain 1997). Still this assumption is reasonable since it has been observed that the rice plant compensates for stemborer damage by producing new tillers (IRRI 1997).

A2. Geographical and temporal dimensions of Bt rice adoption

The initial source of *Bt* rice will come from IRRI

The International Rice Research Institute (IRRI) is the leading institution for rice varietal improvement research in the world[15]. Apart from the institute's own plant breeding activities, it is

[14] Pest infestation in the tropics can be highly variable, non-location specific and often coincides with climatic changes such as drought, irregular rainfall, increased humidity, all of which decrease ouput in itself (Pinstrup-Andersen 2001). Pest infestations that have devastating impact in one year might cause only marginal losses in another year (Yudelman et al 1998).

[15] IRRI was established by the Rockefeller and Ford Foundations in cooperation with the Philippine government in 1960. It is an autonomous, non-profit agricultural research and training center whose goal is to improve the welfare of rice farmers and consumers especially those with low incomes. IRRI programs and activities were then based on the agricultural program that the Rockefeller Foundation had in Mexico which would be the forerunner of the International Center for Maize and Wheat Improvement (CIMMYT). IRRI became the prototype for the 16 non-profit international agricultural research centers supported by an informal association of 40 public and private sector donors known as the CGIAR. IRRI produced its first research output

equally instrumental in the development of improved rice varieties by facilitating the collection, storage and distribution of rice germplasm throughout the world (Evenson and David 1993, Gollin and Evenson 1998)[16]. More than 300 breeding lines developed at IRRI have been released as varieties by national rice improvement programs throughout the world (Cantrell 2001). A study by Gollin and Evenson on the pedigrees of modern rice varieties released in the world from 1960 to 1991 shows that almost half of the 1,700 varieties released have at least one parent from IRRI. Even more remarkable it is estimated that more than 70 percent of the world's rice that is planted originates from IRRI rice breeding materials and progenies (Khush 1995)[17].

In contrast to IRRI's lead R&D role in traditional plant breeding, rice production management and rice biodiversity, IRRI is not the principal[18] center for rice biotechnology research in the world. There are now numerous advanced research institutes (ARI) for rice biotechnology in North America, Western Europe and Asia especially in Korea, Japan, China and India (Toenniessen 1998)[19]. Furthermore, because of strengthened intellectual property rights (IPRs) on rice, the private sector has begun investing in rice biotechnology research (Pray 1998)[20].

Despite the possibility of alternative sources for transgenic rice, this study assumes that *Bt* rice released in the Philippines and Vietnam will originate from the International Rice Research Institute. This assumption is because neither the Philippine or Vietnam NARS are known to carry out *Bt* rice

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in the mid-1960s with the release of its first semi-dwarf rice breeding lines which are credited as having paved the way for the "green revolution" (Barker et al 1985, Cantrell 2001).

[16] Gollin and Evenson (1998) cite three IRRI programs which are instrumental in carrying out rice genetic improvement: (1) IRRI's own plant bredding program, (2) the International Rice Germplasm collection (IRGC), and the International Network for the Genetic Evaluation of Rice (INGER).

[17] Khush shows that among individual countries, the Philippines and Vietnam have released the most number of rice varieties developed with genetic material from IRRI (see **Table 7**).

[18] One area in rice biotechnology that IRRI did not become directly involved in was the highly publicized large scale sequencing of the rice genome. Instead, IRRI has focused on functional genomics where it is considered to have a comparative advantage due to: (1) its access to vast genetic resources, (2) phenotyping skills, (3) databases, and (4) partnerships with advanced research institutes and national agricultural research and extension systems (IRRI 2001c).

[19] The Rockefeller Foundation International Rice Biotechnology Program (IPRB) is often cited as helping lead and develop capacity building in Asia for rice biotechnology research. The program's accomplishments are reviewed in Khush and Toenniessen (1991), Evenson, Herdt and Hossain (1996), Toenniessen (1998), and Evenson, Gollin and Santaniello (1998). IRRI has received tremendous support from the IPRB (CGIAR 1998).

[20] Despite the fact that returns from rice research were high, they still may not induce private sector investment because private firms can not capture gains from management innovations or improved inbred (open pollinated) cultivars (Herdt 1996, 1997). Herdt (1997) further noted that even transgenic crops planted by the private firms in developing countries have been limited to non-food crops since returns from food crops are deemed low. The advent of plant genomics changed all that, as rice became an important model genome for cereal crops (CGIAR 1998, Matsumoto et al 2001, Gale et al 2001). Now that the rice genome has been fully sequenced (IRRI 2001d), efforts have now shifted from "structural genomics" to "functional genomics." The difference between structural genomics and functional genomics can be described in an anology given by Dr. H. Leung of the IRRI functional genomics project (IRRI 2001d) - that by fully sequencing the rice genome, scientists will have "a dictionary full of words with each word representing a gene" (structural genomics). The goal now with functional genomics is to "determine the definition of each word wherein the definition would be akin to the function of each gene". Leung et al (2001) reports that several genes have been identified that give rice an enhanced resistance to various pests and diseases. However, private sector involvement in transgenic pest resistant rice has so far focused on herbidicide tolerant rice systems – the more popular ones are LibertyLink (glufosinate-ammonium resistant) rice produced by Aventis (formerly AgrEvro which merged with Rhone-Poulenc) and Roundup Ready (Glyphosate resistant) rice being developed by Monsanto. Herbicide tolerant rice continues to be a controversial transgenic application to which IRRI is non-commital at best (CGIAR 1998). Still, IRRI is being encouraged to undertake evaluation of this technology (CGIAR 1998).

Table 7. Number of rice varieties released in different countries from IRRI bred materials

Country	No. of varieties released	Country	No. of varieties released
Bangladesh	11	Malaysia	7
Bhutan	2	Laos	2
Brunei	3	Myanmar	15
Cambodia	8	Nepal	9
China	15	Pakistan	6
Fiji	2	Philippines	40
India	33	Sri Lanka	2
Indonesia	32	Vietnam	64
Iran	2	Africa	44
Iraq	2	North, Central, and South America	41

Source: Khush 1995 (p279, Table 3)

research, and no one else (either from Asian ARIs or in the private sector) is currently known or expected to deploy *Bt* rice in Philippines or Vietnam. Even if there are any private sector patent arrangements in IRRI's development of *Bt* rice, this study makes no assumption about the IP arrangement that might take place between the NARS beneficiaries, IRRI and the private sector patent owners[21].

The Philippines and Vietnam are the initial recipients of *Bt* rice in Southeast Asia

This study evaluates the welfare impact of *Bt* rice under the assumption that *Bt* rice is adopted in the Philippines[22] and Vietnam[23]. By targeting the Philippines and Vietnam we considered the factors

[21] In contrast to the publicized donation of IP licenses for IRRI's work on Vitamin A "Golden Rice" from Syngenta Seeds AG, Syngenta Ltd., Bayer AG, Monsanto Company Inc., Orynova BV, and Zeneca Mogen BV (IRRI 2001), IRRI is reported to have purchased outright the IP license from Novartis (formerly Ciba-Geigy) to be able to use *Bt* gene CryIA(b) and obtained other *Bt* genes freely public sector ARIs (IRRI 1997, CGIAR 1998, Pray 1998). In the case of the *Bt* gene from Plantech Research Institute (Mitsubishi Chemical), it is reported that in the initial agreement, IRRI agreed to pay a fee to to use their *Bt* gene for research purposes only with the option of buying outright at a pre-determined price the *Bt* gene's IP license after the research phase was over (IRRI 1997). It still remains to be seen how the private sector will react to any release of trasgenic rice in Southeast Asia if that trasgenic variety is made up of components that are patented by the private sector. As for IRRI, based on personal communication with IRRI scientists, it seems IRRI will take a "hands off" policy when it comes to country level release of transgenic rice varieties which orginated from IRRI.

[22] The Philippines is an archipelago of around 7100 islands located between 4° and 21°Ê N latitude and 116° and 127° Ê E longitude (IRRI RICEWEB). It is bounded by the Pacific Ocean to the east, the South China Sea to the west, the Bashi Channel to the north and the Celebes to the south. The Philippines has a FAO/IISA/ IRRI agroecological zone classification of AEZ 3, characterized as warm humid tropics (Pingali 1997 et al). The Philippine climate is characterized as *tropical marine* with a May to October southwest monsoon and a November to April southwest monsoon (IRRI RICEWEB). During a regular year, most rice farmers begin planting in June, the start of the rainy season and harvest by September or October. Paddy harvests in the fourth quarter, which is commonly referred to as the Wet Season (WS), accounts for 60 percent the of the country's yearly output as both irrigated and rainfed areas are harnessed. Surplus stocks from the WS are used to tide first quarter deficits until the Dry Season (DS) inflows come in by October. Generally, importation is required to cover the deficit through the 2nd and lean 3rd quarter. It is the projected 3rd quarter deficit which directs the Philippine government to order in imports early enough that they do not arrive late as consumers will have suffered from scarce supplies while producers face downward pressure on WS paddy rice (Serrano 1997).

that ensure the introduction of a modern rice technology. For example, it is assumed that *Bt* rice can be adapted to local conditions and extended to farmers, and that the technology will be adopted by a large proportion of farmers (McCalla 1994). The following factors make the Philippines and Vietnam ideal countries to be the first beneficiaries in Southeast Asia for *Bt* rice: (1) Both the Philippines and Vietnam[24] have established NARS (see **Table 8**) for rice and have extensive linkages with IRRI in terms of collaborative research, human resource development and germplasm exchange[25]. This situation means that both countries have the capacity to absorb the technology transfer involved with *Bt* rice deployment and the extension structure to get *Bt* rice into the hands of farmers, (2) Rice growing areas in both the Philippines and Vietnam share the same agro-ecological zone classification: Humid tropical lowland - AEZ 3 under the IRRI/FAO classification (see **Figure 3**, **Table 9**). The production contribution of this zone to world rice supply is quite substantial (see **Tables 10-12**), and (3) Both countries are located in Southeast Asia[26], a region that is one of the most productive rice growing areas in the world (see **Tables 13-15**).

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[23] Vietnam is located along the southeastern margin of the Indochina peninsula of Southeast Asia, extending from 8° to 23° N latitude (IRRI RICEWEB). It is bound to the west by Laos and Cambodia and to the north by China. Vietnam's FAO/IIASA/IRRI rice agroecological classification is AEZ 3. Rice is the most important crop in Vietnam where it accounts for over 80 percent of total farm area and 85 percent of food grain output (IRRI RICEWEB). Wet rice cultivation was first established in Vietnam's Red River Delta around the mid-third millennium B.C. (Roche 1992). In the first half of the 20th century, Vietnam (then French Indo-China) along with Myanmar (then Burma) and Thailand were the leading rice exporters in the world (Roche 1992). The onset of World War II and continuing hostilities till the 1970s saw a decline in Vietnam's rice production. Collectivization imposed on south Vietnam after the war was opposed by farmers and proved a failure (Latham 1998, Wailes et al 2000). A contract system was then introduced in 1981 allowing farmers to run the farms themselves but not allowing them to own the farms and decide what crops to be grown (Latham 1998). Failure of the government to provide necessary incentives and price supports culminating in a disastrous rice harvest in 1987 led to the removal of the contract system in 1989 (Roche 1992). Also in 1989, domestic rice grain trade and marketing of inputs was privatized, the army's rice subsidy was abolished and other reforms increased incentives for farmers. Furthermore, a significant exportable surplus was created and Vietnam returned as major rice exporter in 1989 officially exporting 1.42 mil MT (Roche 1992, Latham 1998).

[24] The research linkage between the Philippine NARS on rice (currently spearheaded by the Philippine Rice Research Institute) and IRRI begun at IRRI's inception and is one of most longstanding ones among all the IRRI-NARS partnerships, in part simply by virtue of IRRI being located in the Philippines. In contrast, the IRRI-Vietnam collaboration didn't begin until after the cessation of hostilities in 1975, although IRRI varieties were introduced as early as 1968 with the introduction of IR 8 (Dalrymple 1984, IRRI 2001b). Gollin and Evenson (1998) reports that modern rice varieties in Vietnam are almost completely based on IRRI lines. Equally significant is that IRRI varieties are estimated to cover as much as 60 percent of the irrigated rice growing area in the Mekong River Delta (IRRI 2001b). The development and implementation of Vietnam's national rice program falls under the responsibility of the Ministry of Agriculture and Rural Development (MARD). Rice biotechnology research in Vietnam is spearheaded by the Agricultural Genetics Institute (AGI) / National Institute of Plant Protection (NIPP), and the Cuu Long (Mekong River) Delta rice research institute – all of which are members of the Asian Rice Biotechnology Network.

[25] Collaboration of national rice improvement programs from around the world with IRRI have either been in the form of borrowing parent lines from IRRI or using genetic material from IRRI in conjunction with breeding lines from other available international sources (Gollin and Evenson 1998).

[26] There are six major rice producing countries in Southeast Asia: Indonesia, Vietnam, Thailand, Myanmar, Cambodia and the Philippines (Robertson 2000). Outside China and India, Southeast Asia represents the most important rice producing and consuming region in the world. It is the most important region in terms of the international rice market - the two largest rice exporters, Thailand and Vietnam, and the largest rice importer, Indonesia, are from Southeast Asia (see **Figures 4 & 5**).

Table 8. Rice research and delivery capacities as determined by the number of arable HA per researcher and the rates of yield increases (1961-98).

National Research Capacity (based on HA per researcher)		National Delivery Capacity (based on rates of yield increases): Low	Medium	High
	High	Malaysia	Japan Pakistan Philippines	Australia USA China Iran South Korea Vietnam
	Medium	North Korea Nepal Thailand	Bangladesh India Sri Lanka	Indonesia
	Low	Bhutan Cambodia	Lao PDR Myanmar	

Source: Bell et al 2001 (p22, Table 9)
Note: National research capacity based on HA per researcher as an index: High = <10,000, Medium = 10,000-20,000, Low = >20,000. National delivery capacity (based on the rate of yield increase, 1961-98): Low = <25, Medium = 25-50, High = >50 KG/HA/year

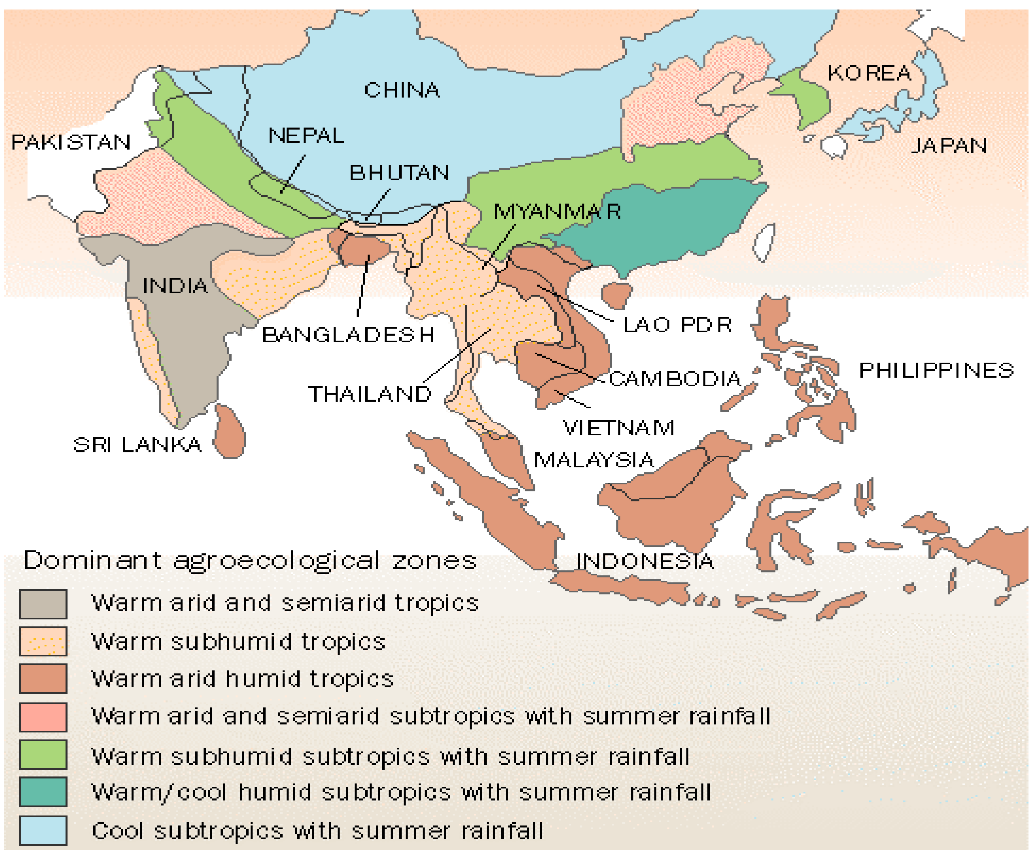

Figure 3. Rice agroecological zones in Asia
(source: http://www.riceweb.org/envi_zones.htm)

Table 9. Geographic delineation of agroecological zones (AEZs) in Asia

Agroecological Zones	Geographical Boundaries
Warm semi-arid tropics (AEZ 1)	Southwestern India (Andhra Pradesh, Kamataka, Tamil Nadu, Maharashtra, Gujarat)
Warm subhumid tropics (AEZ 2)	Thailand, Myanmar, Eastern India (Madhya Pradesh, Orissa, Bihar)
Warm humid tropics (AEZ 3)	Indonesia, Malaysia, Philippines, Vietnam, Cambodia, Laos, Sri Lanka, Bangladesh, parts of India (Assam, Northeastern States, West Bengal, Kerala)
Warm semi-arid subtropics (AEZ 5)	Pakistan, parts of India (Rajasthan, Haryana), parts of China (Helong, Laioning, Jilin, Tianjin, Sandong, Hebei)
Warm subhumid subtropics (AEZ 6)	Northwestern India (Uttar Pradesh, Punjab), Nepal, parts of China (Jiangshu, Anhui, Hubei, Sichuan, Henan, Guizhou, Yunan), North Korea, South Korea
Warm humid subtropics (AEZ 7)	Parts of China (Shanghai, Zehjiang, Fujian, Jianxi, Hunan, Guandong, Guanxi), Taiwan
Cool subtropics temperate zone (AEZ 8)	Parts of India (Himachal Pradesh, Jammu and Kashmir), parts of China (Beijing, Shani, Inner Mongolia, Tibet, Gansu, Ningia, XinJiang, Quinghai)

Source: Garrity et al 1996 (p46, Table 3.3)

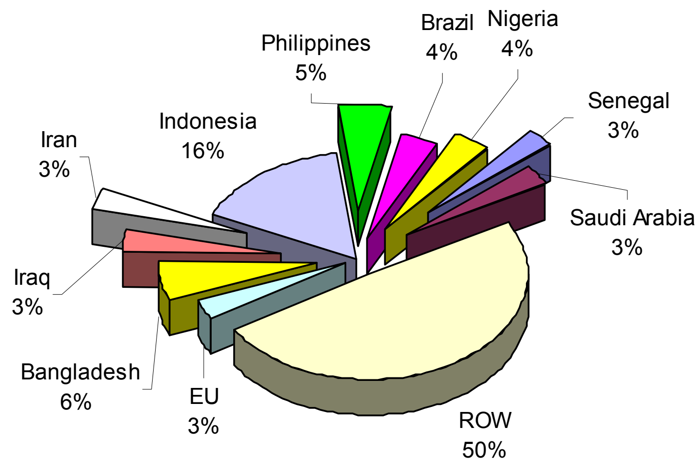

Figure 4. Major rice importing countries by percent share of world total, 1998-2000
(Data source: USDA ERS; 3-year average)

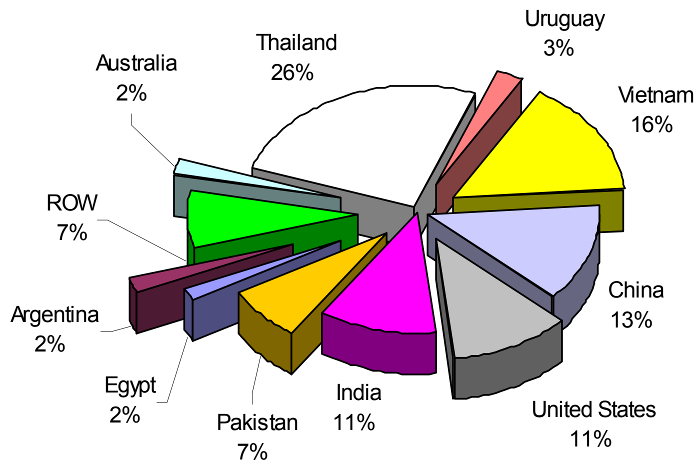

Figure 5. Major rice exporting countries in the world as a percentage of world total, 1998-2000
(Data source: USDA ERS, 3-year average)

Table 10. Relative importance of foodgrain crops by agroecological zones

Agroecological Zones	Rice	Wheat	Maize	Coarse Grains	Pulses	Oilseeds
	-------------------- percent of total area --------------------					
Warm tropics						
Semi-arid	18.5	3.4	2.0	36.1	16.2	23.8
Subhumid	51.3	9.3	6.2	7.6	15.4	10.2
Humid	75.4	1.7	12.9	0.3	3.7	6.0
Warm subtropics						
Semi-arid	9.0	38.0	15.6	12.7	17.9	6.4
Subhumid	35.7	29.4	10.8	4.8	10.0	9.3
Humid	75.6	3.6	3.3	0.1	7.3	10.2
Cool subtropics	3.1	45.3	20.5	6.1	14.0	10.8

Source: Garrity et al 1996 (p47, table 3.4)

Table 11. Sources of growth in rice production in different agroecological zones in Asia, 1975-1991.

AGROECOLOGICAL ZONE	Share of Asian rice area	percent of irrigated rice area	Trend rate of growth (1975-1991) Area	Yield	Production
	percent		*percent per year*		
Semi-arid tropics	7.3	68.2	-0.2	2.2	2.0
Subhumid tropics	30.0	26.8	0.2	2.3	2.5
Humid tropics	26.4	48.2	0.7	3.1	3.8
Subhumid subtropics	18.4	76.8	0.1	3.4	3.5
Humid subtropics	14.2	92.1	-1.1	3.6	2.5

Source: Basic data from IRRI and subnational-level statistics compiled by Hossain and Laborte 1993, cited in Pingali et al 1997 (p17, Table 2.2)

Table 12. The interface between agroecological zones and rice ecosystems.

Agroecological Zones	Total rice cropped area	Irrigated	Rainfed Lowland	Rainfed Upland	Flood-prone
	million HA	*percent of total area in each rice ecosystem*			
Warm tropics					
Semi-arid	9.68	75.0	12.4	10.8	1.8
Subhumid	28.94	23.3	53.9	10.6	12.1
Humid	44.52	42.2	32.0	10.3	15.5
Warm subtropics					
Semi-arid	7.47	99.7	0	0.3	0
Subhumid	23.91	76.6	13.8	5.2	4.4
Humid	18.35	92.1	6.4	1.5	0
Cool subtropics	0.40	100	0	0	0
Total	133.27	56.9	26.7	7.7	8.7

Source: Garrity et al 1996 (p47, table 3.4)

Table 13. World rice paddy production by regional share of total and percent annual growth rate, 1992-2000.

Region / Country	Average Paddy Production 1992-2000	Percent share, 1992-2000 of World	of Asia	of ASEAN	Percent annual growth rate 1992-1996	1996-2000	1992-2000
	metric tons			---------------- *percent* ----------------			
WORLD	564,087,071	100.0			1.48	1.05	1.26
Rest of the World	48,434,573	8.6			0.91	2.67	1.78
ASIA	515,652,499	91.4	100.0		1.53	0.90	1.21
Rest of Asia	67,567,677	12.0	13.1		-0.02	2.18	1.08
China	191,586,565	34.0	37.2		0.91	-0.71	0.10
India	123,432,656	21.9	23.9		2.36	1.83	2.10
Southeast Asia	133,065,601	23.6	25.8	100.0	2.54	1.64	2.09
Brunei	561	0.0	0.0	0.0	-9.63	0.00	-4.94
Cambodia	3,140,941	0.6	0.6	2.4	8.83	2.10	5.41
Indonesia	49,372,392	8.8	9.6	37.1	1.16	-0.04	0.56
Laos	1,639,273	0.3	0.3	1.2	-1.22	8.81	3.67
Malaysia	2,083,207	0.4	0.4	1.6	2.06	-1.78	0.12
Myanmar	17,699,115	3.1	3.4	13.3	3.56	2.50	3.03
Philippines	10,592,851	1.9	2.1	8.0	3.47	1.93	2.70
Thailand	21,878,060	3.9	4.2	16.4	2.31	0.94	1.63
Viet Nam	26,659,200	4.7	5.2	20.0	4.10	4.28	4.19

Data source: FAOSTAT

Table 14. Rice paddy yield averages and percent annual growth, 1992-2000

Region / Country	Average Paddy Yield 1992-1996	Average Paddy Yield 1996-2000	Average Paddy Yield 1992-2000	Percent annual growth rate 1992-1996	Percent annual growth rate 1996-2000	Percent annual growth rate 1992-2000
	metric tons / hectare			*percent*		
WORLD	3.67	3.84	3.75	1.07	0.58	0.92
Rest of the World	2.98	3.21	3.09	1.94	1.04	1.65
ASIA	3.75	3.91	3.83	0.96	0.56	0.84
Rest of Asia	3.35	3.51	3.44	-0.24	1.72	0.82
China	5.94	6.29	6.10	1.37	0.09	0.81
India	2.76	2.92	2.84	1.58	1.28	1.59
Southeast Asia	3.25	3.36	3.30	1.14	0.73	1.04
Brunei	1.69	1.65	1.67	6.02	0.00	3.30
Cambodia	1.56	1.87	1.70	6.91	1.95	4.90
Indonesia	4.37	4.35	4.35	0.33	0.04	0.21
Laos	2.53	2.82	2.69	-0.79	4.12	1.82
Malaysia	3.10	3.02	3.04	1.68	-1.98	-0.19
Myanmar	3.04	3.17	3.11	0.87	1.69	1.42
Philippines	2.87	2.90	2.89	-0.57	1.49	0.51
Thailand	2.31	2.35	2.32	2.08	-0.68	0.77
Viet Nam	3.57	3.99	3.78	2.48	2.44	2.74

Data source: FAOSTAT

Table 15. Harvested area for rice by percent share of total and percent annual growth, 1992-2000.

Region / Country	Average Harvested Area 1992-2000	Percent share, 1992-2000 of World	Percent share, 1992-2000 of Asia	Percent share, 1992-2000 of ASEAN	Percent annual growth rate 1992-1996	Percent annual growth rate 1996-2000	Percent annual growth rate 1992-2000
	hectares	---------------- *percent* ----------------					
WORLD	150,383,634	100.0			0.41	0.46	0.43
Rest of the World	15,657,958	10.4			-1.01	1.61	0.29
ASIA	134,725,677	89.6	100.0		0.57	0.33	0.45
Rest of Asia	19,657,811	13.1	14.6		0.22	0.46	0.34
China	31,385,866	20.9	23.3		-0.46	-0.80	-0.63
India	43,400,311	28.9	32.2		0.77	0.55	0.66
Southeast Asia	40,281,689	26.8	29.9	100.0	1.38	0.90	1.14
Brunei	342	0.0	0.0	0.0	-14.76	0.00	-7.67
Cambodia	1,833,546	1.2	1.4	4.6	1.79	0.15	0.97
Indonesia	11,355,750	7.6	8.4	28.2	0.83	-0.08	0.37
Laos	606,019	0.4	0.4	1.5	-0.43	4.50	2.01
Malaysia	685,914	0.5	0.5	1.7	0.38	0.20	0.29
Myanmar	5,684,964	3.8	4.2	14.1	2.67	0.79	1.73
Philippines	3,658,882	2.4	2.7	9.1	4.07	0.43	2.23
Thailand	9,437,583	6.3	7.0	23.4	0.23	1.63	0.93
Viet Nam	7,018,689	4.7	5.2	17.4	1.58	1.79	1.69

Data source: FAOSTAT

In this study, we assume the Philippines is the first country to field test *Bt* rice for the following reasons: (2) Proximity to IRRI, which is located in the Philippines, assures the Philippine NARS access to IRRI's biotechnology expertise, personnel and resources, (1) the Philippines has the best capacity for rice biotechnology research in Southeast Asia according to Toenniessen (1998) and Aerni (1999) and (3) there is a precedent in field testing a transgenic crop, *Bt* Corn, and therefore it is expected that the Philippines has the capacity to develop the necessary field testing protocols for *Bt* rice. In fact, the Philippines was one of the first nations in Asia to implement biosafety guidelines primarily in response to IRRI's request to carry out transgenic rice research (IRRI, 1997)[27]. Responsibility for nationwide multi-location field testing of promising rice lines in the Philippines is assumed by the National Cooperative Testing (NCT) project for rice[28].

Next to the Philippines, Vietnam is the Southeast Asian country that is in the best position to benefit from pest-resistant transgenic rice deployment[29]. Since no information could be obtained on Vietnam's field testing protocols for rice, the base adoption scenario in this study assumes that Vietnam will adopt the same field testing protocols employed in the Philippines.

<u>*Bt* rice is adopted in the irrigated regions of the Philippines and the Mekong River Delta region in Vietnam</u>

To date it is difficult to ascertain what the adoption rate will be for transgenic rice in Southeast Asia or if it will even be adopted at all by farmers. Since no distinction is made between seed of *Bt* rice and that of a conventionally bred variety, apart from the transgenic pest-resistant mechanism, we characterize the diffusion of *Bt* rice in the same way that we would characterize the diffusion of conventionally bred modern rice varieties.

In this study, we specifically target the irrigated regions of the Philippines and Vietnam. Rice farmers in the irrigated ecosystems[30] of the Philippines and in the Mekong River Delta region have

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[27] The National Committee on Biosafety in the Philippines established in 1990, is responsible for developing policies to regulate the use of genetically modified organisms in the Philippines (De Guzman et al 1999, Duran 1999, Rola 2000). It was the NBCP that granted IRRI the permission to grow and test transgenic rice under greenhouse conditions (IRRI 1997) and it will also be the NBCP that will give IRRI permission to field test *Bt* Rice in the Philippines. No information on the current status of that application could be obtained

[28] The NCT is implemented by a Rice Technical Working Group (RTWG) composed of various agencies and institutions from the government, research and academe The RTWG evaluates the results of the NCT and recommends lines to be approved and released commercially as new varieties by the Philippine National Seed Industry Council (NSIC).

[29] Although Thailand is the world's largest rice exporter and would seem as a more ideal region to evaluate using the economic surplus model in this study, it appears unlikely by Hargrove (2001b) that Thailand will plant transgenic rice in the near future. This is because Thailand banned the import and cultivation of commercial GM seeds around 1998 and the government is considering the banning the field testing of all GM seeds and plants. Furthermore, Thailand is aiming to protect its export markets which demand non-GM crops (Hargrove 2001b).

[30] There are four recognized ecosystems under which rice is grown: irrigated, rainfed lowland, upland and flood-prone (CGIAR 2001). Irrigated ecosystems account for over 75 percent of total rice paddy production even if they only cover 55 percent of the total rice growing area (Fischer 1998). We define the an irrigated lowland rice ecosystem area as level bunded fields with water control; rice transplanted or direct seeded in puddled soil; shallow flooded with anaerobic soil during crop growth (IRRI RICEWEB).

readily adopted improved seed[31] of modern rice varieties in the past[32]. These regions have also been early recipients or adopters of new rice technology and are intensively researched areas at both the NARS and IARC level.

Farmers in both regions will receive their initial source of *Bt* rice seed as part of a government program of distributing certified seed[33]. The price and availability of seed are important factors that will determine its actual rate of adoption (Pingali et al 1997, p230). In most of Southeast Asia, especially in the Philippines, an overwhelming majority of resource poor farmers save their own seed or obtain seed from informal sources. An important assumption then is that the trait resistance in *Bt* rice is inherited through subsequent seasons, in contrast to expensive hybrid seeds which need to be purchased by resource poor farmers every season.

In the base adoption scenario, equivalent *Bt* rice diffusion rates are specified for the Philippines and Vietnam. A simple linear annual diffusion rate of 6 percent is assumed, based on an interpreted calculation of the annual growth rate in the area planted to modern rice varieties from 1967 to 1997 in the Philippines. A ceiling adoption rate of 66 percent is assumed for the Philippines and 60 percent for Vietnam. These values are adapted from Aerni (1999) estimates of a projected ceiling adoption for a transgenic *new plant type* variety developed at IRRI[34]. The base scenario assumes no farmer disadoption of *Bt* rice even if the durability of the plant resistance begins to degrade.

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[31] Seed is the basic and most important input in agricultural crop production. New and improved seed represents the most effective way of getting into the hands of farmers the benefits of varietal improvement research (Bennett 1999). Rice farmers are expected to readily adopt improved seed compared to other forms of rice technologies for two reasons: (1) rice seeds costs (whether purchased or saved) make up a very small if not one of the smallest components of production expenditures and (2) farmers attitudes and perceptions towards improved seed is often positive and in many cases farmers will "try" the new seed because it is "new". According to Heong (2000 personal communication) farmer surveys have indicated that pest resistance is not a primary consideration for rice farmers when deciding to adopt a new variety.

Dawe (1998) foresees that the adoption of new seed in the irrigated ecosystem will still be the most important development in the rice economy in the future as it was thirty years ago at the beginning the green revolution. Barker et al 1985 explains that the adoption in tropical Asia of modern varieties were confined largely to irrigated areas due to variable yield response of rice under different environments. Yield response is much stronger under dry-season irrigated conditions when solar energy is at a peak while yield response is less and and more variable under wet-season conditions. The lack of control and uncertainty of adequate water supply in rainfed and flood-prone areas discouraged the use of fertilizer and adoption of modern varieties. Immediately after the first release of the first generation MVs in the mid 1960s in the Philippine Central Luzon region, Mangahas (1970) showed that the probability of adopting MVs (then referred to as HYVs) was higher in irrigated farms than for rainfed farms. According to Dawe that production in irrigated rice ecosystems will only grow in importance as marginal rice production areas continue to recede and degrade.

[32] It is well established in the literature that farmers in irrigated and favorable rainfed rice growing areas have historically readily adopted modern varieties (e.g. Kikuchi and Hayami 1978, Barker et al 1985, Evenson and David 1993, Otsuka et al 1994). This is because in an irrigated ecosystem, the farmer is assured supply and control of water that makes for a favorable production environment. Thus, the probability of farmers in irrigated ecosystems adopting new rice technology is high compared to other types of ecosystems (Fisher 1998). Historically, the introduction of modern rice cultivars have indeed been more successful in irrigated areas in Asia (Dalrymple and Srivastava 1994) and proved crucial to the success of the green revolution (Evenson and David 1993).

[33] The Philippine DA pursues a policy of distributing certified seeds which it believes can raise yield levels by 10-40 percent. In 2000, the government spent 250 million PHP in purchasing and distributing certified seeds to be planted in an area equal to 500,000 HA or 20 million kg at a seeding rate of 40 kg/HA. The cost of certified seed is computed to be 12.5 PHP/kg or 0.28 USD/kg.

[34] Based on a survey of scientists, extension agents, government officials and non-government organizations , Aerni (1999a) projected a maximum adoption rate of sixty seven percent for the Philippines and fifty seven percent for Vietnam. Specifically, Aerni projected a total irrigated area of 1.63 million HA in Vietnam and 651,100 HA in the Philippines would planted to the NPT Hybrid by 2025.

IIB. Economic Surplus Model

The section presents the economic surplus model to evaluate the expected welfare impacts from *Bt* rice under the base adoption scenario described earlier in the chapter. The concept of economic surplus is the most common approach used in evaluating the welfare effects of agricultural research and innovation in a partial equilibrium framework (Alston, Norton and Pardey 1995).

Figures 6 and **7** illustrate the partial equilibrium economic surplus model of the assumed impact pathway for transgenic rice in Southeast Asia over two phases of adoption in two regions. Panels *a* to *e* in **Figure 6** show the first phase of welfare benefits when the Philippines becomes the first country in Southeast Asia to deploy pest-resistant transgenic rice. The second phase of welfare benefits are illustrated in panels *a* to *e* in **Figure 7** and incorporates the effect of technology spillovers when Vietnam adopts the same transgenic rice variety.

The Philippines is identified as a rice importer modeled as a small open economy (**Figures 6a** and **7a**). The Philippines imposes an *ad valorem* tariff $\tau = T/P_w$ on its rice imports which displaces the initial excess demand curve $ED_{rp,0}$ to $ED(1\text{-}T)_{rp,0}$, where $ED(1\text{-}T)_{rp,0}$ is the initial Philippine import demand curve presented to the rest of the world. The value of T is based on the initial excess supply curve $ES_{row,0}$ and is illustrated by the vertical distance between point *b* and point *c* in **Figure 6b**. In the presence of an *ad valorem* tariff, the Philippine domestic price is a distorted world price $Pw' = Pw(1+T) = Pd_{rp,t}$ for all domestic quantities $Q'_{rp} = Q_{rp,t}$. Being a small country in the world rice trade, the Philippines faces a perfectly elastic excess supply curve (**Figures 6b** and **7b**) and thus changes in its rice import levels do not affect Pw. Initial values for domestic rice production in the Philippines is denoted $Q_{rp,0}$, domestic consumption is $C_{rp,0}$, and with imports $M_{rp,0} = C_{rp,0} - Q_{rp,0}$ (see panel *6a*).

Vietnam is a rice exporting country modeled as a large open economy (panels *6e* and *7e*). No further technology spillout to other regions is assumed after Vietnam's adoption of transgenic rice. Price spillovers though are evaluated because changes in Vietnam's rice export levels influence the world rice price.

The world rice market equilibrium price denoted Pw (see **Figures 6c** and **7c**) is set by the intersection of the Vietnam excess supply curve ES_{vn} and the rest of the world excess demand curve $ED_{row,vn}$ (**Figures 6d** and **7d**). The dynamic partial equilibrium model assumes all supply and demand functions are linear and all shifts are parallel. Thus, any quantity shift is of similar absolute magnitude for all potential prices (Mills 1998). All market prices and quantities refer to milled long grain *Indica* rice and all prices are constant at year 2000 prices.

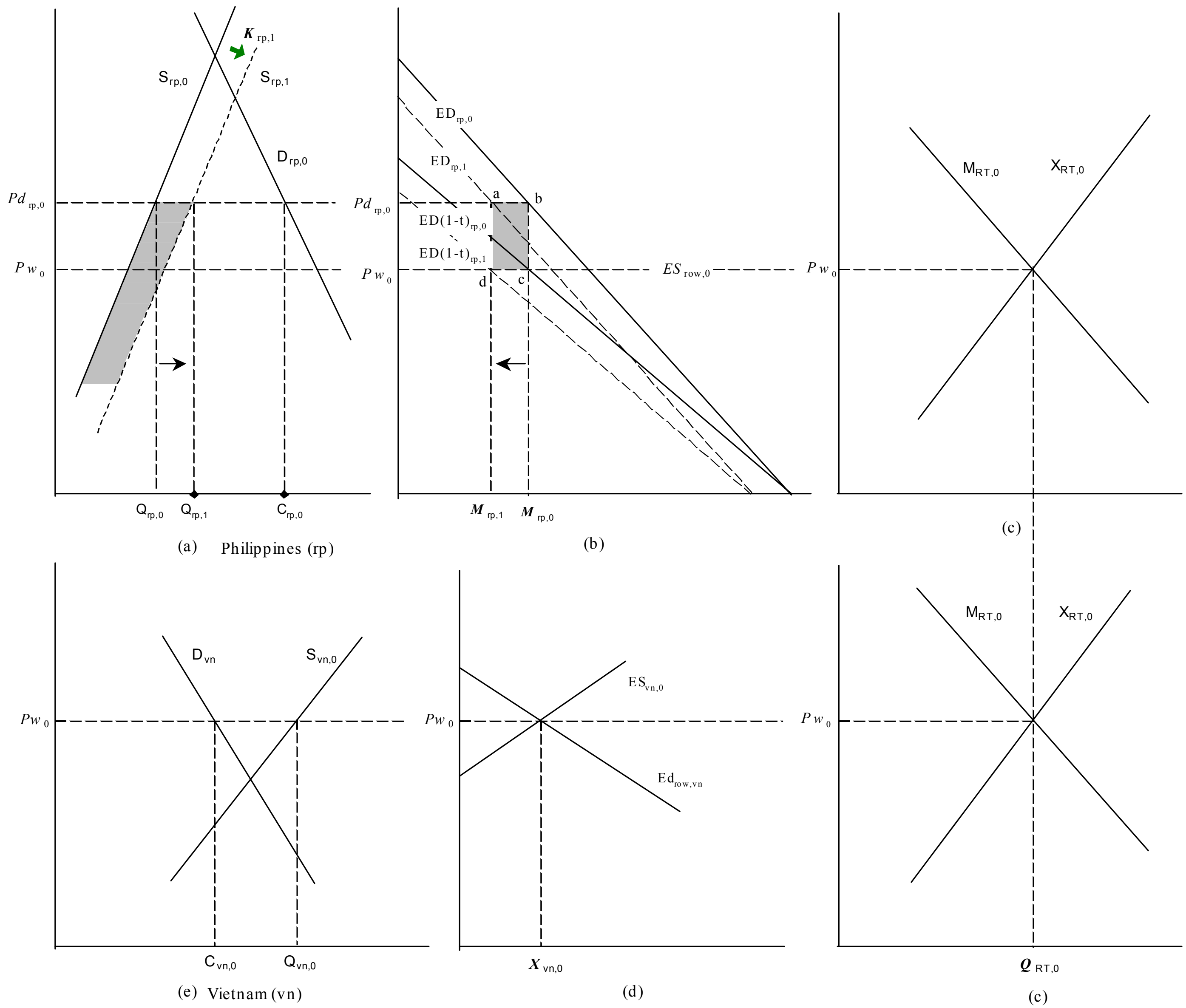

Figure 6. Welfare impact in phase I of transgenic pest-resistant rice adoption in Southeast Asia

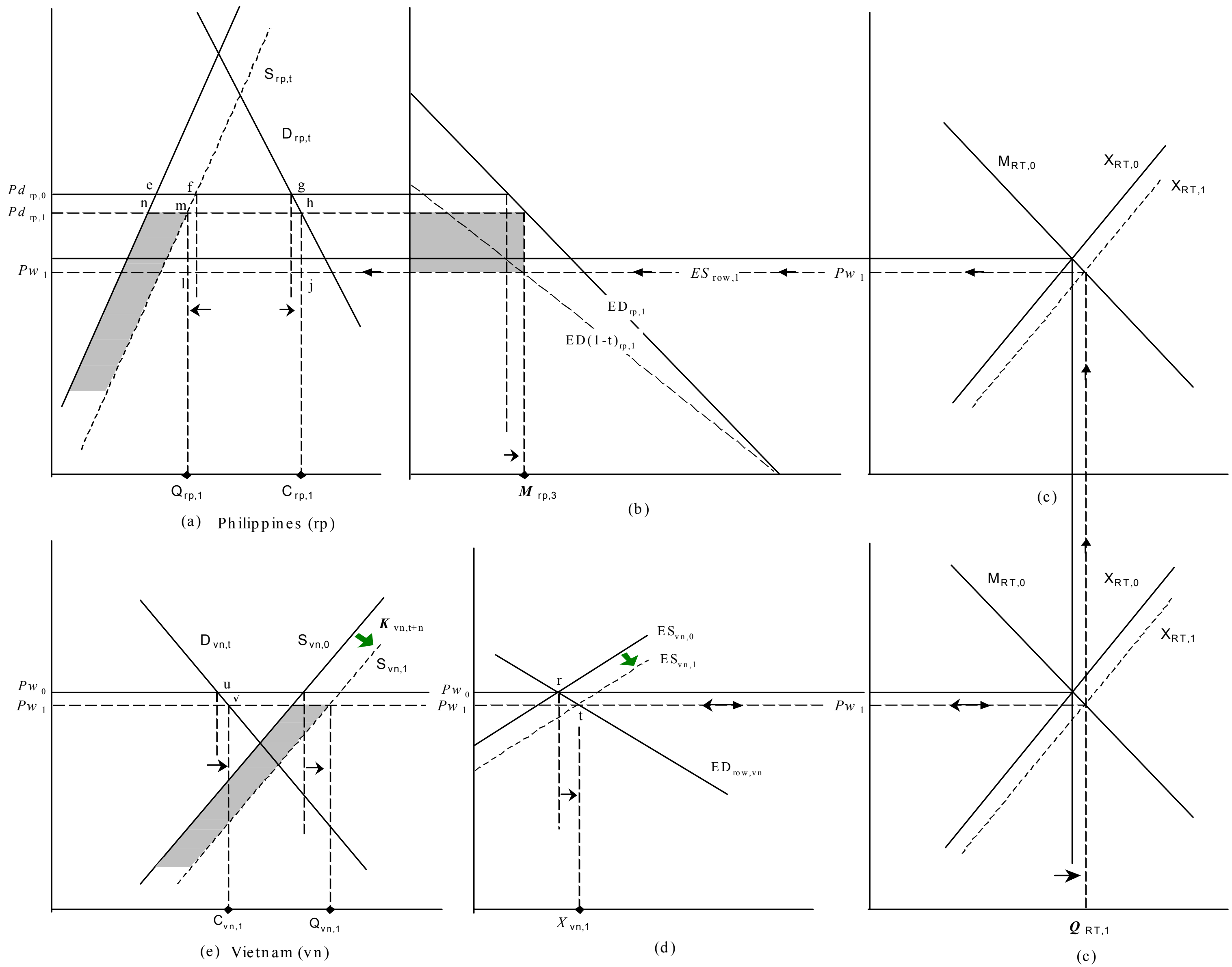

Figure 7. Welfare impact in phase II of transgenic pest-resistant rice adoption in Southeast Asia

B1. Specification of the relevant supply and demand schedules

The relevant excess supply and demand functions for this model are specified as follows:

World import demand for long grain *Indica* rice

From Philippine (*rp*) domestic supply $\boldsymbol{Q_{rp}}$ and consumption $\boldsymbol{C_{rp}}$
Philippine net trade is: $\boldsymbol{Q_{rp} - C_{rp} = M_{rp}}$, $\boldsymbol{M_{rp}}<0$

From *Rest of the world* supply $\boldsymbol{Q_{rowM}}$ and consumption $\boldsymbol{C_{rowM}}$ of rice deficit countries:
Net trade of long grain *Indica* rice importing countries is: $\boldsymbol{Q_{rowM} - C_{rowM} = M_{row}}$, $\boldsymbol{M_{row}}<0$

World import demand for long grain *Indica* rice is: $\boldsymbol{M_{world} = M_{rp} - M_{row}}$, $\boldsymbol{M_{world}}<0$

World export supply for long grain *Indica* rice

From Vietnam (*vn*) domestic supply $\boldsymbol{Q_{vn}}$ and consumption $\boldsymbol{C_{vn}}$:
Vietnam net trade is: $\boldsymbol{Q_{vn} - C_{vn} = X_{vn}}$, $\boldsymbol{X_{vn}}>0$

From *Rest of the world* supply $\boldsymbol{Q_{rowX}}$ and consumption $\boldsymbol{C_{rowX}}$ of rice surplus producing countries:
Net trade of *Rest of the world* rice exporting countries is: $\boldsymbol{Q_{rowX} - C_{rowX} = X_{row}}$, $\boldsymbol{X_{row}}>0$

World rice export supply for long grain *Indica* rice is: $\boldsymbol{X_{world} = X_{vn} + X_{row}}$, $\boldsymbol{X_{world}}>0$

Defining the equilibrium condition in the world market for long grain *Indica* rice:

$\boldsymbol{M_{world} + X_{world}} = 0$ as graphically represented in **Figure 6c** and **Figure 7c**

Since changes in Vietnam rice export levels $\Delta\boldsymbol{X_{vn}}$ affect the world price $\boldsymbol{Pw}$, then world equilibrium price can alternately be determined by equating $ED_{row,vn} = ES_{vn}$, where $ED_{row,vn}$ is the import demand curve from the rest of the world for Vietnam rice exports and is defined as:

$$M_{row,vn} = M_{world} - X_{row} = ED_{row,vn}$$

Thus, the relevant excess supply and demand functions can be specified as:

Rest of the world excess demand (world import demand for Vietnam rice exports):

$$ED_{row,vn} = \gamma_{rowED} - \delta_{rowED} Pw \tag{1}$$

Vietnam excess supply (where *k* represents the *Bt* rice adoption induced supply shift parameter):

$$ES_{vn,t} = \alpha_{vnES} + \beta_{vnES}\left(Pw + k_{vn}\right) = \alpha_{vnES} + \beta_{vnES} Pw + \beta_{vnES} k \tag{2}$$

Setting the Vietnam excess supply $\boldsymbol{ED_{row,t}}$ equal to rest of the world excess demand $\boldsymbol{ES_{vn,t}}$, we obtain the general solution for the *Bt* rice adoption induced change in the world price *Pw*:

$$Pw = \frac{(\gamma_{rowED} - \alpha_{vnES} - \beta_{vnES} k_{vn})}{\left(\beta_{vnES} + \delta_{rowED}\right)} \tag{3}$$

B2. Phase I of adoption

Phase I of pest-resistant transgenic rice adoption in Southeast Asia begins in the first year transgenic rice is deployed in the Philippines and denoted as *t=rp,1*. Starting from the first year that the Philippines adopts a pest-resistant transgenic rice variety, expected production gains from pest related crop losses avoided shifts the domestic supply curve by $K'_{rp,t}$. Where the $K'_{rp,t}$ shift refers to the proportionate supply shift for a given year. In the Philippines, $K'_{rp,t}$ is evaluated from an initial distorted domestic market equilibrium ($Pd'_{rp,0}$, $Q'_{rp,0}$). Using the formula specified by Alston, Norton and Pardey (1995) for calculating the K shift, $K'_{rp,t}$ is defined as:

$$K'_{rp,t} = K_{rp,t} = \left(\frac{E(Y)_{gm}}{\varepsilon'_{rp}} - \frac{E(C)_{gm}}{1+E(Y)} \right) pA_{rp,t}(1-\delta) \tag{4a}$$

Where $E(Y)_{gm}$ is the expected proportionate yield change per hectare from adopting a given transgenic pest-resistant rice variety, $E(C)_{gm}$ is the gross proportionate reduction in marginal cost of production per metric ton of output, ε'_{rp} is the domestic own price elasticity of supply, p is the probability that adoption will achieve the expected yield gain, and $A_{rp,t}$ is the adoption rate in period *t*.

In calculating the K shift in our base adoption scenario, no assumption is made on cost savings and neither technology depreciation nor disadoption is factored in. We also assume that a given pest-resistant transgenic rice variety will exhibit total resistance to its targeted pest (i.e. *Bt* rice is completely resistant to stemborer infestation). In the base adoption scenario, $E(C)_{gm} = 0$, p=1, and δ=0, therefore the formula for $K_{rp,1}$ reduces to:

$$K_{rp,t} = \left(\frac{E(Y)}{\varepsilon'_{rp}} \right) A_{rp,t} \tag{4b}$$

The proportionate supply curve shift from $S_{rp,0}$ to $S_{rp,1}$ increases domestic production from $Q_{rp,0}$ to $Q_{rp,1}$ starting from time *t=rp,1*. Welfare gains accrue only to domestic producers with no changes in domestic consumer welfare considered since the Philippines does not affect the world price. Increased production leads to a decrease in imports from $M_{rp,0}$ to $M_{rp,1}$ as represented in **Figure 6b** by the downward shift of the import demand curve from $ED(1\text{-}T)_{rp,0}$ to $ED(1\text{-}T)_{rp,1}$. Government surplus is reduced by a value represented by area ***abcd*** in **Figure 6b**. The value of the producer surplus change starting at period *t=rp,1* is equal to the shaded area in panel *a* and is calculated as:

$$\Delta PS_{rp,1} = Pw_0(1+T_{rp})K_{rp,1}Q_{rp,0}(1+0.5K_{rp,1}\varepsilon_{rp}) = Pd_{rp,0}K_{rp,1}Q_{rp,0}(1+0.5K_{rp,1}\varepsilon_{rp}), \tag{5}$$

while the formula for computing the reduction in government revenue is:

$$\Delta GS_{rp,t} = -T\Delta M_{rp} = -T_{rp}\beta_{rp}k = -\tau Pd_{rp,0}Q_{rp,0}K_{rp,1}\varepsilon_{rp} \tag{6}$$

Between the first year that the Philippines adopts transgenic rice at *t=rp,1* up to the period *t=vn,1*, total change in welfare benefits is just the sum of producer and government revenue changes in the Philippines:

$$\Delta TS_{t} = \Delta PS_{rp,t} + \Delta GS_{rp,t} \tag{7}$$

B3. Phase II of adoption

Phase II of pest-resistant transgenic rice adoption in Southeast Asia begins in the first year transgenic rice is deployed in Vietnam and is denoted as *t=vn,1*.

The model assumes that production output gains from adopting transgenic rice in the Philippines is fully transferable to Vietnam. Therefore $E(Y)_{gm} = E(Y)_{rp} = E(Y)_{vn}$. Though actual production conditions may vary between Vietnam and the Philippines, it is still possible for both countries to achieve equivalent proportionate supply shifts from adopting the same transgenic variety given that each country's rice growing area as a whole is classified under the same agro-ecological zone.

Technology spillovers are incorporated into the model when the supply shift in the Philippines is followed by an adoption induced supply shift in Vietnam. The Vietnam supply curve shifts from $S_{vn,0}$ to $S_{vn,1}$ starting from the first year that Vietnam adopts the pest-resistant transgenic rice variety (see **Figure 7e**). Increased domestic production leads to an increase in exportable surplus as illustrated by the shift outward of the Vietnam excess supply curve from $ES_{vn,0}$ to $ES_{vn,}$ along the rest of the world excess demand curve $ED_{row\ 1}$ that causes the world price to fall from Pw_0 to Pw_1 (see **Figure 7e**). Philippine producer gains starting at *t=vn,1* are now defined relative to both K_{rp} and $Z_{vn,1}$, which is the absolute value of the reduction in the world price relative to the initial equilibrium world price. $Z_{vn,t}$ is computed using the following formula from Alston, Norton and Pardey:

$$Z_{vn,t} = Z_{t} = \frac{s_{vn}\varepsilon X_{vn}K_{vn,t}}{x_{vn,t}\varepsilon X_{vn,t} + m_{row,t}\eta M_{row,t}} \tag{8}$$

Where Z_t is the absolute value of a Vietnam supply shift induced reduction in the world price relative to the initial pre-adoption price, εX_{vn} is the price elasticity of excess supply or supply elasticity for Vietnam rice exports, and $\eta M_{row,vn}$ is the rest of the world price elasticity of excess demand for Vietnam rice exports. Vietnam's share of global exports of *Indica* long grain rice exports is $s_{vn}=X_{vn}/X_{RT}$ and $m_{row}=M_{row}/M_{RT}$ is the rest of the world's share of global *Indica* rice imports. It is assumed that world trade in long grain *Indica* rice will account for 75 percent of total world rice exports throughout the evaluation period.

To solve for the change in the world price from Pw_0 to Pw_1, we multiply the value of the reduction in the world price Z by the initial world price Pw_0:

$$\Delta Pw_t = -Z_t Pw_t \tag{9}$$

The shaded area of the graph in **Figure 7e** shows the welfare gains to producers in Vietnam from adopting transgenic rice. Welfare gain to consumers is represented by area Pw_0uvPw_1 in **Figure 7e**. Formulas for calculating changes in consumer and producer surplus for Vietnam starting from time *t=vn,1* are:

$$\Delta PS_{vn,1} = Pw_0 Q_{vn,0}\left(K_{vn,1} - Z_1\right)\left(1 + 0.5 Z_1 \varepsilon_{vn}\right) \tag{10}$$

$$\Delta CS_{vn,1} = Pw_0 C_{vn,0} Z_1\left(1 + 0.5 Z_1 \eta_{vn}\right) \tag{11}$$

Where the supply shift relative to Vietnam's initial market equilibrium price is:

$$K_{vn,1} = \left(\frac{E(Y)_{vn}}{\varepsilon_{vn}}\right) pA_{vn,t+n} \tag{12}$$

With Vietnam's adoption of *Bt* rice, the change in Philippine producer surplus at time *t=vn,1* is evaluated at a new domestic price $Pd_{rp,1}$ which is just the distorted world price Pw'_1. The effect then of a technology spillover to Vietnam is to reduce Philippine producer welfare gains by a value equal to area ***efmn*** in **Figure 7a**. A decrease in the world price leads to a decrease in distorted prices received by domestic consumers who gain welfare benefits equivalent to area $Pd_{rp,0}ghPd_{rp,1}$ (also in **Figure 7a**). Philippine government revenue starting from the period *t=vn,1* is represented by area ***mhjl*** in **Figure 7a** and by the shaded area in **Figure 7b**.

Changes in Philippine producer, consumer, and government revenue from the first year that Vietnam adopts the transgenic rice variety are computed using the following formulas:

$$\Delta PS_{rp,t} = Pw_t Q_{rp,t}\left(K_{rp,t} - Z_1\right)\left[1 + 0.5\left(K_{rp,t} - Z_1\right)\varepsilon_{rp}\right] \tag{13}$$

$$\Delta CS_{rp,t} = Pd_{rp,t} C_{rp,t} Z_1\left(1 + 0.5 Z_1 \eta_{rp}\right) \tag{14}$$

$$\Delta GS_{rp,t} = -\tau Pd_{rp,1} Q_{rp,t} \varepsilon_{rp}\left(K_{rp,t} - Z_1\right) \tag{15}$$

The rest of the world also gains from a reduction in the world traded price. Total welfare effect for the rest of the world starting from period $t=vn,1$ is illustrated by area $\boldsymbol{I_0 rt I_1}$ in **Figure 7e**. We can calculate the total surplus change for the rest of the world using the formula (where $X_{vn,0}$ is the initial level of Vietnam rice exports):

$$\Delta TS_{row,t} = Pw_t X_{vn,t} Z(1+0.5Z\eta M_{row,vn}) \tag{16}$$

Total change in welfare benefits in phase II of transgenic pest-resistant rice adoption is the sum of the relevant net economic surplus changes in the Philippines, Vietnam and the rest of the world.

$$\Delta TS_{rp} + \Delta TS_{vn} + \Delta TS_{row} \tag{17}$$

B4. Evaluating the Benefit Stream

A present value (PV) formula is used to summarize the stream of future benefits and costs from adopting transgenic pest-resistant rice. The PV calculation allows us to place all future gains on a common base by discounting benefit streams to year 2000 prices:

$$PV_{gm} = \sum \frac{B_t}{(1+r)^t} \tag{18b}$$

where ***Bt*** is the benefit stream in year *t* and *r* is the discount rate assessed as the appropriate rate of time preference for money. For discounting the benefit streams, we consider 5 percent to be the most appropriate discount rate[35]. Model calculations using a 10 percent discount rate provide a perspective on the importance of discounting[36].

IIC. Model Parameterization

This section presents the development of the baseline projection used in the study. The baseline projection is presented as rice supply-demand balance sheets for the Philippines, Vietnam, and the rest of the world. These projections are derived from estimates of future levels of rice supply and demand without the adoption of transgenic pest-resistant rice. This baseline projection is not intended as a forecast of future market conditions as this can greatly vary from year to year due to weather

[35] This is considered a risk free real rate of return derived from the difference between the prime rate and the inflation rate.

[36] This premise is based on the practice of lending institutions like the World Bank or Asian Development Bank to use a discount rate of around 10 to 12 percent when calculating the net present value or internal rate of return of a project, to reflect the higher opportunity cost of capital in developing countries (ADB 2001).

(Wailes et al 2001). Rather, it serves as a point from which the size of welfare gains from adopting transgenic rice can be determined.

This section also identifies the variables and parameters for estimating the baseline projection and doing model calculations. The key variables and parameters discussed are prices, consumption demand, production supply, rice trade and price elasticities. Historical trends and assumptions underlying each variable and parameter are briefly reviewed along with the data source or reference[37].

Selected key parameter values and assumptions for developing the baseline projection are listed in **Table 16**, while **Tables 17-19** report the results of the baseline projection for the Philippines, Vietnam and the World in the form of food balance sheets through the years 2000-2020.

C1. Prices

There is no world or "central" market price[38] for rice and no clear price discovery process in the international rice trade (Aerni 1999). This is because the inherent structure of the world rice market makes it difficult to select a "world" price for which to standardize our welfare benefits. Prices and quantities traded in the world rice market can be highly volatile because the rice that is traded in the world market is essentially residual or surplus to the needs of exporting countries (Latham 1998).[39] Wide price differentials reflect the many rice types and wide range of classes and quality grades demanded in a highly segmented and differentiated world rice market (Siamwala and Haykin 1983, Barker et al 1985, Cramer et al 1993, Sombilla and Rosegrant 1993, Jayne 1993).

For model calculation purposes, a milled rice price of 180 USD/MT C&F (Cost and Freight) is used to value economic surplus changes in the base adoption scenario. This value is the average price paid for Philippine rice imports in the year 2000. It is derived from Castillo's (2001a) review of Philippine National Food Authority (NFA) rice import purchases conducted in the year 2000.

A 365 day average interbank exchange rate is used to convert prices in local currencies into year 2000 U.S. dollars (USD). The average Philippine peso (PHP) to US Dollar (USD) exchange rate for the year 2000 was 44.35 PHP = 1 USD and 14,176 VND = 1 USD for the Vietnamese Dong (VND).

[37] Brown (1996), Pingali et al (1997), and Evenson (1998) suggest that past projection studies on future rice supply levels have been too optimistic by relying on past trends and overestimating Asia's capacity to produce and meet future food requirements. They argue that past projections have failed to consider the biological limits to rice productivity growth and evident intensification-induced degradation over an expanding range of irrigated rice agroecologies. Thus, whenever possible, assumptions on future growth rates are taken from literature that considers the ecological aspects of future production rather than just extrapolating from past trends.

[38] The closest thing to a world price is that calculated by the USDA as part of its the loan repayment scheme for domestic rice farmers. In the year 2000, the average USDA calculated world rice price was 145 USD/MT. This value is 5 USD less than the average domestic milled rice price in Vietnam of 150 USD/MT.

[39] The residual characteristic of the world rice market is often described as being "thin" because the amount traded is only a small proportion of the total world output. In the year 2000, the total amount of rice traded in the world market estimated at 22.5 million MT. This value represented less than 5 percent of world rice consumption.

Table 16. Selected key parameters and assumptions

ITEM	PHILIPPINES	VIETNAM	World	REFERENCE
PRICES				
EXCHANGE RATE				
local currency to 1 USD	44.35 PHP	14,176 VND		Interbank Exchange Rate (365 day average)
FARMGATE PADDY PRICE				
in local currency	8.52 PHP/kg	1300 VND/kg		BAS 2001, USDA FAS 2001a
in USD (per KG)	0.19	0.09		calculated from exchange rate
in USD (per MT)	192	90	90	calculated from exchange rate
RETAIL (MILLED RICE) PRICE				
in local currency	18.58 PHP/kg	2100 VND/kg		BAS 2001, MARD & USDA FAS 2001a
in USD (per KG)	0.42	0.15		calculated from the exchange rate
in USD (per MT)	437	150	145	calculated from exchange rate, USDA ERS
TRADED PRICES (average yr2000)				
Vietnam CF price (USD/MT)	180			Castillo 2001a
Vietnam 5% broken		198		USDA ERS
Thai 5% broken		207		USDA ERS
ELASTICITIES				
Own Price of Supply	0.30	0.34		Hossain 1998, Minot and Goletti 1997
Own Price of Demand	-0.93	-0.955		Hossain 1998, Minot and Goletti 1997
SUPPLY				
HARVESTED AREA (million HA)				
Total	4.03	7.66	153.77	BAS 2001, MARD/USDA FAS 2001a
In targeted region/s	1.30	3.90		BAS 2001, NIA (RP) 1999, USDA FAS 2001a
Assumed annual growth rate	-0.00132	-0.00136		calculated from FAPRI 2001
YIELD (MT/HA)				
National Average	3.07	4.25		BAS 2001, FAOSTAT
Assumed annual growth rate				
2000-2010	0.00583	0.01896		calculated from FAPRI 2001
2011-2020	0.000756	0.000519		interpreted calculation from Evenson 1998b
PRODUCTION (million MT)				
Total Paddy	12.4	31.4	598.9	BAS 2001, MARD/USDA FAS 2001a
In targeted region/s	9.4	>15		BAS 2001, MARD & USDA FAS 2001a
Milling Recovery Rate	0.65 (NSO)	0.66 (GSO)	0.67 (FAO)	
DEMAND				
POPULATION				
Initial year 2000 (million)	76.50	78.14		NSO 2001, UN 2001
Projected year 2020 (million)	121.97	99.80		NSO 2001, UN 2001
Assumed annual growth rate	0.0236 (2000-25)	.013 (2001-15) .011 (2016-25)		calculated from NSO 2001, UN 2001
CONSUMPTION				
Annual per capita (kg)	116.90	212.70		USDA FAS/MARD, BAS 2001, Wailes et al 2001
Total Domestic (million MT)	8.9	16.6	398.5	USDA, MARD, BAS 2001, Wailes et al 2001
Assumed annual growth rate	-0.00722	-0.00086		calculated from FAPRI 2001, Wailes et al 2000
TRADE				
Total Net	-650,000 MT	3.37 mil MT	22.5 mil MT	NFA, MARD, USDA FAS, FAOSTAT
Philippine-Vietam Trade		616,583 MT		USDA FAS 2001a, NFA

Notes: in year 2000 prices/values unless specified

FAOSTAT is Food and Agriculture Organization World Agricultural Information Center Statistical Database

GSO is Government Statistical Office (Vietnam) — NSO is National Statistics Office (Philippines)

USDA is United States Department of Agriculture — NFA is National Food Authority (Philippines)

USDA FAS is USDA Foreign Agricultural Service — BAS is Bureau of Agricultural Statistics (Philippines)

USDA ERS is USDA Economic Research Service — FAPRI is Food and Agricultural Policy Research Institute

MARD is Ministry of Agriculture and Rural Development (Vietnam)

Table 17. Projected Philippine rice supply and demand without *Bt* rice adoption, 2000-2020.

YEAR	Total Area	Yield	Milled Production	Beginning Stocks	Total Supply	Population	CONSUMPTION Per Capita	CONSUMPTION TOTAL	Ending Stocks	required IMPORTS	30 day buffer
	hectares	*mt/ha*	*---------- metric tons ----------*				*kg*	*--------------------- metric tons ----------------------*			
2000	4,038,085	3.07	8,053,118	2,355,500	10,408,618	76,498,735	116.90	8,942,702	1,465,916	650,000	735,017
2001	4,032,774	3.04	7,962,633	2,115,916	10,078,548	78,304,105	111.77	8,751,780	1,326,768	774,000	719,324
2002	4,027,471	3.07	8,039,702	2,046,093	10,085,794	80,152,082	110.96	8,893,678	1,192,116	730,987	730,987
2003	4,022,174	3.10	8,116,555	1,923,104	10,039,658	82,043,671	110.16	9,037,877	1,001,781	742,839	742,839
2004	4,016,885	3.14	8,193,192	1,744,621	9,937,812	83,979,902	109.36	9,184,414	753,398	754,883	754,883
2005	4,011,602	3.17	8,269,613	1,508,282	9,777,894	85,961,827	108.58	9,333,327	444,568	767,123	767,123
2006	4,006,326	3.20	8,345,819	1,211,691	9,557,509	87,990,527	107.79	9,484,654	72,856	779,561	779,561
2007	4,001,058	3.24	8,421,810	852,416	9,274,226	90,067,103	107.01	9,638,434	-364,208	1,156,408	792,200
2008	3,995,796	3.27	8,497,587	792,200	9,289,787	92,192,687	106.24	9,794,709	-504,921	1,309,966	805,045
2009	3,990,541	3.31	8,573,150	805,045	9,378,195	94,368,434	105.48	9,953,516	-575,322	1,393,419	818,097
2010	3,985,293	3.34	8,648,500	818,097	9,466,597	96,595,529	104.71	10,114,899	-648,302	1,479,663	831,362
2011	3,980,052	3.34	8,643,652	831,362	9,475,013	98,875,184	103.96	10,278,898	-803,885	1,648,726	844,841
2012	3,974,818	3.34	8,638,806	844,841	9,483,647	101,208,638	103.21	10,445,557	-961,910	1,820,449	858,539
2013	3,969,590	3.35	8,633,963	858,539	9,492,502	103,597,162	102.46	10,614,917	-1,122,415	1,994,874	872,459
2014	3,964,370	3.35	8,629,123	872,459	9,501,582	106,042,055	101.72	10,787,023	-1,285,442	2,172,047	886,605
2015	3,959,156	3.35	8,624,285	886,605	9,510,890	108,544,647	100.99	10,961,920	-1,451,031	2,352,010	900,980
2016	3,953,949	3.35	8,619,450	900,980	9,520,430	111,106,301	100.26	11,139,653	-1,619,223	2,534,811	915,588
2017	3,948,750	3.36	8,614,618	915,588	9,530,206	113,728,410	99.54	11,320,267	-1,790,061	2,720,494	930,433
2018	3,943,557	3.36	8,609,789	930,433	9,540,222	116,412,400	98.82	11,503,810	-1,963,588	2,909,107	945,519
2019	3,938,370	3.36	8,604,962	945,519	9,550,480	119,159,733	98.11	11,690,328	-2,139,848	3,100,697	960,849
2020	3,933,191	3.36	8,600,138	960,849	9,560,987	121,971,902	97.40	11,879,871	-2,318,884	3,295,312	976,428

Source: FAOSTAT 2001, FAPRI 2001, Wailes et al 2000, USDA ERS, USDA FAS, Evenson 1998b

Notes:

Population: Year 2000 is from NSO 2001, projected 2001-2020 is based on an annual growth rate of 2.36 percent

Per capita consumption: Initial is based on 24,500mt/day national consumption rate / population * 365 days,
projected 2001-2020 assumes an annual growth rate of -0.0072161 based on an interpreted calculation of FAPRI 2001

Area: Year 2000 is from BAS 2001, 2001-2020 assumes an annual growth rate of -0.0013151 based on an interpreted calculation of FAPRI 2001

Yield: Year 2000 is from BAS 2001, 2001-2010 is from FAPRI 2001, 2011-2020 assumes an annual growth rate of 0.0007555 based on an interpreted calculation of Evenson 1998b

Total Supply = [Milled Production] + [Beginning Stocks]

Beginning Stocks: 2000-2001 is [Ending Stocks]+[Required Imports] from previous year
2002-2007 is [Ending Stocks] from previous year + [30 Day Buffer Stock] from previous year
2008-2020 is [30 Day Buffer Stock] from previous year
30 Day Buffer Stock = ([Total Consumption] / 365) * 30 days

Ending Stocks = [Total Supply] - [Total Consumption]

Required Imports: Initial two years is from USDA FAS, NFA
2002-2006 is [30 Day Buffer Stock]
2007-2020 is [30 Day Buffer Stock] + [Ending Stocks]

Table 18. Projected Vietnam rice supply and demand without *Bt* rice adoption, 2000-2020.

	AREA			Milled	Beginning	Total		CONSUMPTION		SURPLUS		Carryover
YEAR	Mekong Delta	Vietnam	Yield	Production	Stocks	Supply	Population	Per Capita	TOTAL	Exportable	Expected	Stocks
	hectares		*mt/ha*	---------- *metric tons* ----------				*kg*	------------------------ *metric tons* ------------------------			
2000	3,900,000	7,654,900	4.25	21,485,640	----	21,485,640	78,137,000	212.66	16,617,000	4,868,640	3,370,000	1,498,640
2001	3,748,709	7,447,747	4.21	20,704,200	1,498,640	22,202,840	79,128,889	212.48	16,813,536	5,389,304	4,000,000	1,389,304
2002	3,603,286	7,394,846	4.29	20,947,067	1,389,304	22,336,372	80,133,369	212.30	17,012,396	5,323,976	5,323,976	----
2003	3,463,505	7,373,917	4.37	21,283,983	----	21,283,983	81,150,601	212.12	17,213,608	4,070,376	4,070,376	----
2004	3,329,146	7,378,716	4.46	21,701,815	----	21,701,815	82,180,745	211.94	17,417,199	4,284,616	4,284,616	----
2005	3,200,000	7,383,393	4.54	22,127,474	----	22,127,474	83,223,966	211.76	17,623,199	4,504,275	4,504,275	----
2006	3,200,000	7,396,048	4.63	22,585,837	----	22,585,837	84,280,431	211.58	17,831,635	4,754,201	4,754,201	----
2007	3,200,000	7,409,633	4.71	23,056,519	----	23,056,519	85,350,306	211.39	18,042,537	5,013,982	5,013,982	----
2008	3,200,000	7,429,960	4.80	23,558,309	----	23,558,309	86,433,762	211.21	18,255,933	5,302,376	5,302,376	----
2009	3,200,000	7,445,604	4.90	24,055,707	----	24,055,707	87,530,972	211.03	18,471,852	5,583,855	5,583,855	----
2010	3,200,000	7,462,674	4.99	24,568,196	----	24,568,196	88,642,111	210.85	18,690,326	5,877,870	5,877,870	----
2011	3,200,000	7,452,518	4.99	24,547,487	----	24,547,487	89,767,354	210.67	18,911,384	5,636,104	5,636,104	----
2012	3,200,000	7,442,376	4.99	24,526,796	----	24,526,796	90,906,881	210.49	19,135,056	5,391,740	5,391,740	----
2013	3,200,000	7,432,247	5.00	24,506,121	----	24,506,121	92,060,874	210.31	19,361,373	5,144,748	5,144,748	----
2014	3,200,000	7,422,132	5.00	24,485,465	----	24,485,465	93,229,516	210.13	19,590,367	4,895,097	4,895,097	----
2015	3,200,000	7,412,031	5.00	24,464,825	----	24,464,825	94,413,000	209.95	19,822,071	4,642,754	4,642,754	----
2016	3,200,000	7,401,944	5.00	24,444,203	----	24,444,203	95,466,043	209.77	20,026,002	4,418,201	4,418,201	----
2017	3,200,000	7,391,871	5.01	24,423,599	----	24,423,599	96,530,832	209.59	20,232,030	4,191,568	4,191,568	----
2018	3,199,314	7,381,811	5.01	24,403,011	----	24,403,011	97,607,497	209.41	20,440,179	3,962,833	3,962,833	----
2019	3,194,960	7,371,765	5.01	24,382,442	----	24,382,442	98,696,170	209.23	20,650,468	3,731,973	3,731,973	----
2020	3,190,612	7,361,732	5.01	24,361,889	----	24,361,889	99,796,987	209.05	20,862,921	3,498,968	3,498,968	----

Source: FAOSTAT 2001, FAPRI 2001, Wailes et al 2000, USDA ERS, USDA FAS, Evenson 1998b, UN 2001

Notes: Population is from UN 20001

Area: Year 2000 is from FAO, 2001-2020 assumes an annual growth rate of -0.00136 based on an interpreted calculation of FAPRI 2001

Mekong River Delta (MRD) Area: Initial is from USDA FAS 2001b, 2001-2005 is from MARD Development Plan for MRD region

MRD Area for 2018-2020 is Wailes et al 2000 assumption that MRD will account for 43 percent share of total Vietnam harvested area to rice

Yield: Year 2000 is from FAOSTAT, 2001-2010 assumes an annual growth rate of 0.02 based on an interpreted calculation of FAPRI 2001,

2011-2020 assumes an annual growth rate of 0.000519 based on an interpreted calculation of Evenson 1998b

Production: Year 2000 is from FAOSTAT, milledQ 2001-2010 is from FAPRI 2001, paddyQ is FAPRI/0.66, 2011-2020 is from Evenson 1998b* [Vietnam Area]

Exportable Surplus = [Total Supply] - [Total Consumption]

Expected Surplus is actual 2000-2001, 2002-2020 is [Exportable Surplus]

Table 19. Projected World rice supply and demand without *Bt* rice adoption, 2000-2020.

YEAR	AREA	mt/ha	Paddy	Milled	Beginning Stocks	Total Supply	Consumption	Ending Stocks	Total Use	World Trade
	hectares	*mt/ha*				*metric tons*				
2000	153,765,832	3.88	596,400,000	399,588,000	61,700,000	461,288,000	401,421,000	59,867,000	461,288,000	22,500,000
2001	151,008,595	3.90	588,412,000	394,236,040	59,867,000	454,103,040	401,791,000	52,312,040	454,103,040	22,255,000
2002	150,591,510	3.91	589,072,000	394,678,240	52,312,040	446,990,280	405,700,000	41,290,280	446,990,280	22,089,000
2003	150,480,206	4.09	614,804,111	411,918,754	41,290,280	453,209,034	412,752,292	40,456,742	453,209,034	22,660,452
2004	150,473,619	4.13	621,328,056	416,289,797	40,456,742	456,746,540	416,380,892	40,365,647	456,746,540	22,837,327
2005	150,362,842	4.17	627,192,350	420,218,875	40,365,647	460,584,522	419,793,604	40,790,918	460,584,522	23,029,226
2006	150,273,246	4.21	633,050,910	424,144,110	40,790,918	464,935,027	423,588,156	41,346,871	464,935,027	23,246,751
2007	150,105,468	4.25	638,682,881	427,917,530	41,346,871	469,264,401	427,119,377	42,145,024	469,264,401	23,463,220
2008	150,049,889	4.29	644,340,842	431,708,364	42,145,024	473,853,389	431,326,597	42,526,792	473,853,389	23,692,669
2009	149,814,233	4.33	649,042,974	434,858,792	42,526,792	477,385,584	435,043,081	42,342,503	477,385,584	23,869,279
2010	149,565,554	4.36	652,677,058	437,293,629	42,342,503	479,636,132	439,052,634	40,583,498	479,636,132	23,981,807
2011	149,330,957	4.37	651,907,857	436,778,264	40,583,498	477,361,762	439,257,899	38,103,863	477,361,762	23,868,088
2012	149,096,728	4.37	651,139,562	436,263,506	38,103,863	474,367,370	439,463,260	34,904,110	474,367,370	23,718,368
2013	148,862,866	4.37	650,372,172	435,749,355	34,904,110	470,653,466	439,668,717	30,984,749	470,653,466	23,532,673
2014	148,629,371	4.37	649,605,687	435,235,810	30,984,749	466,220,559	439,874,270	26,346,290	466,220,559	23,311,028
2015	148,396,243	4.37	648,840,106	434,722,871	26,346,290	461,069,160	440,079,919	20,989,242	461,069,160	23,053,458
2016	148,163,480	4.37	648,075,426	434,210,535	20,989,242	455,199,777	440,285,664	14,914,113	455,199,777	22,759,989
2017	147,931,082	4.38	647,311,648	433,698,804	14,914,113	448,612,917	440,491,505	8,121,412	448,612,917	22,430,646
2018	147,699,049	4.38	646,548,770	433,187,676	8,121,412	441,309,088	440,697,443	611,645	441,309,088	22,065,454
2019	147,467,379	4.38	645,786,791	432,677,150	611,645	433,288,795	440,903,477	-7,614,682	433,288,795	21,664,440
2020	147,236,073	4.38	645,025,710	432,167,225	-7,614,682	424,552,543	441,109,607	-16,557,064	424,552,543	21,227,627

Source: FAOSTAT 2001, FAPRI 2001, AGRM 2000, USDA ERS, USDA FAS, Evenson 1998b

Notes:

Area: Year 2000 is from FAOSTAT, 2001-2020 assumes an annual growth rate of 0.00157 based on an interpreted calculation of FAPRI 2001.

Yield: Year 2000 is from FAOSTAT, 2001-2010 is calculated from [Paddy Production]/[Area], 2011-2020 assumes an annual growth rate based on an interpreted calculation of Evenson 1998b.

Production: Year 2000 Paddy and Milled Production is from FAOSTAT, 2001-2002 Paddy Production is from USDA ERS,

2003-2010 Paddy Production = (FAPRI projection of milled production / FAO milling conversion rate = 0.67

2011-2020 Paddy and Milled Production is [AREA] * [YIELD]

Consumption: 2000-2003 is from USDA ERS, 2003-2010 is from FAPRI, 2011-2020 is based from an interpreted calculation of the annual food consumption growth rate from Evenson 1998b

World Rice Trade: Year 2000 is from FAOSTAT, 2002-2003 is from USDA ERS, 2003-2020 assumes 5 percent share of world [Milled Production]

Beginning Stocks: Year 2000 is from Wailes et al 2001, 2001-2020 is [Ending Stocks] from previous year

C2. Consumption

A simple equation is used to project milled rice consumption levels in the Philippines and Vietnam. It is based on the assumption that population growth is expected to remain as the primary determinant of growth in future rice consumption (Evenson et al 1996, Pingali et al 1997, Hossain 2001). Total consumption in metric tons C_t^{mt} for milled rice in time *t* is estimated from the population level of the previous year P_{t-1}, expected annual population growth rate (PGR) and per capita consumption of rice in kilograms (*percap*):

$$C_t^{mt} = \left[P_{t-1}\left(1 + PGR\right) * percap\right] / 1000 \tag{19}$$

In the year 2000, total milled rice consumption in the Philippines was estimated at 8.9 million MT and 16.6 million MT for Vietnam.

C3. Production and Supply

The projected level in metric tons of a country's total milled rice production Q_t^{mt} in year *t* is a function of the expected area harvested for paddy rice *At*, expected average rice paddy yield per hectare *Yt*, and the milling recovery rate *mrr* :

$$Q_t^{mt} = \left[A_{t-1}\left(1 + AGR\right) * Y_{t-1}\left(1 + YGR\right)\right] * mrr \tag{20}$$

where A_{t-1} is the area in hectares (HA) harvested to rice from the previous year, *AGR* is the assumed growth rate for the harvested areas, Y_{t-1} is the yield in metric tons / hectare (MT/HA), and *YGR* is the assumed annual growth rate in rice paddy yield.

Rice production statistics from the Philippines generally assume a milling recovery rate of 65 percent from total paddy production after deducting the estimated amount for seed, feed and waste (BAS 2001). For Vietnam, the General Statistics Office (GSO) along with MARD use a milling recovery rate of 66 percent to report rice production statistics (as used in USDA FAS 2001b) while the FAO uses a milling recovery rate of 67 percent.

Philippine paddy production in 2000 was estimated at 12.4 million MT with 9.4 million harvested from irrigated areas (BAS 2001). Total paddy production in year 2000 for Vietnam was estimated at 31.4 million MT with more than 15 million MT of rice harvested from the Mekong River Delta region (USDA FAS 2001a, Wailes et al 2001).

HARVESTED AREA

The harvested area for rice in the Philippines in the year 2000 was 4.03 million HA with irrigated rice comprising around 1.3 million HA (BAS 2001). Harvested area for rice in the Philippines from 2000-2020 is projected to decline an annual 0.1315 percent (based on an interpreted calculation of FAPRI 2001). As for the total irrigated rice area in the Philippines, this is held constant at 1.3 million HA throughout the evaluation period.[40]

Harvested area for rice in Vietnam in the year 2000 over three cropping seasons was 7.66 million HA (USDA FAS 2001a). In the year 2000, total area harvested in the Mekong River Delta reached 3.9 million hectares producing nearly 18 million MT of paddy rice (USDA FAS 2001a). Total area harvested to paddy rice in Vietnam from 2000-2020 is projected to decline an annual 0.136 percent (based on an interpreted calculation of FAPRI 2001). As for the rice paddy area in the Mekong River Delta region, MARD has reported that as part of its rural economy restructuring plan, the Mekong River Delta area planted to rice by 2005 will be reduced from 3.9 to 3.2 million HA that would reduce output to around 15.5 to 16 million MT (Reuters, Hanoi, 5/8/2001[41]). This translates into an annual growth rate –3.87 percent in the harvested area of the Mekong River Delta from 2000-2005. Harvested area for rice is then set at 3.2 million HA from 2005-2017. From 2018 to 2025, we assume the rice production area around the Mekong River Delta region will comprise around 43 percent of the total harvested area in Vietnam (Wailes et al 2001).

PADDY YIELD

The yield potential of modern varieties (MVs) of *Indica* rice has hardly increased since the introduction of IR8 in 1966 (Peng et al 2001).[42] In the last decade or so, a declining growth trend in yield increases has been a major concern for future global food security (Pingali 1994, Pingali et al 1997). The annual growth rate in rice paddy yield in the Philippines, Vietnam and for the rest of the world has declined in the 1990s from the previous decade. (see **Figure 8**).

[40] Irrigated rice farmland in the Philippines over the last two decades has remained below 1.5 million hectares. This is less than half the potential irrigable area and less than the 2 million hectares necessary for the country to achieve rice self-sufficiency (PECC 1999). Pingali et al (1997) foresees limited expansion for irrigated rice in the Philippines and reports irrigated area is actually in net decline due to degradation brought about by increased salinization and waterlogging. Pingali et al also adds that the Philippines is seeing an increased diversion of water from agricultural for urban use water diversion for urban and industrial use and declining irrigation investment. IRRI estimates that upper watershed degradation in the Philippines has resulted in an incremental loss of 4,200 HA/yr of wet season irrigated land and 2,700 HA/yr for dry season irrigated land (Pingali et al 1997). Pingali et al cites the example of the Angat Dam reservoir the primary water source for Central Luzon which is increasingly being diverted to supply water to Metro Manila. From 1980 to 1995, Pingali et al reports that an annual 800 million cubic meters or about 10 percent annual increase in water being diverted from agricultural irrigation for urban use. These annual rates of water withdrawals are supposedly the largest in Asia.

[41] Plan reported by Agricultural Minister Le Huy Ngo was aimed by the government to convert flood prone areas into fruit, cotton and dairy farming areas. An initial conversion of 130,000 has of rice growing areas is took place in 2001 and farmers in flood prone areas were also discouraged from planting a third crop thus cutting the paddy output in the summer-autumn crop to 6.76 mil MT.

[42] Even if subsequent MVs had a shorter maturity period, incorporated improved traits in grain quality, pest and disease resistance, it still did not shift the yield frontier (Pingali et al 1997).

The national rice paddy yield average in the year 2000 for the Philippines was estimated at 3.07 MT/HA . The average yield in the Philippines is projected to grow an annual 0.583 percent from 2000-2010 (based on an interpreted calculation of FAPRI 2001) and 0.0755 percent from 2010-2020 (based on an interpreted calculation of Evenson 1998b).

The national rice paddy yield average in the year 2000 for the Vietnam was estimated at 4.25 MT/HA (FAOSTAT). Vietnam's national average rice paddy yield is projected to grow an annual 1.896 percent from 2001-2010 (based on an interpreted calculation of FAPRI 2001) and 0.0519 percent from 2010-2020 (based on an interpreted calculation of Evenson 1998b).

C4. Rice Trade

The welfare effect is evaluated between two countries that trade rice with each other: The Philippines as the rice importer is modeled as a small open economy and Vietnam as the exporter is modeled as a large open economy with no market distortions. The base adoption scenario assumes that throughout the evaluation period, the Philippines imposes an ad valorem tariff equivalent to 100 percent of the import C&F price while Vietnam exports rice under free trade conditions.

PHILIPPINE RICE IMPORTATION

The Philippine government has always pursued a policy of targeting self-sufficiency in domestic rice production. However, the Philippines has been self-sufficient in only nine of the last thirty one years achieving the longest stretch of self-sufficiency between 1978 to 1982. Since 1995, the Philippines had annually imported over 600,000 MT to cover shortfalls in domestic supply (see **Table 20**).[43] In the year 2000, the Philippines imported an estimated 650,000 MT of milled rice of which 616,583 MT came from Vietnam (MARD/USDA FAS 2001a).

[43] Since 1972, rice importation in the Philippines is the official sole responsibility of the National Food Authority (NFA), a government agency tied in with the Philippine Department of Agriculture (DA). Philippine law requires the NFA build a 90 day rice buffer stock before the lean production months of July, August, and September. Based on NFA guidelines, the ideal distribution of the buffer stock inventory is for government warehouses to maintain a 30 day buffer stock while the remaining 60 day buffer stock is held by household sector (40 days) and the commercial sector (20 days) (Serrano 1997a). The government maintained buffer stock of 30 days is referred to as the In the year 2000, the 30 day buffer stock was equivalent to an estimated 735,017 MT based on a national daily consumption rate of 24,500 MT.

Rice import requirements are based on the production output from the previous year, carryover stocks and the expected harvest from the first half of the year. Rice imports are determined by the Department of Agriculture in January and an initial purchase or import tender carried out in February or within the first quarter, with shipments arriving in March-April to help build a required 90 day buffer stock by the end of June to meet consumption requirements for the lean months of July, August, September. Because it is critical that the Philippine government is able on source its rice imports to help meet buffer stock requirements, the NFA conducts most its import procurements via government to government negotiations.

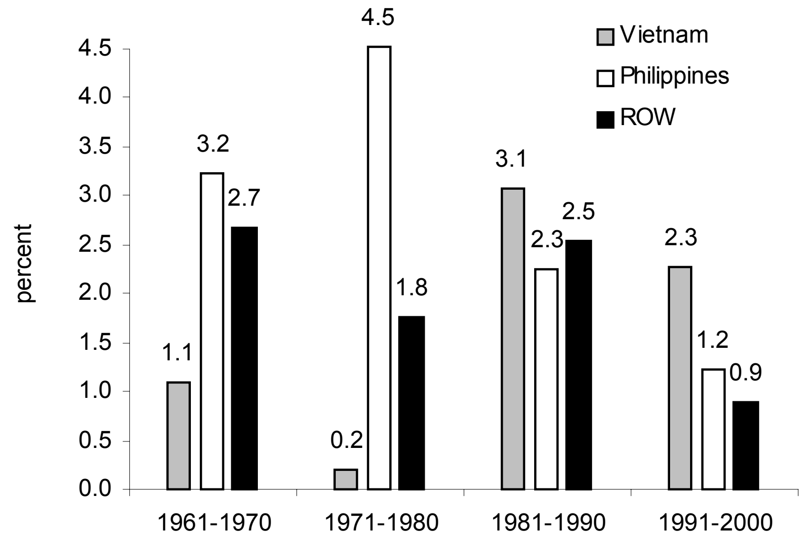

Figure 8. Annual growth rate in rice paddy yield, 1961-2000.
(Data source: USDA ERS)

Table 20. Philippine milled rice imports by country, 1989-2000.

YEAR	Thailand	Vietnam	China	India	U.S.A.	Others	Total
				metric tons			
1989	51,050	103,574				54,245	208,869
1990	94,636	334,817				191,341	620,794
1993	209,994						209,994
1995	169,043	60,680		23,229			252,952
1996	157,100	372,179		159,573	21,521	196,160	906,533
1997	212,484	335,445	159,546		12,734		720,209
1998	179,473	578,352	1,338,209	39,400			2,135,434
1999	103,900	508,840	339,497	39,375			991,612
2000		616,583				33,417	650,000
TOTAL	1,177,680	2,910,470	1,837,252	261,577	34,255	475,163	

Source: Philippine National Food Authority

The assumption used in this study that the Philippines imposes a tariff on rice beginning in 2005 is based on Philippine commitment to a Common Effective Preferential Tariff (CEPT) scheme under the Asian Free Trade Agreement (AFTA)[44]. Under the CEPT, the Philippines is committed to replace its quantitative restrictions (QRs) on rice imported from ASEAN countries like Vietnam by 2005 with equivalent tariffs (DA 2001).

[44] Countries grouped in AFTA are Brunei, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam.

Assuming an ad valorem tariff rate equivalent to 100 percent of the C&F price is reasonable since the Philippine government is generally under intense political pressure to protect domestic rice farmers (Serrano 1997,1998, David and Huang 1996).

VIETNAM RICE EXPORTS

Vietnam rice exports by destination in the year 2000 are listed in **Table 21**. From 1998-2000, Vietnam rice exports made up approximately 16 percent of total world rice exports (FAOSTAT).

In this study, we assume that Vietnam exports rice under free trade conditions. Previously, the Vietnamese government implemented an export quota policy when the country began exporting rice in 1989 (Minot & Goletti 1997). These export quotas were abolished in April 4, 2001 when the Vietnamese prime minister Nguyen Manh Cam signed decree No. 46/2001/QD-TTg otherwise known as Vietnam's Export-Import Management Mechanism 2001-2005.[45]

C5. Elasticities

DOMESTIC OWN PRICE ELASTICITIES

Domestic own price elasticities used in the study are taken from previous studies. A value of 0.335 for the domestic price elasticity of supply and -0.955 for the domestic price elasticity of demand estimated by Minot and Goletti (1997) are used for calculating welfare results in Vietnam. A value of 0.3 for the domestic price elasticity of supply and -0.93 for the domestic price elasticity of demand estimated in the 1995 IFPRI/IRRI Rice Supply and Demand Project (Hossain 1998) for calculating welfare results in the Philippines

EXCESS SUPPLY AND DEMAND ELASTICITIES

Excess demand and supply elasticities are computed for each year of the evaluation period[46]. Philippine excess demand elasticity $\eta \boldsymbol{M}_{rp,t}$ is computed using the following formula:

$$\eta M_{rp,t} = \frac{Q_{rp,t}}{M_{rp,t}} \varepsilon_{rp} + \frac{C_{rp,t}}{M_{rp,t}} \eta_{rp} \qquad (21)$$

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[45] ORYZA Vietnam market report. Accessed 27 April 2001 from http://oryza.com/asia/vietnam, VNA 2001. Government revamps export, import rules. Vietnamese News Agency. Article accessed 10 April 2001 from http://www.vnagency.com.vn/Public/Readnewse.asp?FileN=frak1004.004

[46] Siamwalla (1975) argues that short run export demand elasticities are not constant but changes with fluctations in export supplies and input demand.

Table 21. Vietnam year 2000 rice exports by destination and grade

DESTINATION	5%	10%	15%	25%	35%	55%	100%	Other	Total
					metric tons				
ASIA	267,329	748,696	554,618	448,969	1,500	11,527	13,636	38,914	2,085,189
Iraq	25,920	659,488							685,408
Philippines	36,212	4,620	283,017	277,496			3,200	2,000	**606,545**
Indonesia	42,496	53,103	179,675	115,847		11,527	850	26,616	430,114
Malaysia	121,423	19,464	25,729	24,196	700			140	191,652
Singapore	11,306	8,009	22,482	4,700			8,336	6,163	60,996
Bangladesh	8,621		24,540	10,300					43,461
Palau	5,250		5,950	7,100	800		1,500		20,600
Yemen	5,500		5,015					550	11,065
Nepal		4,012	4,010						8,022
Cambodia			2,000	6,000					8,000
Japan	5,010								5,010
Hongkong	2,166			1,600					3,766
Marianas	1,100		1,000					200	2,300
AFRICA	229,137	33,723	223,075	155,861	11,630		192,327	4,959	850,712
Wesl Africa				900			38,593		39,493
Tanzania			28,342						28,342
Senega				1,002			17,981		18,983
Algeria	31,964								31,964
Syria	12,756								12,756
Gabon	6,850								6,850
AngolE	6,018								6,018
Ghana			5,015						5,015
E.U.	58,169	33,106	31,266	2,500			250	21,080	146,371
Poland	23,879	23,768	27,350	2,500			250	150	77,897
Russia	18,115	5,800	2,000						25,915
Slovenia		3,007							3,007
Ukraine	11,733	131	1,436						13,300
Holland	322	110							432
AMERICA	3,500	31,014	25,000	113,274					172,788
Cuba	3,500	25,000	25,000	113,274					166,774
Hawaii		6,014							6,014
AUSTRALIA	466							1,100	1,566
Unknown	8,170			5,000				99,734	112,904
TOTAL	566,771	846,539	833,959	725,604	13,130	11,527	206,213	165,787	3,369,530

Source: USDA Foreign Agricultural Service

where $\eta M_{rp,t}$ is the excess demand elasticity or Philippine import demand for rice, $M_{rp,t}$ is the quantity of Philippine rice imports at time t, ε_{rp} is the Philippine domestic own price supply elasticity of rice, η_{rp} is the absolute value of Philippine own rice price elasticity of demand, and Q_{rp}, C_{rp} is Philippine domestic consumption and production of rice at time t.

The Vietnam excess supply elasticity εX_{vn} is computed using the following formula:

$$\varepsilon X_{vn} = \frac{Q_{vn}}{X_{vn}} \varepsilon_{vn} + \frac{C_{vn}}{X_{vn}} \eta_{vn} \tag{22}$$

where $\varepsilon \boldsymbol{X_{vn}}$ is the elasticity of supply for Vietnam rice exports, ε_{vn} is Vietnam domestic own price elasticity of rice, $\boldsymbol{\eta_{vn}}$ is the absolute value of Vietnam domestic own price elasticity of demand, and $\boldsymbol{Q_{vn}}$ **,** $\boldsymbol{C_{vn}}$ are Vietnam domestic consumption and production of rice, and $\boldsymbol{X_{vn}}$ is the level of Vietnam rice exports.

In computing for the price elasticity of demand for Vietnam rice exports, we adapt the approach of Minot and Goletti (1997) of relating the Vietnamese rice export demand elasticity to the demand elasticity for Thailand's rice exports which is treated as a function of Thailand's share of the world rice market. Minot and Goletti (1997) adapt Panayotou's (1989) endorsement of a World Bank estimate that the short run elasticity for Thai rice exports is on the order of 4.0. They then related the level of Vietnam's rice exports to Thailand's export share of the world rice market. Minot and Goletti reasoned out that since Vietnam's share of the world rice market is one third that of Thailand, the world excess demand elasticity value for Vietnamese rice exports is approximately three times greater than the value of the world demand for Thai rice exports. A formula based on that approach is specified as follows:

$$\eta M_{vn} = \eta M_{th} * \frac{s_{th}}{s_{vn}} \tag{23}$$

where $\varepsilon \boldsymbol{X_{th}}$ is the elasticity of demand for Thai rice exports and is assumed to be 4.0 throughout the evaluation period, $\boldsymbol{s_{th}}$ is Thailand's export share of world long grain *Indica* rice exports and is likewise assume constant at 25 percent throughout the evaluation period, and $\boldsymbol{s_{vn}}$ is Vietnam's share of world long grain *Indica* rice exports[47].

IID. Model Simulation

This section describes the set of simulations run using the economic surplus model developed in section IIB. We begin by using the model to determine the size and distribution of benefits of *Bt* rice under the base adoption scenario described in section IIA. The results from this simulation are referred to as the base scenario results. The model is then used to estimate the welfare impact of *Bt* rice under various scenarios related to the technology delivery process. Areas examined in the

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[47] Thailand and Vietnam share of world rice exports are computed based on Child (1999) estimates that long grain *Indica* rice exports account for 75 percent of the total world rice market. This value is assumed for throughout the evaluation period.

technology delivery process are: adoption sequence and lag, ceiling and annual adoption rate and farmer dis-adoption and technology depreciation. The next set of simulations evaluates the value of welfare impact under various price levels determined in part by the level of distortion in the trade arrangement between the Philippines and Vietnam. The model is then used to assess the sensitivity of base scenario results to changes in selected rice price elasticities. The last set of simulations estimate the size of benefits from adopting other types of transgenic pest-resistant rice.

Given the ex-ante nature of this evaluation, there are certain critical parameters used in the analysis which are subject to uncertainty either from the lack of reliable data or because they refer to future events. Hence, the evaluation of results focuses more on the direction of the change and order of the magnitude of the welfare effect rather than actual numerical results.

D1. Determining the welfare effects by adoption sequence and transfer lag

The first set of simulations are intended to examine how the adoption sequence and delay of field testing or the research transfer lag might affect the magnitude and distribution of benefits from *Bt* rice deployment. In the base scenario, the adoption sequence has the Philippines adopting *Bt* rice first with a technology spillover and subsequent adoption in Vietnam. The research transfer lag in this study refers to the duration from the base year to the first year *Bt* rice is commercially released. In the base adoption scenario, 5 years is assumed for the Philippines and 7 years for Vietnam. Six alternative adoption sequences and transfer lag assumptions are examined. They are:

1i. Field testing of *Bt* rice is delayed by one year (transfer lag extended by one year)

1ii. Field testing of *Bt* rice is delayed by five years (transfer lag extended by five years)

1iii. Sequence of *Bt* rice adoption is reversed; Vietnam adopts first instead of the Philippines

1iv. Both the Philippines and Vietnam adopt *Bt* rice simultaneously

1v. Only Vietnam adopts *Bt* rice

1vi. Only the Philippines adopts *Bt* rice

D2. Determining the aggregate benefits by ceiling and annual adoption rate

The second set of simulations estimate the effect different adoption rates may have on the size of aggregate benefits from *Bt* rice deployment. In this study, the adoption rate for *Bt* rice is defined as the percentage area planted to *Bt* rice of the total area targeted for planting *Bt* rice. It is characterized in two ways: (1) the *ceiling* adoption rate *Cmax* defined as the fraction of the total targeted area ultimately planted to *Bt* rice, and (2) the *annual* adoption rate defined as the proportional increase per year in the area planted to *Bt* rice.

In the base scenario, a 6 percent linear annual adoption rate is assumed for both the Philippines and Vietnam. One simulation (***2i***) is run to estimate the welfare effect of increasing the annual adoption rate from 6 to 7 percent.

Under the base scenario, a ceiling rate of 66 percent is assumed for the Philippines and 60 percent for Vietnam. Four cases are evaluated using a logistic adoption curve to provide a perspective on how the shape of the adoption curve affects the aggregate welfare impact. These are: (***2ii***) using base scenario ceiling rate assumptions, (***2iii***) increasing the base scenario ceiling rate by 1 percent for both the Philippines and Vietnam, (***2iv***) assuming a conservative ceiling rate of 25 percent for both countries, and (***2v***) and an optimistic ceiling rate of 100 percent for both countries. The S-curve or logistic curve is specified in an equation adapted from Alston, Norton and Pardey (p 357)[48]:

$$At = \frac{C\max}{1 + e^{-(\alpha + Bt)}}$$

where *At* is the actual adoption rate *t* years from the initial release of *Bt* rice , *Cmax* is the ceiling adoption rate, the parameter α specifies the "width" or "steepness" of the sigmoidal curve, and the parameter β specifies the time when the curve reaches ½ *Cmax*[49].

The time it takes from the initial release of *Bt* rice to the first year the ceiling rate is reached is referred to as the adoption lag. In the base scenario, the adoption lag for the Philippines is 11 years and 10 years for Vietnam. The same adoption lag assumptions are applied to cases ***2ii*** and ***2iii***. Case 2iv assumes an equivalent adoption lag of 5 years for both the Philippines and Vietnam. For case ***2v*** the adoption lag is from the first of release to the last year of the evaluation period for the Philippines (16 years) and Vietnam (14 years). In case ***2i***, the adoption lag for both countries is just one year less than that in the base scenario.

D3. Determining the aggregate benefits by Philippine tariff schedule and price level

Because the actual future Philippine tariff schedule for rice imports is still unknown, the third set of simulations estimate the value of the welfare impact from adopting *Bt* rice under different rates for

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[48] Herdt and Capule (1983, p23-24) report that most rice adoption studies that support the S-shaped adoption curve were based on data that were simply plotted percentage adoption rates based on the number of farmer-adopters against time.

[49] To facilitate the fitting of the S-curve we adapt the approach derived by Meyer et al (1999) of replacing α with a variable that specifies the time required for the trajectory to grow from 10 to 90 percent of the limit *Cmax*. They refer to this period as the *characteristic duration* or Δt. Meyer et al relate Δt to α by Δt= ln(81)/ α. They re-label the parameter β as *tm* and specify the formula for the logistic curve as:

$$At = \frac{C^{MAX}}{1 + \exp\left(-\frac{\ln(81)}{\Delta t}(t - tm)\right)}$$

a Philippine ad valorem tariff on rice imports. The tariff rate tested are: (3i) 99 percent, (3ii) 50 percent, (3iii) zero tariff or a free trade case, and (3iv) to reflect the Philippine commitment to the both AFTA and the WTO agreements on rice tariffication, a simulation is run with a variable tariff schedule that assumes the Philippines imposes a 100 percent tariff rate from 2005-2009 and then reduces the tariff to 50 percent from 2010 to 2019 and completely phases out tariffs by 2020. The last case in this section involves valuing the welfare impact using the USDA set world price for the year 2000 of 145 USD/MT (3v).

D4. Welfare effects in the presence of farmer disadoption and technology depreciation

Farmer disadoption and technology depreciation are factors that diminish the benefits of *Bt* rice. Farmers may stop planting *Bt* rice if consumers do not accept its grain quality or have a general negative perception of genetically modified food crops like *Bt* rice. Technology depreciation in *Bt* rice occurs when the durability of the plant resistance to stemborer infestation begins to deteriorate. To determine the effect these limiting factors may have on the size of aggregate benefits, four cases of farmer disadoption are tested: (4i) gradual farmer disadoption starting from the first year ceiling rate is achieved, (4ii) complete farmer disadoption in three years starting from first year ceiling rate is achieved, (4iii) complete farmer disadoption after first year of release, and (4iv) complete farmer disadoption 5 years from the first year of release. To simulate the effects of having technology depreciation in *Bt* rice, four cases are examined: (4v) *Bt* rice plant resistance degrades at rate of one percent per year, (4vi) *Bt* rice plant resistance degrades at rate of one percent per year, (4vii) *Bt* rice plant resistance degrades at rate of one percent per year, and (4viii) *Bt* rice plant resistance degrades at a rate of one percent per year.

D5. Testing the sensitivity of base scenario results to changes in price elasticities

Estimates of consumer and producer surplus are often questioned for their sensitivity to a given level of supply and demand elasticities. Sensitivity analysis is undertaken to measure the variation in the welfare effect of base scenario results with variations in selected price elasticities. Hence, the sensitivity of base scenario results to the following rice price elasticity values were tested:

4i. Philippine price elasticity of demand at –0.92, -0.10, -0.35, and -0.50

4ii. Philippine price elasticity of supply at 0.29, 0.31, 0.10, and 0.60

4iii. Vietnam rice price elasticity of demand at –0.945, -0.10, -0.30, and -0.50

4iv. Vietnam price elasticity of supply at 0.33, 0.35, 0.10, and 0.60

4v. World price elasticity of demand for Vietnam rice exports at -4, -6, -8, and -12

D6. Determining the benefits of selected potential transgenic pest-resistant rice

To provide another perspective on the magnitude of the aggregate benefits of adopting *Bt* rice, we relate its value to the estimated welfare effects of four other types of transgenic pest resistance that are currently being researched and developed for rice. These are resistance or tolerance to: (6i) Bacterial Leaf Blight (see **Figure 9**), (6ii) Leaf Blast (see **Figure 10**), (6iii) Weeds (see **Figure 11**), and (6iv) multiple disease and insect pest[50] resistance- a major breeding objective of the new plant type (see **Figure 12**). Each of the pest constraint is evaluated using crop loss estimates taken from Savary et al (2000b)[51].

This chapter presented the procedures and methods for evaluating the welfare impact from adopting *Bt* rice in the Philippines and Vietnam. An adoption scenario was first constructed and based on assumptions on how, when and where *Bt* rice would be deployed. The conceptual framework was developed in order to explain the expected welfare effect given the existing socio-economic environment of the rice economy in both countries. We then specified and provided a brief background on the key variables and parameters for initializing the empirical model and projecting baseline estimates or food balance sheets from the year 2000 to the year 2020 for the Philippines, Vietnam and the world. Lastly, an outline was made of the list of measurements and simulations to be run using the empirical model. The next chapter presents the results of model calculations.

[50] for online background information on tropical pests of rice see http://www.irri.org/Troprice/Default.htm

[51] the following crop loss estimates are expressed in terms of percent loss based on an attainable yield of 5.5 MT/HA: weed tolerance = 23 percent, leaf blast resistance = 5 percent, bacterial leaf blight = 0.2 percent, multiple pest resistance = 37 percent

Figure 9. Bacterial Leaf Blight

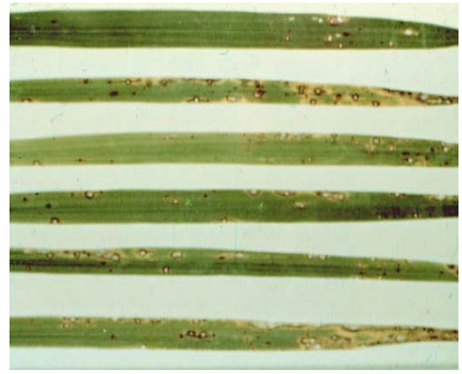

Figure 10. Leaf Blast

Figure 11a. *Echinochloa glabrescens*

Figure 11c. *Monochoria vaginalis*

Figure 11b. *Leptochloa chinesis*

Figure 11d. *Sphenoclea zeylanica*

Figure 11. Common tropical rice weeds evaluated in Savary et al (2000b).
Source: IRRI TropRice, all photos from Mueller (1983)

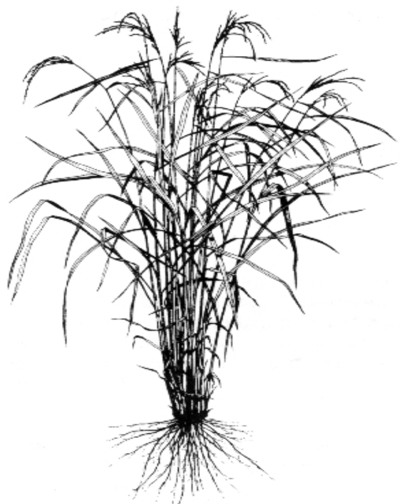

Figure 12a. Traditional Rice Plant Architecture

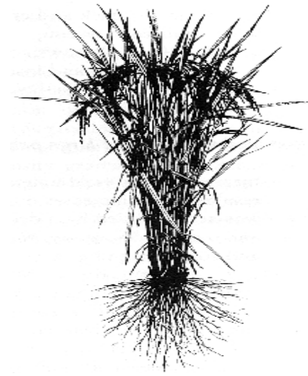

Figure 12b. Current Modern Rice Varieties

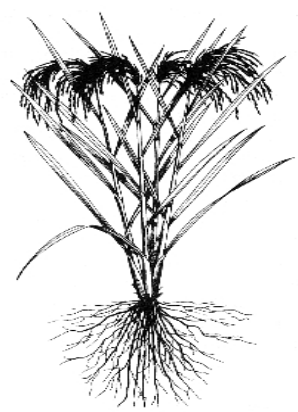

Figure 12c. New Plant Type[52]

Figure 12. Rice plant architechture for different types of irrigated rice
Source: Khush 1996 (p61, Figure 4.1)

[52] When the rice plant's architecture was first transformed (Figure 12a to Figure 12b) in the 1960s, the genetic yield potential of tropical rice doubled as the result. Since then, only marginal improvements have occurred in the yield potential. To address growing food security concerns amidst an exploding global population particularly in LDCs, Khush g(1996) reports that the *new plant type* (NPT) for rice was conceptualized and a breeding program started in 1989. By 1996, prototype breeding lines had been developed. In comparing it to the current MVs, the NPT is characterized by having a short stature, no unproductive tiller coupled with low tillering, thick sturdy stems and thicker, dark green and erect leaves (for higher photosynthetic rates). Approximately, the so called, "yield barrier" limits for rice production in the tropics is around 10 mt/ha. It is hoped that these new plant types will have a 20 percent higher yield potential than existing modern indica varieties. These new NPTs will also be used to develop news japonica and indica hybrids which could have a 20-25 percent yield advantage over the best inbred lines. In all, Khush (1996) claims that combining both approaches could raise the yield potential of tropical rice by as much as 50 percent

CHAPTER III. RESULTS AND DISCUSSION

The results of the study are presented in this section. First, we describe the welfare effect of adopting *Bt* rice under the base adoption scenario. We then assess the welfare effects under alternative adoption scenarios: (1) various adoption sequences and lags, (2) various ceiling and adoption rates, and (3) presence of farmer disadoption and technology depreciation. The present value of aggregate benefits of *Bt* rice adoption are then evaluated with different price levels and Philippine tariff schedules. This chapter also examines the sensitivity of base scenario results to alternative price elasticities. Lastly, the economic benefits of *Bt* rice are compared to the estimated potential benefit of four other types of transgenic pest-resistant rice. To facilitate discussion, estimated welfare effects are expressed in present values in year 2000 prices computed from benefit streams discounted at 5 percent.

IIIA. Base scenario results and adoption sequence and lag

Total economic benefits of adopting *Bt* rice under the base scenario is estimated at 618.8 million USD. The aggregate benefits by region are estimated at 269.6 million USD for the Philippines, 329.1 million USD for Vietnam, and 20.1 million USD for the rest of the world (see first column of **Table 22**). To put these numerical estimates into perspective, the value of total benefits estimated in the base scenario represent only 5.7 percent of the combined value of 5.4 billion USD for milled rice production in the Philippines and Vietnam in the year 2000[53]. Conversely, the total budget allocation of 4.523 million USD by IRRI in the year 2000 for all rice biotechnology research related activities[54] is less than 2 percent of the 306.5 million USD in benefits generated by *Bt* rice adoption.

As for the distribution of the total welfare effect, results show that producers in both countries capture 66.5 percent while 25. 9 percent accrues to consumers. The rest of the world receives 3 percent of the welfare effect while the loss in Philippine government revenue accounts for 4.6 percent of the total welfare effect (see first row of **Table 23**). As a group, producers in Vietnam gain the most or an estimated 39.6 percent share of the total economic benefits from *Bt* rice. As for the other economic surplus changes in the base scenario, an increase in the Philippine domestic supply reduces the level of required imports and is reflected in a reduction of Philippine government revenue by 16.12 million USD. This value accounts for 9.4 percent of total economic surplus change in the

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[53] The total value of milled rice production in the Philippines in the year 2000 is estimated at around 1.2 billion USD (at 145 USD/MT) to 1.5 billion USD (at 180 USD/MT). While the year 2000 milled rice production in Vietnam is valued at an estimated 3.2 billion USD (at 145 USD/MT) to 3.9 billion USD (at 180 USD/MT). Total world production can be valued anywhere from 58.1to 72.2 billion USD, of that Asian rice production accounts for 53 to 65.8 billion USD. Production based on FOASTAT.

[54] Excludes functional genomics. Based on IRRI Medium Term Plan 2000-2002 budget allocation for Cross-ecosystems (CE) research projects that are related to transgenic pest resistant applications namely: CE2-Applying biotechnology to accelerate rice breeding and broaden the rice genepool (2.42 million USD) and CE3-Exploiting biodiversity for sustainable pest management (2.103 million USD).

Philippines. The results on the estimated welfare impact of adopting *Bt* rice under alternative assumptions of the adoption sequence and research transfer lag are listed in **Tables 22** and **23**. Results show that delaying field testing by one year or increasing the research transfer lag in both countries by one year result in foregone benefits equivalent to 11.9 percent of the aggregate benefits in the base scenario. Increasing the transfer lag up to 5 years results in foregone aggregate benefits that are an estimated 54.7 percent less than that under the base scenario.

Other adoption sequences evaluated included one where Vietnam adopts *Bt* rice before the Philippines and another wherein both countries adopt *Bt* rice simultaneously. As expected, estimated benefits in both cases were larger than the benefits estimated in the base scenario (sixth and seventh column of **Table 22**). Between the two cases though, results indicate almost 4 percent more gains are to be had if Vietnam were to adopt *Bt* rice first as opposed to simultaneous adoption in both countries. This is because the reduction in Philippine producer and government revenue is greater in the latter case (see fourth and fifth rows of **Table 23**).

Table 22. Gross aggregate benefits from adopting *Bt* rice in Southeast Asia by adoption sequence and transfer lag, 2000-2020.

COUNTRY / REGION	Discount Rate	BASE Adoption Scenario	ADOPTION SEQUENCE OR LAG: Delayed 1 year	Delayed 5 years	Reverse[a]	Simultaneous adoption	Vietnam only	Philippines only
			present value is in year 2000 prices (million USD)					
PHILIPPINES	0.05	269.6	239.77	131.38	302.50	276.11	30.18	227.47
			(11.1)	*(51.3)*	*12.2*	*2.4*	*(88.8)*	*(15.6)*
	0.10	136.5	118.25	58.93	149.48	140.44	14.38	116.04
			(13.4)	*(56.8)*	*9.5*	*2.9*	*(89.5)*	*(15.0)*
VIETNAM	0.05	329.1	288.39	141.72	415.45	415.45	325.78	0
			(12.4)	*(56.9)*	*26.2*	*26.2*	*(1.0)*	
	0.10	159.9	136.54	61.38	212.91	212.91	158.25	0
			(14.6)	*(61.6)*	*33.2*	*33.2*	*(1.0)*	
Rest of of the World	0.05	20.1	17.20	7.47	26.26	26.26	19.90	0
			(14.4)	*(62.8)*	*30.6*	*30.6*	*(1.0)*	
	0.10	10.1	8.39	3.29	13.83	13.83	9.97	0
			(16.6)	*(67.3)*	*37.4*	*37.4*	*(1.0)*	
TOTAL	0.05	618.8	545.36	280.57	744.20	717.82	375.87	227.47
			(11.9)	*(54.7)*	*20.3*	*16.0*	*(39.3)*	*(63.2)*
	0.10	306.5	263.18	123.61	376.22	367.18	182.60	116.04
			(14.1)	*(59.7)*	*22.8*	*19.8*	*(40.4)*	*(62.1)*

Note: percent difference from base adoption scenario results indicated in italics with negative values indicated in parenthesis.
[a] Vietnam adopts first.

Table 23. Distribution of benefits from adopting *Bt* rice in Southeast Asia by adoption rate and sequence, 2000-2020.

ADOPTION	Philippines				Vietnam			ROW	TOTAL		
SCENARIO	PS	CS	GS	TS	PS	CS	TS	TS	PS	CS	TS[a]
Base adoption scenario	207.92	92.86	(31.14)	269.64	245.22	83.86	329.08	20.11	453.13	176.72	618.82
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total[b]	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*25.9*	*100*
Base-lag by one (1) year	186.08	81.56	(27.87)	239.77	214.91	73.48	288.39	17.20	400.99	155.04	545.36
Percent difference from base	*(10.5)*	*(12.2)*	*10.5*	*(11.1)*	*(12.4)*	*(12.4)*	*(12.4)*	*(14.4)*	*(11.5)*	*(12.3)*	*(11.9)*
Percent share within region	*63.0*	*27.6*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*31.0*	*13.6*	*4.6*	*49.2*	*35.8*	*12.2*	*48.0*	*2.9*	*66.7*	*25.8*	*100*
Base-lag by five (5) years	107.33	40.13	(16.08)	131.38	105.89	35.82	141.72	7.47	213.22	75.95	280.57
Percent difference from base	*(48.4)*	*(56.8)*	*48.4*	*(51.3)*	*(56.8)*	*(57.3)*	*(56.9)*	*(62.8)*	*(52.9)*	*(57.0)*	*(54.7)*
Percent share within region	*65.6*	*24.5*	*9.8*	*100*	*74.7*	*25.3*	*100*				
Percent share of total	*34.3*	*12.8*	*5.1*	*52.3*	*33.9*	*11.5*	*45.3*	*2.4*	*68.2*	*24.3*	*100*
Reverse (VN adopts first)	219.47	115.89	(32.86)	302.50	309.91	105.54	415.45	26.26	529.38	221.43	744.20
Percent difference from base	*5.6*	*24.8*	*(5.5)*	*12.2*	*26.4*	*25.9*	*26.2*	*30.6*	*16.8*	*25.3*	*20.3*
Percent share within region	*59.6*	*31.5*	*8.9*	*100*	*74.6*	*25.4*	*100*				
Percent share of total	*27.1*	*14.3*	*4.1*	*45.5*	*38.3*	*13.0*	*51.3*	*3.2*	*65.4*	*27.3*	*100*
Simultaneous adoption	187.95	116.31	(28.15)	276.11	309.91	105.54	415.45	26.26	497.86	221.85	717.82
Percent difference from base	*(9.6)*	*25.2*	*9.6*	*2.4*	*26.4*	*25.9*	*26.2*	*30.6*	*9.9*	*25.5*	*16.0*
Percent share within region	*56.5*	*35.0*	*8.5*	*100*	*74.6*	*25.4*	*100*				
Percent share of total	*24.3*	*15.0*	*3.6*	*42.9*	*40.0*	*13.6*	*53.7*	*3.4*	*64.3*	*28.7*	*100*
Vietnam only	(72.66)	91.94	10.91	30.18	242.76	83.02	325.78	19.90	315.42	174.96	375.87
Percent difference from base	*(134.9)*	*(1.0)*	*135.0*	*(88.8)*	*(1.0)*	*(1.0)*	*(1.0)*	*(1.0)*	*(30.4)*	*(1.0)*	*(39.3)*
Percent share within region	*41.4*	*52.4*	*6.2*	*100.0*	*74.5*	*25.5*	*100*				
Percent share of total	*13.9*	*17.6*	*2.1*	*33.7*	*46.6*	*15.9*	*62.5*	*3.8*	*60.5*	*33.6*	*100*
Philippines only	267.52	0	(40.05)	227.47	0	0	0	0	267.52	0	227.47
Percent difference from base	*28.7*	*na*	*(28.6)*	*(15.6)*	*na*	*na*	*na*	*na*	*(41.0)*	*(100.0)*	*(63.2)*
Percent share within region	*87.0*	*0*	*13.0*	*100*	*0*	*0*	*0*				
Percent share of total	*87.0*	*0*	*13.0*	*100*	*0*	*0*	*0*	*0*	*87.0*	*0*	*100*

Note: * size of w elfare effect is present value evaluated at 5 percent discount rate expressed in million USD and distribution of w elfare effect is expressed as percent share of absolute value of total w elfare effect. PS = producer surplus, CS = consumer surplus, GS = government surplus, TS = total surplus

[a] TS = Philippine TS + Vietnam TS + ROW TS, [b] based on total w elfare effect w hich is TS + absolute value of Philippine GS.

Results in the last two columns in Table 22 and the last two rows of Table 23 represent the welfare effect in scenarios where only one country is assumed to adopt *Bt* rice. If no technology spillovers occur and only the Philippines adopts *Bt* rice, benefits are estimated at 227.47 million USD. Under the Philippines only scenario, all gains accrue to Philippine producers while the loss in government revenue is estimated at 40.05 million USD.

When only Vietnam adopts *Bt* rice, aggregate benefits are estimated at 375.87 million USD or around 65 percent more than the Philippines only scenario. When only Vietnam adopts *Bt* rice, over 62.5 percent of the benefits are received in Vietnam (sixth row of **Table 23**). For all cases evaluated by adoption sequence, gains to the rest of the world, in terms of percent share of total benefits, are largest in this scenario. This is because even if no technology spillout occurs from Vietnam adoption, price spillovers are generated. As a result, consumers absorb almost all the gains recorded for the Philippines while producers lose up to 72.66 million USD. This is also the only scenario where the change in the Philippine government revenue is positive.

IIIB. Ceiling and annual adoption rate

The estimated welfare impacts of adopting *Bt* rice under alternative ceiling adoption rates are shown in **Table 24**. Results in the fourth column of Table 24 show that aggregate benefits are estimated to be 11.1 percent larger when a logistic adoption curve is used instead of a linear curve given the same base ceiling rate parameters. The welfare effect becomes only slightly larger when the ceiling rate is increased by one percent (fifth column). Aggregate benefits are about 41 percent less than that for the base scenario if a conservative assumption is made that the ceiling rate is only one fourth that of the targeted area. Although a 100 percent ceiling rate is unrealistic, one simulation is run to estimate the size of aggregate benefits if complete adoption were achieved at the end of the evaluation period in 2020. Results show that aggregate gains are estimated at 908.39 million USD or 46.8 percent more than that for the base scenario (seventh column of **Table 24**). The last column of Table 24 lists the results from increasing the linear annual adoption rate to 7 percent holding ceiling rates at base scenario values. Aggregate benefits in this scenario are estimated at 670.7 million USD or 8.4 percent greater than that under the base scenario.

IIIC. Philippine tariff schedule and price level

The estimated present values of aggregate benefits from adopting *Bt* rice given alternative price levels and Philippine ad valorem tariff rates on rice imports are reported in **Table 25**. If we disregard transaction costs and all forms of geographically related price wedges and use instead a USDA year 2000 world price of 145 USD/MT, the total welfare effect is valued at an estimated 376.8 million USD or around 40 percent less than the value of the base scenario welfare impact.

Table 24. Gross aggregate benefits from adopting *Bt* rice in Southeast Asia by annual and ceiling adoption rate, 2000-2020.

COUNTRY / REGION	Discount Rate	BASE Adoption Scenario	CEILING ADOPTION RATE* Base rate	base rate +1 percent	25 percent	100 percent	Annual adoption rate +1 percent**
			present value is in year 2000 prices (million USD)				
PHILIPPINES	0.05	269.64	297.06	301.56	141.79	368.03	291.81
			10.2	*11.8*	*(47.4)*	*36.5*	*8.2*
	0.10	136.53	151.85	154.14	76.44	181.11	149.49
			11.2	*12.9*	*(44.0)*	*32.7*	*9.5*
VIETNAM	0.05	329.08	367.46	373.51	187.46	509.61	356.79
			11.7	*13.5*	*(43.0)*	*54.9*	*8.4*
	0.10	159.85	180.24	183.19	96.10	243.01	175.11
			12.7	*14.6*	*(39.9)*	*52.0*	*9.5*
Rest of	0.05	20.11	22.91	23.29	12.15	30.75	22.10
of the World			*14.0*	*15.9*	*(39.6)*	*53.0*	*9.9*
	0.10	10.07	11.57	11.76	6.42	15.09	11.18
			14.9	*16.8*	*(36.3)*	*49.8*	*11.0*
TOTAL	0.05	618.82	687.43	698.37	341.40	908.39	670.70
			11.1	*12.9*	*(44.8)*	*46.8*	*8.4*
	0.10	306.45	343.66	349.09	178.96	439.21	335.78
			12.1	*13.9*	*(41.6)*	*43.3*	*9.6*

Note: percent difference from base adoption scenario results indicated in italics with negative values indicated in parenthesis
* ceiling adoption rate scenarios assumes a logistic adoption curve (base rate +1 percent, 25 percent & 100 percent)
** a linear curve is assumed for scenario that assumes an increase by 1 percent in the annual adoption rate

The base adoption scenario assumes that the Philippines levies a 100 percent ad valorem tariff rate. Results show that a one percent decrease in the tariff rate reduces the level of aggregate benefits in the Philippines by an estimated 0.4 percent. If the tariff rate is set at 50 percent, aggregate benefits will be 22.1 percent less than that for the base scenario. If the Philippines were to import rice duty free throughout the evaluation period, aggregate benefits in the country will be 44.2 percent less that for the base scenario. A more likely scenario is that the Philippine government will impose variable tariff schedule. The results in the last column of Table 25 represent one such scenario and aggregate benefits in this case are estimated 214.58 million USD or about 20.4 percent less than that under the base scenario. The results may suggest that aggregate gains from adopting *Bt* rice are greater in the presence of a Philippine ad valorem tariff then they would be under free trade conditions. However, it must be noted that these results need to be put into context. The presence or level of the ad valorem tariff will not change the total benefit from research (the shaded portion below area ***efnm*** in **Figure 7**), it does however affect the distribution of benefits . This is because even if imports decrease as the

Table 25. Gross aggregate benefits from adopting *Bt* rice in Southeast Asia by tariff schedule and price level, 2000-2020.

COUNTRY / REGION	Discount Rate	BASE Adoption Scenario	PHILIPPINE AD VALOREM TARIFF RATE 99 percent	50 percent	free trade (zero tariff)	Variable Tariff Schedule	USDA World Price=145 USD
			present value is in year 2000 USD prices (million USD)				
PHILIPPINES	0.05	269.64	268.44	210.01	150.39	214.58	95.52
			(0.4)	*(22.1)*	*(44.2)*	*(20.4)*	*(64.6)*
	0.10	136.53	135.93	106.43	76.32	110.76	48.11
			(0.4)	*(22.0)*	*(44.1)*	*(18.9)*	*(64.8)*
VIETNAM	0.05	329.08	329.08	329.08	329.08	329.08	265.09
			0	*0*	*0*	*0*	*(19.4)*
	0.10	159.85	159.85	159.85	159.85	159.85	128.77
			0	*0*	*0*	*0*	*(19.4)*
Rest of of the World	0.05	20.11	20.11	20.11	16.20	20.11	16.20
			0	*0*	*(19.4)*	*0*	*(19.4)*
	0.10	10.07	10.07	10.07	8.11	10.07	8.11
			0	*0*	*(19.4)*	*0*	*(19.4)*
TOTAL	0.05	618.82	617.63	559.20	495.66	563.76	376.80
			(0.2)	*(9.6)*	*(19.9)*	*(8.9)*	*(39.1)*
	0.10	306.45	305.85	276.35	244.29	280.69	185.00
			(0.2)	*(9.8)*	*(20.3)*	*(8.4)*	*(39.6)*

Note: percent difference from base adoption scenario results indicated in italics w ith negative values indicated in parenthesis

tariff level increases, producer benefits are greater and offset reduced government revenues. In the model, a free trade price level negates any of the gains that Philippine producers and the Philippine government make under a tariff. Lastly, the calculations do not take into account the deadweight costs and consumer losses that accompany a tariff irrespective of *Bt* rice research.

IIID. Farmer disadoption and technology depreciation

In the base scenario, no farmer disadoption or technology depreciation is factored into the model. Results on the welfare effect of incorporating various cases of farmer disadoption into the model are reported in **Table 26** while **Table 27** shows the welfare effects when different rates of technology depreciation for *Bt* rice are assumed.

Farmers may dis-adopt *Bt* rice for a host of reasons. Welfare effects in a pessimistic scenario where farmers immediately dis-adopt *Bt* rice after only one year of planting *Bt* rice, is estimated at 8.4 million USD (sixth column of Table 26). In contrast, a relatively conservative scenario that assumes farmers gradually dis-adopt *Bt* rice after the adoption lag or ceiling rate has been reached, aggregate benefits will only be 9.3 percent less than base scenario benefits (fourth column of Table 26).

Table 26. Gross aggregate benefits from adopting *Bt* rice in Southeast Asia by time of disadoption, 2000-2020.

COUNTRY / REGION	Discount Rate	BASE Adoption Scenario (no disadoption)	TIME OF DISADOPTION 1 year after Cmax* (gradual disadoption)	1 year after Cmax (3 year disadoption)	1 year from 1st year of release	5 years from 1st year of release
			present value is in year 2000 prices (million USD)			
PHILIPPINES	0.05	269.64	242.51 *(10.1)*	189.02 *(29.9)*	3.26 *(98.8)*	46.87 *(82.6)*
	0.10	136.53	125.63 *(8.0)*	103.78 *(24.0)*	2.44 *(98.2)*	30.90 *(77.4)*
VIETNAM	0.05	329.08	299.95 *(8.9)*	241.31 *(26.7)*	4.82 *(98.5)*	89.52 *(72.8)*
	0.10	159.85	148.33 *(7.2)*	124.95 *(21.8)*	3.32 *(97.9)*	53.19 *(66.7)*
Rest of of the World	0.05	20.11	18.76 *(6.7)*	16.02 *(20.3)*	0.32 *(98.4)*	6.90 *(65.7)*
	0.10	10.07	9.53 *(5.3)*	8.44 *(16.2)*	0.22 *(97.8)*	4.10 *(59.3)*
TOTAL	0.05	618.82	561.21 *(9.3)*	446.35 *(27.9)*	8.40 *(98.6)*	143.29 *(76.8)*
	0.10	306.45	283.49 *(7.5)*	237.16 *(22.6)*	5.98 *(98.0)*	88.18 *(71.2)*

Note: percent difference from base adoption scenario results indicated in italics with negative values indicated in parenthesis
* Cmax is time of disadoption after ceiling adoption rate is achieved.

The technology depreciation in this study is interpreted as the annual rate of breakdown in *Bt* rice resistance to stemborer infestation. The aggregate benefits were estimated applying a range of depreciation rates from 1 percent up to 15 percent. Results show that aggregate benefits are estimated to be anywhere from 8.2 percent to 86.2 percent less than that for the base scenario (Table 27).

IIIE. Sensitivity Analysis

<u>Domestic price elasticities of demand</u>

What is immediately clear from a cursory glance of the results is the minute impact that alternative values of the Philippine domestic rice price elasticity of demand η_{rp} will have on both the size and distribution of benefits (see **Table 28**). Likewise, the levels of aggregate benefits are not very sensitive to changes in the Vietnam price elasticity of demand η_{vn} (see **Table 29**). However, changes in η_{vn} do affect the distribution of benefits. With a relatively inelastic η_{vn} (-0.1), consumer benefits account for only 12.1 percent of the total welfare effect or less than half the value of

Table 27. Gross aggregate benefits from adopting *Bt* rice in Southeast Asia by annual rate of depreciation, 2000-2020.

COUNTRY / REGION	Discount Rate	BASE Adoption Scenario*	ANNUAL DEPRECIATION RATE AFTER FIRST YEAR OF RELEASE			
			One percent (0.01)	Five percent (0.05)	Ten percent (0.10)	Fifteen percent (0.15)
			present value is in year 2000 prices (million USD)			
PHILIPPINES	0.05	269.64	245.99	151.42	61.55	33.24
			(8.8)	*(43.8)*	*(77.2)*	*(87.7)*
	0.10	136.53	125.53	81.56	37.99	21.94
			(8.1)	*(40.3)*	*(72.2)*	*(83.9)*
VIETNAM	0.05	329.08	303.38	200.62	89.44	48.61
			(7.8)	*(39.0)*	*(72.8)*	*(85.2)*
	0.10	159.85	148.28	102.01	50.89	29.55
			(7.2)	*(36.2)*	*(68.2)*	*(81.5)*
Rest of of the World	0.05	20.11	18.66	12.89	6.50	3.70
			(7.2)	*(35.9)*	*(67.7)*	*(81.6)*
	0.10	10.07	9.40	6.74	3.72	2.25
			(6.6)	*(33.1)*	*(63.0)*	*(77.7)*
TOTAL	0.05	618.82	568.02	308.35	157.49	85.55
			(8.2)	*(50.2)*	*(74.5)*	*(86.2)*
	0.10	306.45	283.21	161.58	92.60	53.74
			(7.6)	*(47.3)*	*(69.8)*	*(82.5)*

Note: percent difference from base adoption scenario results indicated in italics w ith negative values indicated in parenthesis
* base adoption scenario assumes no depreciation in the durability of host plant resistance

consumer gains under the base scenario (see third row of Table 29). An inelastic η_{vn} increases the value of producer benefits by 21 percent and their share of the total welfare gain to 81 percent from 66.5 percent under the base scenario.

Domestic price elasticities of Supply

Changes in the Philippine price elasticity of supply ε_{rp} only affect the size and distribution of benefits in the Philippines. The results indicate that a one percent change in ε_{rp} results in an equivalent change in Philippine government revenues and a 4-5 percent change in producer benefits (second and third row of **Table 30**). If ε_{rp} were relative elastic (0.6), almost half the share of benefits will accrue to consumers as the value of benefits to producers are 67.7 percent less than that under the base scenario (sixth row of **Table 30**). In contrast, a relatively inelastic ε_{rp} (0.1) increases the share of Philippine producers to 85.4 percent compared to its 62.6 percent share in the base scenario (fifth row of **Table 30**).

Changes in the Vietnam price elasticity of supply ε_{vn} have the same effect on the size of total welfare benefits as those estimated for changes in ε_{rp} (see **Table 31**). An inelastic price elasticity of supply ε yields more benefits than that under the base scenario and vice versa for an elastic ε.

Distribution effects however are opposite. From an inelastic ε_{rp} to an elastic ε_{rp} the share of total benefits to producers decrease and share of benefits to consumers increase - all as a result of changes in the Philippine welfare effect. In contrast, from a relatively inelastic ε_{vn} to an elastic ε_{vn}, aggregate producer benefits increase and consumer benefits decrease (fourth and fifth rows of **Table 31**). However, the size of the distribution effect from changes in ε_{vn} is less than those for the same range of changes in ε_{rp}. This is because the distribution welfare effect for Vietnam is offset by opposite effects in the Philippines (e.g. loss in the share of benefits by producer in Vietnam are offset by producer gain in share of Philippine benefits). Lastly, results show that percent changes in aggregate benefits to the rest of the world from changes in ε_{vn} are virtually equal to the effect on consumers in both countries.

World price elasticity of demand for Vietnam rice exports

In the base scenario, the world price elasticity of demand for Vietnam rice exports is computed for each year. Given the uncertainty regarding this parameter, a range of elasticity values from 4 to 12 was tested to examine its effects on the size and distribution of benefits.

Results show that as the world price elasticity of demand for Vietnam rice exports $\eta_{row,vn}$ becomes more elastic, the share of benefits going to producers increases (**Table 32**). An elastic $\eta_{row,vn}$ also translates into lesser gains to consumers in both countries as the reduction in the world price also becomes smaller. The size however of total benefits were relatively small as this decreased from only 0.2 to 2.9 percent based on the range of elasticity values tested.

Choice of Discount Rate

In this study, we also presented the results for present values discounted at 10 percent. According to Quaim (1999b), this discount rate is commonly used as an indicator of the opportunity cost of capital in less developed countries. The results showed that increasing the discount rate to 10 percent from 5 percent reduced by around one half the present value of aggregate benefits.

Table 28. Sensitivity of results to changes in the Philippine price elasticity of demand for rice

ADOPTION SCENARIO	Philippines				Vietnam			ROW	TOTAL		
	PS	CS	GS	TS	PS	CS	TS	TS	PS	CS	TS
Base Scenario (η_{rp}= -0.93)	207.92	92.86	(31.14)	269.64	245.22	83.86	329.08	20.11	453.13	176.72	618.82
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*25.9*	*100*
η_{rp}= -0.92	207.92	92.86	(31.14)	269.64	245.22	83.86	329.08	20.11	453.13	176.72	618.82
Percent difference from base	*0*	*0.002*	*0*	*0.0007*	*0*	*0*	*0*	*0*	*0.0*	*0.0*	*0.0003*
Percent share within region	*62.6*	*28.0*	*9.4*	*100.0*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*25.9*	*100*
η_{rp}= -0.50	207.92	92.95	(31.14)	269.72	245.22	83.86	329.08	20.11	453.13	176.81	618.91
Percent difference from base	*0*	*0.092*	*0*	*0.0318*	*0*	*0*	*0*	*0*	*0.00*	*0.049*	*0.0139*
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*26.0*	*100*
η_{rp}= -0.35	207.92	92.98	(31.14)	269.75	245.22	83.86	329.08	20.11	453.13	176.84	618.94
Percent difference from base	*0*	*0.12*	*0*	*0.043*	*0*	*0*	*0*	*0*	*0.0*	*0.065*	*0.019*
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*26.0*	*100*
η_{rp}= -0.10	207.92	93.03	(31.14)	269.80	245.22	83.86	329.08	20.11	453.13	176.89	618.99
Percent difference from base	*0*	*0.18*	*0*	*0.061*	*0*	*0*	*0*	*0*	*0.0*	*0.09*	*0.027*
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.7*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*26.0*	*100*

Note: * size of welfare effect is present value evaluated at 5 percent discount rate expressed in million USD and distribution of welfare effect is expressed as percent share of absolute value of total welfare effect. PS = producer surplus, CS = consumer surplus, GS = government surplus, TS = total surplus

[a] TS = Philippine TS + Vietnam TS + ROW TS, [b] based on total welfare effect which is TS + absolute value of Philippine GS.

Table 29. Sensitivity of results to changes in the Vietnam price elasticity of demand for rice

ADOPTION	Philippines				Vietnam			ROW	TOTAL		
SCENARIO	PS	CS	GS	TS	PS	CS	TS	TS	PS	CS	TS[a]
Base Scenario (η_{vn}= -0.955)	207.92	92.86	(31.14)	269.64	245.22	83.86	329.08	20.11	453.13	176.72	618.82
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*25.9*	*100*
η_{vn}= -0.945	208.29	92.39	(31.20)	269.48	245.75	83.43	329.18	20.00	454.04	175.82	618.67
Percent difference from base	*0.18*	*(0.5)*	*(0.2)*	*(0.1)*	*0.22*	*(0.5)*	*0.03*	*(0.5)*	*0.20*	*(0.5)*	*(0.0)*
Percent share within region	*62.8*	*27.8*	*9.4*	*100*	*74.7*	*25.3*	*100*				
Percent share of total	*30.6*	*13.6*	*4.6*	*48.7*	*36.1*	*12.3*	*48.3*	*2.9*	*66.7*	*25.8*	*100*
η_{vn}= -0.50	226.88	68.97	(33.98)	261.87	272.07	62.34	334.41	14.92	498.95	131.31	611.21
Percent difference from base	*9.1*	*(25.7)*	*(9.1)*	*(2.9)*	*11.0*	*(25.7)*	*1.6*	*(25.8)*	*10.1*	*(25.7)*	*(1.2)*
Percent share within region	*68.8*	*20.9*	*10.3*	*100*	*81.4*	*18.6*	*100*				
Percent share of total	*33.4*	*10.2*	*5.0*	*48.6*	*40.1*	*9.2*	*49.2*	*2.2*	*73.5*	*19.3*	*100*
η_{vn}= -0.30	236.59	56.73	(35.43)	257.89	285.83	51.28	337.12	12.27	522.43	108.01	607.28
Percent difference from base	*13.8*	*(38.9)*	*(13.8)*	*(4.4)*	*16.6*	*(38.8)*	*2.4*	*(39.0)*	*15.3*	*(38.9)*	*(1.9)*
Percent share within region	*72.0*	*17.3*	*10.8*	*100*	*84.8*	*15.2*	*100*				
Percent share of total	*34.9*	*8.4*	*5.2*	*48.5*	*42.1*	*7.6*	*49.7*	*1.8*	*77.0*	*15.9*	*100*
η_{vn}= -0.10	247.34	43.17	(37.04)	253.48	301.06	39.03	340.10	9.35	548.41	82.21	602.92
Percent difference from base	*19.0*	*(53.5)*	*(18.9)*	*(6.0)*	*22.8*	*(53.5)*	*3.3*	*(53.5)*	*21.0*	*(53.5)*	*(2.6)*
Percent share within region	*75.5*	*13.2*	*11.3*	*100*	*88.5*	*11.5*	*100*				
Percent share of total	*36.5*	*6.4*	*5.5*	*48.4*	*44.5*	*5.8*	*50.2*	*1.4*	*81.0*	*12.1*	*100*

Note: * size of w elfare effect is present value evaluated at 5 percent discount rate expressed in million USD and distribution of w elfare effect is expressed as percent share of absolute value of total w elfare effect. PS = producer surplus, CS = consumer surplus, GS = government surplus, TS = total surplus

[a] TS = Philippine TS + Vietnam TS + ROW TS, [b] based on total w elfare effect w hich is TS + absolute value of Philippine GS.

Table 30. Sensitivity of results to changes in the Philippine price elasticity of supply for rice

ADOPTION	Philippines				Vietnam			ROW	TOTAL		
SCENARIO	PS	CS	GS	TS	PS	CS	TS	TS	PS	CS	TS[a]
Base Scenario (η_{vn}= -0.955)	207.92	92.86	(31.14)	269.64	245.22	83.86	329.08	20.11	453.13	176.72	618.82
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*25.9*	*100*
η_{vn}= -0.945	208.29	92.39	(31.20)	269.48	245.75	83.43	329.18	20.00	454.04	175.82	618.67
Percent difference from base	*0.18*	*(0.5)*	*(0.2)*	*(0.1)*	*0.22*	*(0.5)*	*0.03*	*(0.5)*	*0.20*	*(0.5)*	*(0.0)*
Percent share within region	*62.8*	*27.8*	*9.4*	*100*	*74.7*	*25.3*	*100*				
Percent share of total	*30.6*	*13.6*	*4.6*	*48.7*	*36.1*	*12.3*	*48.3*	*2.9*	*66.7*	*25.8*	*100*
η_{vn}= -0.10	247.34	43.17	(37.04)	253.48	301.06	39.03	340.10	9.35	548.41	82.21	602.92
Percent difference from base	*19.0*	*(53.5)*	*(18.9)*	*(6.0)*	*22.8*	*(53.5)*	*3.3*	*(53.5)*	*21.0*	*(53.5)*	*(2.6)*
Percent share within region	*75.5*	*13.2*	*11.3*	*100*	*88.5*	*11.5*	*100*				
Percent share of total	*36.5*	*6.4*	*5.5*	*48.4*	*44.5*	*5.8*	*50.2*	*1.4*	*81.0*	*12.1*	*100*
η_{vn}= -0.30	236.59	56.73	(35.43)	257.89	285.83	51.28	337.12	12.27	522.43	108.01	607.28
Percent difference from base	*13.8*	*(38.9)*	*(13.8)*	*(4.4)*	*16.6*	*(38.8)*	*2.4*	*(39.0)*	*15.3*	*(38.9)*	*(1.9)*
Percent share within region	*72.0*	*17.3*	*10.8*	*100*	*84.8*	*15.2*	*100*				
Percent share of total	*34.9*	*8.4*	*5.2*	*48.5*	*42.1*	*7.6*	*49.7*	*1.8*	*77.0*	*15.9*	*100*
η_{vn}= -0.50	226.88	68.97	(33.98)	261.87	272.07	62.34	334.41	14.92	498.95	131.31	611.21
Percent difference from base	*9.1*	*(25.7)*	*(9.1)*	*(2.9)*	*11.0*	*(25.7)*	*1.6*	*(25.8)*	*10.1*	*(25.7)*	*(1.2)*
Percent share within region	*68.8*	*20.9*	*10.3*	*100*	*81.4*	*18.6*	*100*				
Percent share of total	*33.4*	*10.2*	*5.0*	*48.6*	*40.1*	*9.2*	*49.2*	*2.2*	*73.5*	*19.3*	*100*

Note: * size of w elfare effect is present value evaluated at 5 percent discount rate expressed in million USD and distribution of w elfare effect is expressed as percent share of absolute value of total w elfare effect. PS = producer surplus, CS = consumer surplus, GS = government surplus, TS = total surplus

[a] TS = Philippine TS + Vietnam TS + ROW TS, [b] based on total w elfare effect w hich is TS + absolute value of Philippine GS.

Table 31. Sensitivity of results to changes in the Vietnam price elasticity of supply for rice

ADOPTION SCENARIO	Philippines				Vietnam			ROW	TOTAL		
	PS	CS	GS	TS	PS	CS	TS	TS	PS	CS	TS[a]
Base Scenario (ε_{vn}= 0.34)	207.92	92.86	(31.14)	269.64	245.22	83.86	329.08	20.11	453.13	176.72	618.82
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*25.9*	*100*
ε_{vn}= 0.33	206.16	95.07	(30.88)	270.35	253.33	85.85	339.18	20.59	459.49	180.92	630.12
Percent difference from base	*(0.8)*	*2.4*	*0.8*	*0.3*	*3.3*	*2.4*	*3.1*	*2.4*	*1.4*	*2.4*	*1.8*
Percent share within region	*62.1*	*28.6*	*9.3*	*100*	*74.7*	*25.3*	*100*				
Percent share of total	*29.8*	*13.7*	*4.5*	*48.0*	*36.6*	*12.4*	*49.0*	*3.0*	*66.4*	*26.1*	*100*
ε_{vn}= 0.35	209.57	90.78	(31.39)	268.96	237.57	81.98	319.55	19.65	447.14	172.76	608.17
Percent difference from base	*0.8*	*(2.2)*	*(0.8)*	*(0.3)*	*(3.1)*	*(2.2)*	*(2.9)*	*(2.3)*	*(1.3)*	*(2.2)*	*(1.7)*
Percent share within region	*63.2*	*27.4*	*9.5*	*100*	*74.3*	*25.7*	*100*				
Percent share of total	*31.2*	*13.5*	*4.7*	*49.4*	*35.4*	*12.2*	*47.6*	*2.9*	*66.6*	*25.7*	*100*
ε_{vn}= 0.10	71.82	263.67	(10.77)	324.72	891.18	238.08	1,129.26	58.08	963.00	501.75	1,512.06
Percent difference from base	*(65.5)*	*183.9*	*65.4*	*20.4*	*263.4*	*183.9*	*243.2*	*188.9*	*112.5*	*183.9*	*144.3*
Percent share within region	*20.7*	*76.1*	*3.1*	*100*	*78.9*	*21.1*	*100*				
Percent share of total	*4.7*	*17.2*	*0.7*	*22.6*	*58.1*	*15.5*	*73.6*	*3.8*	*62.8*	*32.7*	*100*
ε_{vn}= 0.60	233.44	60.73	(34.96)	259.22	129.89	54.84	184.74	13.11	363.34	115.58	457.06
Percent difference from base	*12.3*	*(34.6)*	*(12.3)*	*(3.9)*	*(47.0)*	*(34.6)*	*(43.9)*	*(34.8)*	*(19.8)*	*(34.6)*	*(26.1)*
Percent share within region	*70.9*	*18.5*	*10.6*	*100*	*70.3*	*29.7*	*100*				
Percent share of total	*44.3*	*11.5*	*6.6*	*62.5*	*24.6*	*10.4*	*35.1*	*2.5*	*68.9*	*21.9*	*100*

Note: * size of w elfare effect is present value evaluated at 5 percent discount rate expressed in million USD and distribution of w elfare effect is expressed as percent share of absolute value of total w elfare effect. PS = producer surplus, CS = consumer surplus, GS = government surplus, TS = total surplus

[a] TS = Philippine TS + Vietnam TS + ROW TS, [b] based on total w elfare effect w hich is TS + absolute value of Philippine GS.

Table 32. Sensitivity of results to changes in the price elasticity of demand for Vietnam rice exports

ADOPTION	Philippines				Vietnam			ROW	TOTAL		
SCENARIO	PS	CS	GS	TS	PS	CS	TS	TS	PS	CS	TS[a]
Base Scenario (variable ηM_{row})	207.92	92.86	(31.14)	269.64	245.22	83.86	329.08	20.11	453.13	176.72	618.82
Percent share within region	*62.6*	*28.0*	*9.4*	*100*	*74.5*	*25.5*	*100*				
Percent share of total	*30.5*	*13.6*	*4.6*	*48.7*	*36.0*	*12.3*	*48.3*	*3.0*	*66.5*	*25.9*	*100*
rowED=4	211.48	88.77	(31.68)	268.57	250.25	80.05	330.30	18.89	461.73	168.82	617.77
Percent difference from base	*1.7*	*(4.4)*	*(1.7)*	*(0.4)*	*2.1*	*(4.5)*	*0.4*	*(6.0)*	*1.9*	*(4.5)*	*(0.2)*
Percent share within region	*63.7*	*26.7*	*9.5*	*100*	*75.8*	*24.2*	*100*				
Percent share of total	*31.0*	*13.0*	*4.7*	*48.7*	*36.7*	*11.8*	*48.5*	*2.8*	*67.8*	*24.8*	*100*
rowED=6	229.96	65.43	(34.44)	260.95	276.43	59.00	335.42	13.92	506.39	124.42	610.29
Percent difference from base	*10.6*	*(29.5)*	*(10.6)*	*(3.2)*	*12.7*	*(29.6)*	*1.9*	*(30.8)*	*11.8*	*(29.6)*	*(1.4)*
Percent share within region	*69.7*	*19.8*	*10.4*	*100*	*82.4*	*17.6*	*100*				
Percent share of total	*33.9*	*9.6*	*5.1*	*48.6*	*40.7*	*8.7*	*49.4*	*2.0*	*74.6*	*18.3*	*100*
rowED=8	240.73	51.81	(36.05)	256.49	291.69	46.71	338.40	11.02	532.42	98.52	605.90
Percent difference from base	*15.8*	*(44.2)*	*(15.8)*	*(4.9)*	*19.0*	*(44.3)*	*2.8*	*(45.2)*	*17.5*	*(44.3)*	*(2.1)*
Percent share within region	*73.3*	*15.8*	*11.0*	*100*	*86.2*	*13.8*	*100*				
Percent share of total	*35.5*	*7.6*	*5.3*	*48.5*	*43.0*	*6.9*	*49.9*	*1.6*	*78.5*	*14.5*	*100*
rowED=10	247.79	42.88	(37.10)	253.56	301.68	38.66	340.34	9.11	549.47	81.54	603.02
Percent difference from base	*19.2*	*(53.8)*	*(19.1)*	*(6.0)*	*23.0*	*(53.9)*	*3.4*	*(54.7)*	*21.3*	*(53.9)*	*(2.6)*
Percent share within region	*75.6*	*13.1*	*11.3*	*100*	*88.6*	*11.4*	*100*				
Percent share of total	*36.6*	*6.3*	*5.5*	*48.4*	*44.5*	*5.7*	*50.3*	*1.3*	*81.1*	*12.0*	*100*
rowED=12	252.77	36.58	(37.85)	251.50	308.74	32.98	341.72	7.77	561.50	69.56	600.99
Percent difference from base	*21.6*	*(60.6)*	*(21.5)*	*(6.7)*	*25.9*	*(60.7)*	*3.8*	*(61.3)*	*23.9*	*(60.6)*	*(2.9)*
Percent share within region	*77.3*	*11.2*	*11.6*	*100*	*90.3*	*9.7*	*100*				
Percent share of total	*37.4*	*5.4*	*5.6*	*48.4*	*45.6*	*4.9*	*50.5*	*1.1*	*83.0*	*10.3*	*100*

Note: * size of w elfare effect is present value evaluated at 5 percent discount rate expressed in million USD and distribution of w elfare effect is expressed as percent share of absolute value of total w elfare effect. PS = producer surplus, CS = consumer surplus, GS = government surplus, TS = total surplus

[a] TS = Philippine TS + Vietnam TS + ROW TS, [b] based on total w elfare effect w hich is TS + absolute value of Philippine GS.

IIIF. Economic benefits of other potential transgenic pest-resistant rice varieties

The aggregate benefits of four other type of transgenic pest resistance were estimated using crop loss estimates based on Savary et al 2000b and the same base scenario parameter values.

Results from this set of calculations are reported in **Table 33**. With the exception of bacterial leaf blight (BLB) resistance, the potential welfare effect estimated for leaf blast, weeds and multiple pest resistance are all greater than that estimated for *Bt* rice. Aggregate benefits for BLB resistant rice are estimated at 51.53 million USD and 1.3 billion USD for a Leaf Blast resistant variety. The model estimated that a rice variety resistant or tolerant to weeds has a potential welfare impact of almost 6 billion USD. To highlight the economic value of developing host plant resistance into the new plant type, this study estimates that a multiple disease and insect pest-resistant rice variety can generate as much as 9.7 billion USD in benefits when adopted in both the Philippines and Vietnam.

Table 33. Estimated aggregate benefits of adopting other potential types of transgenic pest-resistant rice in Southeast Asia, 2000-2020.

COUNTRY / REGION	Discount Rate	TYPE OF TRANSGENIC PEST RESISTANCE* Stemborer resistance	Weed tolerance	Leaf Blast resistance	Bacterial Leaf Blight resistance	Multiple pest resistance
		present value is in year 2000 prices (million USD)				
PHILIPPINES	0.05	269.64	2,593.55	368.96	14.71	2,792.22
			862	*36.8*	*(94.5)*	*936*
	0.10	136.53	1,313.42	190.89	7.61	1,442.74
			862	*39.8*	*(94.4)*	*957*
VIETNAM	0.05	329.08	3,174.58	686.15	27.40	5,129.81
			865	*109*	*(91.7)*	*1459*
	0.10	159.85	1,541.49	333.29	13.31	2,490.24
			864	*108*	*(91.7)*	*1458*
Rest of the World	0.05	20.11	205.29	42.23	1.66	344.02
			921	*110*	*(91.7)*	*1611*
	0.10	10.07	102.40	21.14	0.83	171.18
			917	*110*	*(91.7)*	*1600*
TOTAL	0.05	618.82	5,973.41	1,290.39	51.53	9,656.47
			865	*109*	*(91.7)*	*1460*
	0.10	306.45	2,957.31	639.01	25.52	4,779.80
			865	*109*	*(91.7)*	*1460*

Note: percent difference from stemborer resistance (*Bt* rice) indicated in italics with negative values indicated in parenthesis
* evaluated using the following crop loss estimates for each pest constraint where crop loss is defined as the percentage yield loss based on an attainable yield of 5.5 MT/HA: stemborer resistance = 2.4 percent, weed tolerance = 23 percent, leaf blast resistance = 5 percent, bacterial leaf blight = 0.2 percent, multiple pest resistance = 37 percent

CHAPTER IV. SUMMARY AND CONCLUSION

This study used an ex-ante analytical framework to evaluate the welfare impact of adopting *Bt* rice in the Philippines and Vietnam through the years 2000-2020. The size and distribution of economic benefits were estimated using an ex-ante partial equilibrium economic surplus model. We first developed a base scenario that described a likely adoption impact pathway for *Bt* rice in Southeast Asia. Under the base scenario, the total welfare gain from adopting Bt rice in the Philippines and Vietnam was estimated at 618.8 million USD. The aggregate benefits by region were estimated at 269.6 million USD for the Philippines, 329.1 million USD for Vietnam, and 20.1 million USD for the rest of the world. Simulation results indicate that producers in both countries will capture 66.5 percent of the total welfare effect from Bt rice adoption, 25.9 percent will accrue to consumers, consumers from the rest of the world receives 3 percent, and the loss in Philippine government revenue accounts for 4.6 percent of the total welfare effect. The study also estimated the welfare impact of deploying *Bt* rice under alternative scenarios that considered: (1) the adoption sequence and transfer lag, (2) the rate and extent of farmer adoption, (3) the price level and Philippine tariff schedule for rice, and (4) the presence of farmer disadoption and technology depreciation. The sensitivity of base scenario results to changes in price elasticities were then tested. Finally, the model was used to estimate the potential economic benefits from adopting other kinds of transgenic pest-resistant rice.

Results suggest (1) that releasing *Bt* rice in Vietnam first instead of the Philippines will generate a larger welfare impact, (2) depending on the ceiling rate, the range of aggregate benefits can be anywhere from 341.40 million USD to 908.39 million USD and (3) there are still sizeable benefits generated even when farmer disadoption and technology depreciation are considered in the evaluation. Results of the sensitivity analysis show that the price elasticity of supply of either the Philippines and Vietnam will have the most impact in varying the size and distribution of benefits from adopting *Bt* rice. In evaluating other types of transgenic pest-resistant rice, results show that aside from multiple pest resistance, resistance or tolerance to weeds is the single most important transgenic trait for rice. Though controversial especially for the public sector, the huge potential gains from adopting weed tolerant or resistant rice cannot be ignored.

Limitations of the study and further research

While this study provides some insights on the potential size and distribution of economic benefits that *Bt* rice deployment in Southeast Asia will generate, several limitations are apparent.

One, welfare effects are expressed in terms of gross benefits. No cost assumptions were made and thus net benefits were not estimated mainly because there is no available information on research and development costs for *Bt* rice. Still, numerical estimates on the benefits from *Bt* rice that accrue to both the Philippines and Vietnam are not expected to differ considerably even if research costs are considered. This is because the bulk of research and development costs are not assumed by the two countries but borne instead by the public sector ARCs like IRRI.

General budget reports from public research institutions can serve as an indicator of upper bound estimates on research and development costs or investment levels. Still, deriving reliable cost estimates specifically for *Bt* rice R&D will be difficult since both the inputs and outputs in rice biotechnology research generally overlap in function and application. For example, investments made on developing genetic engineering tools are not only applied for *Bt* rice but for other pest constraints as well. As the private sector become more involved in rice biotechnology research, it will be essential to account for IPR cost related issues (e.g. technology fees). Another consideration would to be to reflect in an economic evaluation concerns raised by certain groups opposed to transgenic food crops and try to account for potential social costs associated with the release of *Bt* rice.

A second limitation of the study comes from the ex-ante framework and the hypothesis that the size and distribution of aggregate benefits will depend on the nature of the adoption impact pathway. The ex-ante framework only allows us to lend evidence to this hypothesis. Once field testing and commercial release of *Bt* rice takes place, this will allow us to test the validity of this hypothesis and the assumptions made in this study within an ex-post framework.

Another limitation of the study is that adoption impact pathway only covered the Philippines and Vietnam. Our model did not account for potential changes in the rice production and consumption in Thailand, the world's largest rice exporter and Indonesia, the world's largest importer thus both countries significantly influence the world rice market. By including them in future evaluations either as adopters or as non-adopters gives a more complete estimate of the economic impact that *Bt* rice deployment will have in Southeast Asia and the rest of the world.

Lastly, the study assumed homogeneity of prices, grain quality, consumers and producers. However, the rice market is highly segregated and substitution effects are inherent. More insight into the potential welfare impact of *Bt* rice can come from further research that considers the substitution effects between *Bt* rice seed and non-*Bt* rice seed and segregating the welfare effect between consumers and producers of *Bt* rice and non-*Bt* rice consumers and producers.

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