Is Rice Improvement Still Making a Difference? Assessing the Economic, Poverty, and Food Security Impacts of Rice Varieties Released from 1989 to 2009 in Bangladesh, Indonesia and the Philippines

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Executive summary

The productivity impact of the initial diffusion of modern varieties (MVs) of rice across Asia during the 1960s through the 1980s, as part of the "Green Revolution", is one of the most documented successes of international development assistance in agriculture. However, much less is known about whether continued efforts to further improve rice varieties are making similar contributions to on farm productivity. This study assesses the degree to which post 1989 MVs of rice have led to increased agricultural productivity, economic surplus, welfare for the poor, food security and environmental benefits in Bangladesh, Indonesia and the Philippines.

The study begins by characterizing the traits embodied in new varieties, including attainable yields, disease and pest resistance, and assessing the changes in resistances over time. Subsequently, nationally representative data are used to estimate subnational patterns of varietal and trait adoption over time and space. Panel and quasi panel national data are used in econometric fixed effects production function and damage abatement models to identify on farm yield effects attributable to trait adoption. This is accompanied by bio-economic modeling of disease resistance effects in a spatial framework.

The yield effect estimates and adoption parameters are used to estimate supply shifts attributable to the diffusion of post 1989 modern varieties (MVs) of rice and International Rice Research Institute (IRRI) contributions to those varieties. These supply shifts are then used in a new subnationally disaggregated partial equilibrium model to quantify welfare effects for consumers, producers, hired labor, populations under specific poverty lines, the environment and the food insecure over the period.

The econometrics applied suggest that newer popular modern varieties increase Boro yields in Bangladesh by 7 to 8% where adopted. In Indonesia, it is found that the elasticity of actual yield to the yield of adopted varieties under experimental conditions is a significant 0.4, while host plant resistances to blast and brown planthopper have significant coefficients indicating that they help to protect yields. For the Philippines, the statistically significant elasticity of actual yield to the experimental yield of adopted varieties is similar in the dry season at 0.4, but lower in the wet season at 0.2. In the Philippines there are significant brown planthopper resistance effects when insecticides are used, and slightly significant tungro resistance effects.

Under the main set of modeling assumptions in which the supply function has a positive shutdown price, the study suggests that over (2005) PPP$25 billion of benefits are generated over the period in the three focal countries by the diffusion of post 1989 MVs, of which PPP$9 billion are attributable to IRRI genetic contributions, with similar distributional implications to the total effect of newer MVs. Total benefits are approximately halved if the supply function has a shutdown price of zero. Approximately 45% of benefits are captured by those under the PPP$2.0 per day poverty line, while the aggregate impact on health from reduced caloric insufficiency due to post 1989 MVs is nearly 1.5 million Disability Adjusted Life Years (DALYs). The vast majority of these benefits arise from increased attainable yield of newer varieties, rather than pest or disease resistance and occur in Indonesia.

1. Introduction

Rice genetic improvement is the single largest source of documented agricultural research impact in the developing world (Raitzer and Kelley, 2008, Maredia and Raitzer, 2012). As the technology that underpinned the seed-fertilizer-irrigation "Green Revolution" of the 1960s through the 1980s, semi-dwarf yield-potential varieties of rice received considerable attention from economists. By the late 1990s, modern varieties (MVs) and rice hybrids had replaced traditional varieties (TVs) on more than 100 million harvested hectares annually in developing Asia. According to Hossain et al. (2003), the annual gains from modern varieties of rice in South and Southeast Asia were $10.8 billion (nominal) per year in the late 1990s.

However, recent observations have raised critical questions about whether genetic improvement continues to underpin rice productivity improvement in the manner documented previously. Work by physiologists has demonstrated that there has been little improvement in absolute yield potential since the "miracle rice" variety IR8 was released in 1965 at IRRI (Peng et al., 1999), as the pace of varietal replacement has slowed in many parts of Asia (Wang et al., 2012). Concomitant observations have concluded that rates of yield growth have strongly declined on farm, and that these rates are falling below the rate of consumption growth, threatening future food security (Mohanty et al., 2010).

Moreover, prior estimates, which conclude that rice genetic improvement has had major impact, have three important limitations. First, prior analyses of the impact of rice genetic improvement have focused on MV replacement of TVs, and have revealed little about the continued impact of MV replacement in the decades since the Green Revolution. Second, the analyses that have been conducted to date do not adequately address problems of selection bias, as differences between the farms and farmers that adopt newer modern varieties and those that do not have been conflated with varietal effects on farm. Third, welfare consequences for the poor and the food insecure have not been quantified explicitly to identify the actual level of benefit reaching target populations. These limitations, in the context of observed reductions in the rate of genetic progress, have necessitated a more rigorous and detailed approach to understanding whether recent (post 1989) genetic progress has continued to contribute substantially to production growth and whether that production growth is really benefiting the poor.

The present study uses time series-cross sectional data on varietal adoption, input use, and outputs, along with innovative econometric methods, to try to assess the contribution of recent modern varieties and traits to yield with a new level of rigor. It does so in the context of three countries where rice is an essential crop, substantial poverty remains present, and cross sectional time series data are available: Bangladesh, Indonesia and the Philippines. It then applies econometric estimates in welfare modeling to explore how benefits generated have been distributed and with what consequences.

1.1. Context

The development of modern varieties of rice can be conceptualized as going through a series of stages. In the first stage, IR8 and initial MVs produced during the 1960s and 1970s introduced semi-dwarfing, which enabled high fertilizer application rates without lodging.

This caused a great leap in yield potential. However, these varieties lacked resistance to major pests and diseases, often had poor grain quality, and had limited tolerance to abiotic stresses (Khush et al., 2001). In the late 1970s and early 1980s, resistance to multiple pests and diseases was introduced into newer modern varieties, while duration from planting to harvesting was also reduced and grain quality improved during the 1980s. Over successive generations, the adaptability of varieties also improved through minor abiotic stress tolerances, which enabled cultivation over a wider range of environments, while varieties for environments with particular stresses, such as drought and salinity were also developed (Khush, 1995).

Many of the popular varieties developed in the 1960s, 70s and 80s were direct crosses by the International Rice Research Institute (IRRI). These were designated as “IR” varieties, initially by IRRI, with the designation later retained by the Philippine Seed Board during the national release process until 1989 for IRRI bred varieties, after which all releases in the Philippines shared the same designation, so that IRRI varieties were not clearly distinguished. The IR varieties from the 1980s had widespread and visible adoption, culminating with IR64, which became the most popular rice variety in the world in the 1990s (Khush and Virk, 2005).

In the “post IR” period starting in 1990, the contributions of subsequent IRRI research products have been much less obvious. A number of IRRI studies suggested that the genetic potential of rice had nearly been exhausted via conventional breeding with the IR varieties (Peng et al.,1999; Peng et al., 2000; Peng et al., 2010), as yield potential for the best varieties released in the late 1990s and early 2000s was no higher than for IR8 in the 1960s. In parallel, progress in varietal release yield appeared to slow down. No new IRRI bred “mega-varieties” were observed to dominate tens of millions of hectares, as had been observed for IR64, and in many countries, the pace of varietal replacement has appeared to slow down, with continuing adoption of varieties from the 1970s and 80s. Dramatic innovations in quality were no longer apparent, and new special stress tolerant varieties were observed to have limited adoption (Pandey et al., 2012).

This potential deceleration of innovation has occurred in the context of economic growth and structural transformation in much of rice dependent developing Asia, in which both the economic contribution of agriculture and the share of agricultural production value from rice are declining (Timmer, 2007). The result of this structural transformation has been reduction in poverty, such that the greatest poverty rates no longer exist in many of the rice-dependent countries of Asia. Increased real purchasing power has meant that the share of household income spent on rice has been declining in real terms over the past decades. This raises questions about whether rice research has continued to offer benefits that are as important in terms of poverty reduction as in the past.

Consequently, it is no longer clear whether continued efforts to develop modern varieties are continuing to offer economic and poverty alleviation impacts in the manner that has been documented historically. It is possible that the genetic improvement process has encountered diminishing marginal returns, such that historical rates of impact are no longer being achieved. This study is intended to help resolve these uncertainties by revealing the production, economic, poverty and food security impacts of the “post IR” MVs released in the 1990s, as well as IRRI’s contributions to those impacts.

1.2 Background: Prior studies

This study is by no means the first analysis of rice genetic improvement impacts. An extensive set of literature on the impacts of modern varieties of rice has developed over the past decades. However, much of it has methodological flaws, leaves substantial room for further investigation, or is no longer relevant in an era in which most modern varietal adoption concerns the replacement of older modern varieties. To contextualize this work, and identify the issues that remain unaddressed effectively, it is worthwhile to review what has been done previously.

1.2.1 Early literature on the impacts of modern varietal replacement of traditional varieties

In the mid 1970s Dalrymple (1972, 1977, 1978) began to systematically collect information on the diffusion of modern varieties of wheat and rice. These data were used by Evenson (1974) and Flores-Moya et al. (1978) in the mid 1970s to make the first estimates of the economic impacts of modern varieties. The methods employed to identify the productivity effects of modern varieties were twofold: first average yields of farms with modern varieties and traditional varieties were compared and second, a two-stage Cobb Douglas production function was estimated, which regressed production on modern varietal area, land area and fertilizer. The latter was a pooled regression across 12 countries using national data. Dalrymple (1977) concurrently reported estimates using an “index number approach” based on a similar MV-TV yield comparison. Both analyses took the estimated yield increases as pivotal shifts into partial equilibrium closed economy economic surplus models to identify welfare benefits.

The studies conducted in the 1970s used somewhat simplistic gross comparisons between MV and TV yields or aggregate production functions that omitted key variables such as irrigation. A major advance was made in a landmark study by Herdt and Capule (1983) that took into account irrigation and fertilizer conditions through the use of individually estimated MV and TV production functions by country, with MV effects identified as the difference between the production functions with inputs held constant.

In the mid 1990s, David and Otsuka (1994) moved assessment of the impacts of modern varieties in Asia beyond a focus on land productivity and aggregate economic benefits to include assessment of distributional implications. The main focus of the analysis was to determine whether modern varietal adoption increases or reduces labor demand, and how those demand shifts translate into wage effects for poor and landless laborers. The approaches relied on cross-sectional regressions including modern varietal (versus traditional) adoption as an independent variable.

1.2.2 Prior studies on traits imparted through varietal replacement

There is a small body of literature on the impacts of the diffusion of individual traits through modern varietal replacement. However, the most recent of this work is nearly 20 years old.

Unnevehr (1986) used hedonic pricing framework to measure the value of grain quality characteristics. Along with varietal adoption data for Indonesia and the Philippines the study estimated a demand shift attributable to quality improvement through breeding. The demand shift was subsequently applied in a closed economy economic surplus model to provide the first measures of economic benefits attributable to traits other than yield.

Also, in the mid 1990s, a pioneering study by Widawsky et al. (1998) identified the effects of host plant resistance on yields and on insecticide use for eight townships in southeastern China. A least squares dummy variable fixed effects model was used with instrumental variables to address simultaneity bias in insecticide use, while host plant resistances were incorporated as ordinary independent variables in the production function. Significant yield effects were found for insect resistance, but not disease resistance.

At roughly the same time, Evenson (1997) applied a somewhat similar hedonic trait valuation approach, in which yield and other productivity measures were regressed on areas of host plant resistances in Indonesia and India. This appears to have been based on pooled OLS regressions of trait area and interaction terms between trait areas and environmental factors in India and a two stage least squares approach for Indonesia to account for endogeneity in pest control. In India, significant yield effects were identified from disease resistances, but not insect resistances, while only effects from insect resistance were successfully identified in Indonesia.

1.2.2.1 Recent studies

Using data from the late 1990s, Hossain et al. (2003) estimated gross benefits of modern varieties based on secondary adoption statistics and gross differences in farm revenues between TV and MV adopters. Similarly, in the mid 2000s, Hossain et al. (2006) used a combination of data from mean comparisons between adopters and non-adopters of MVs in Bangladesh and qualitative analysis to identify the poverty relevance of benefits generated.

More recently, Brennan and Malabayabas (2011) applied an "index of varietal improvement" (IVI) approach to assess benefits from diffusion of newer rice varieties using data from the Philippines, Indonesia and Vietnam. Such an approach defined attributable impact as the differences between subsequent years and a base period in the products of area of MV adoption and attainable yield (from the varietal release process). This study identified very large benefit values attributable to improved varieties and IRRI germplasm. The IVI approach is typical of a number of impact studies, such as work initially published by Dalrymple in 1975 and carried forward by others, such as Byerlee and Traxler (1995) for wheat, which collectively represent a large share of the documented aggregate economic impact from agricultural research.

1.2.2.2. Aspects not sufficiently addressed previously

While most of these studies represented important methodological advancements in their respective eras, they still leave many issues unresolved. First, a majority of the studies to date focus on MV replacement of TVs. Given that modern varieties now have been available for more than 50 years in most of Asia, and that they have now covered a majority of rice area for decades, this is no longer a counterfactual of relevance to more recent investments in research. A much more pertinent issue today is whether recent improvements in modern varieties continue to confer benefits as has been documented previously for TV replacement by MVs.

Issues of conflation of varietal effects with other factors pervade much of the literature. For example, the Brennan and Malabayabas (2011) IVI approach, along with other “index number” methods, conflates the effects of other changes with those of rice genetic improvement. Weather, input availability, input quality, and output prices are all shifting over time to affect yields. Secondly, varietal selection and adoption is conditioned by growing environment, and the relative share of production in irrigated, favorable growing environments is increasing over time. Ceteris paribus, as a result of this relative irrigation expansion, the IVI will rise, because irrigated varieties have higher release yields than rainfed varieties, so that the MV-area attainable-yield product rises, even if the newer irrigated or rainfed varieties have no yield advantage over older ones within their respective ecologies.

While prior regression based approaches better account for observable factors that condition yields, and more recent attempts focus on individual traits, they too may be subject to conflated causal identification. In addition, pooled ordinary least squares (OLS) regressions with varietal characteristics as independent variables may be susceptible to selection bias, as more progressive or better endowed farmers may be more likely to adopt better or more locally appropriate varieties. As a result, the effects of differences in these characteristics may be conflated with the consequences of adoption.

One strain of literature has also suggested that “damage abating” inputs should not be treated as normal inputs in production function specifications, because the inputs that determine attainable yield are distinct from the processes of applying damage control inputs that indirectly mitigate yield loss by reducing crop damage (Lichtenberg and Zilberman, 1986, Zhengfei et al., 2005). As a result, most recent studies of the effects of damage control inputs follow a functional specification that multiplies a Cobb-Douglas production function (to define attainable yield) by a damage abatement function that reflects the proportion of yield maintained after abatement actions are applied. This advancement in functional form has never been applied in prior studies of rice traits related to damage abatement, such as host plant resistances.

Moreover, the valuation approaches employed to estimate the economic surplus effects of MV diffusion have arguably been flawed. Many previous studies, such as Brennan and Malabayabas (2011) and Hossain et al. (2003) have based surplus estimation on differences in average farm budgets identified as attributable to MV diffusion, extrapolated over the area of MV adoption. This approach is essentially analogous to a parallel shift of a linear supply curve in an economic surplus model with perfectly elastic demand, which is a functional form associated with implausible producer behavior assumptions, as well as benefit overestimation (Sampath and Nobe, 1983; Scobie, 1976; Wohlgenant, 1997). Rice is also a commodity with relatively inelastic demand and low price transmission from international to domestic markets, which makes the distributional results of models previously applied based on assumptions of perfectly elastic demand implausible., as benefits of increased productivity will often be transferred from producers to consumers through lower prices. Thus, distributional analysis of MV adoption often requires explicit welfare modeling to understand the implications of these effects, both for consumers and for non-adopters.

In sum, no prior study has applied rigorous econometrically rooted estimates of the contributions of traits imparted through modern varietal replacement of other modern varieties in analysis of welfare effects for the poor or food insecure using a theoretically defensible model. All prior literature on rice with a distributional analysis component has focused on MV replacement of TVs and has largely ignored price interactions. Thus, the welfare and poverty implications of more recent varietal improvements remain largely unknown.

1.3 Study objectives

The focus of this study is to help resolve these information gaps in the context of countries where MVs have been previously documented as generating large impacts. It does do by applying regression specifications that are less prone to selection bias, and which are more biologically appropriate than previous functional forms, to identify effects attributable to trait adoption, with a focus on adoption and contributions in the period from 1990 to the present. This is complemented by bio-economic modeling approaches for host plant resistance characteristics, which may avoid issues of endogeneity entirely. Effects attributable to adoption will be fed into a detailed partial equilibrium model to identify effects for the poor and insecure in more detail than ever before.

The key hypotheses to be tested are:

1. That rice research continues to have substantial effects on farm yields, as a result of diffusion of new traits in modern varieties.
2. That the economic benefits from newer generations of modern varieties continue to be substantial.
3. That a large share of economic benefits generated is captured by poor populations (as defined by international poverty lines).

1.4 Approach

The overall study approach consists of a series of stages. The first is to ascertain adoption of varietal traits in the focal countries by spatial unit and over time. This requires detailed characterization of the traits associated with each popular variety, including how those traits may be changing over time, as well as data on adoption by variety.

The second stage of the approach is to identify what adoption of those traits has meant in terms of farm yield. This relies principally on econometric production functions that are structured to drop out the effects of time invariant factors that may condition both adoption and rice productivity. Some bio-economic modeling accompanies this to assess the effects of adoption of traits that are difficult to assess econometrically.

Although the first two stages are purely empirical, the third stage also involves approximation based on partial equilibrium market models to ascertain both the magnitude of economic benefits generated and how price interactions affect the distribution of benefits, as well as patterns of production. Spatial and temporal patterns in benefits and land use effects are then applied with ancillary information on poverty, hunger and environmental footprints of production to approximate benefits to the poor, food insecure and the environment.

1.5 Study countries and focal traits

This study focuses on three countries, Bangladesh, Indonesia and the Philippines, in which rice is a crop of fundamental importance, prior impact assessment work on rice genetic improvement has been conducted as a point of comparison, adoption of varieties developed internationally is widespread, and detailed subnationally disaggregated time series or panel data are available on modern varietal diffusion over time. The period of analysis is the period after initial diffusion of MVs became widespread, and is approximately 1990-2010 (the period in individual countries may vary slightly, depending on data availability).

1.5.1 Bangladesh

Rice is Bangladesh’s most important crop, as it occupies 75% of land area and provides two-thirds of average caloric intake (BRRI, 2013). In Bangladesh there are three principal production seasons—Aman (wet season), Aus (dry season) and Boro (irrigated dry season). The Aman and Aus seasons are lower yielding and have limited use of irrigation. The key focus for analysis in Bangladesh is the Boro (dry) season, as adoption of newer modern varieties is limited in the Aman season, where the leading varieties were developed prior to the 1980s. Among the seasons in Bangladesh, the Boro season has the highest intensity of modern varietal adoption at more than 90% over the entire analytical period of 1990 to 2010.

The Boro season is dramatically expanding as a share of paddy production area. Within the analytical period, the cultivated Boro area more than doubles (Fig 1.1). This means that the absolute area of varietal adoption under a constant relative adoption rate in the Boro season doubles over the period.

Within the Boro season, there is a level of fertilizer use, but the rate appears to be time invariant. Other inputs, such as insecticide and labor are declining over the period, while irrigation cost is rising in real terms. Despite the absence of intensified chemical input use, yields are rapidly rising at 2.6% annually. A key focus of this analysis will be to determine how much of this yield growth is attributable to the diffusion of post 1989 MVs.

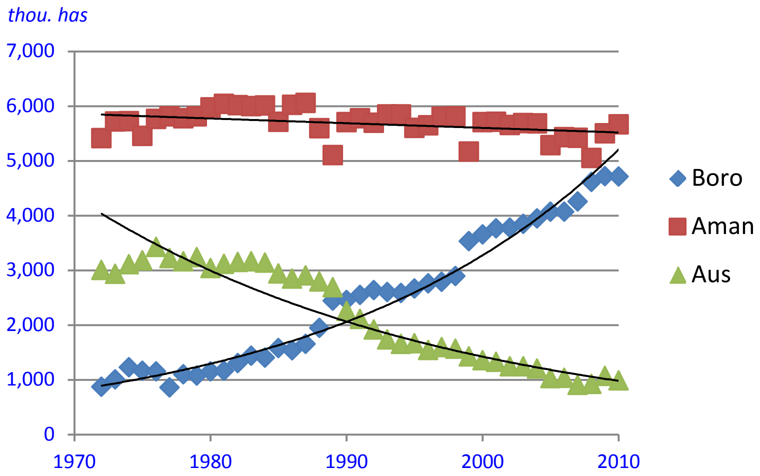

Figure 1.1. Bangladesh harvested rice area by season, 1970-2010.

Table 1.1. Fertilizer, pesticide, labor use, yield and area trends: Bangladesh.

	2000	2008	Annual growth rate (2000—2008)
		Aman	
Urea, kg/ha	126.13	130.14	0.46
Insecticide cost, 2005 PPP/ha	11.93	11.78	0.51
Labour, md/ha	124.55	107.93	-1.80
Irrigation cost, 2005 PPP/ha	4.29	5.16	6.00
Harvested area, 1000 has	5704.87	5048.16	-1.3
Yield, t/ha	1.81	1.91	0.5
		Boro	
Urea, kg/ha	234.62	234.79	-0.03
Insecticide cost, 2005 PPP/ha	31.69	23.79	-1.88
Labour, md/ha	141.64	129.97	-1.11
Irrigation cost, 2005 PPP/ha	273.23	302.11	1.26
Harvested area, 1000 has	3652	4608	2.5
Yield, t/ha	3.02	3.85	2.58

Source of input data: BIDS-IRRI 62 village panel database of Bangladesh
Source of area and yield data: Bangladesh Bureau of Statistics

1.5.2 Indonesia

Rice is the dominant crop in Indonesia, covering 30% of agricultural land with cultivation by 77% of farmers (USDA, 2012). It is the source of nearly 50% of caloric intake (Dodge and Gemessa, 2012). Indonesia is characterized by an intensive rice production situation with high levels of irrigation coverage, high levels of input use, high cropping intensity and little differentiation between wet and dry seasons in terms of productive potential or varietal adoption. Indonesia was one of the first tropical developing Asian countries to reach high levels of MV adoption in the early 1980s. Estudillo and Otsuka (2006) estimated that by 1985 about 93% of irrigated area is planted to MVs.

Although fertilizer use levels were already high in Indonesia by the early 1990s, due to substantial input subsidies, levels of fertilizer use have continued to grow over the following decades. However, insecticide use in terms of active ingredient quantities has fallen and irrigation coverage appears to be stagnant. Yields have grown about 0.8% annually over the period, while harvested area has grown 0.7%. However, much of the yield growth has occurred during the 2000s.

Table 1.2. Fertilizer, pesticide, irrigation, yield and area trends: Indonesia.

	1992	**2008**	**Annual growth rate (1992—2008)**
Physical area irrigated	66.7%	68.5%	0.17%
Urea, kg/ha	190	243	1.54%
DAP, kg/ha	110	92	-1.16%
Other fertilizer, kg/ha	27	52	4.21%
Insecticide, kg a.i./ha	1.96	1.42	-1.99%
Harvested area, 1000 has	11,103	12,327	0.66%
Yield, t/ha	4.35	4.89	0.75%

Source of input data: See section 2.3.4.3 of this paper

Source of area and yield data: Budan Pusat Statistik

1.5.3 Philippines

Rice is important in the Philippines, as the source of nearly 40% of caloric intake, and as a crop covering over 40% of harvested agricultural area (CountrySTAT Philippines, 2013). The Philippines is similar to Indonesia as an intensive rice production situation with high levels of irrigation coverage, early saturation of rice area with MVs in the 1970s, and little differentiation between the main production seasons in terms of yields or varietal adoption patterns. However, the levels of fertilizer and insecticide use are much lower, as nitrogen application rates in the late 2000s are 50% higher in Indonesia than the Philippines. This is largely due to the absence of fertilizer subsidies, which are present in Indonesia and Bangladesh. Yields are concomitantly lower than in Indonesia. However, the Philippines has the fastest growth rate of fertilizer use and overall yields among the countries in the study.

Table 1.3. Fertilizer, pesticide, labor use, irrigation, yield and area trends: Philippines.

	1996/7	2006/7	Annual growth rate (1996/7--2006/7), %
		Wet season	
Irrigation, % area	63.1%	70.1%	0.66
Nitrogen, kg/ha	63.80	86.55	3.28
Phosphorus, kg/ha	6.68	18.82	6.91
Potassium, kg/ha	9.40	30.63	7.23
Herbicide, kg a.i./ha	0.12	0.27	18.99
Pesticide, kg a.i./ha	0.20	0.35	3.82
Pre-harvest labour, md/ha	46.39	34.76	-2.56
Harvested area, 1000 has	2,285	2,390	1.22
Yield, t/ha	2.77	3.68	3.23
		Dry season	
Irrigation, % area	68.5%	79.3%	0.92
Nitrogen, kg/ha	57.97	83.48	4.17
Phosphorus, kg/ha	5.78	17.82	7.34
Potassium, kg/ha	7.85	14.87	5.47
Herbicide, kg a.i./ha	0.10	0.26	11.61
Pesticide, kg a.i./ha	0.15	0.25	3.19
Pre-harvest labour, md/ha	46.25	36.36	-2.25
Harvested area, 1000 has	1,624	1,804	1.48
Yield, t/ha	2.98	3.70	2.75

Source of input data: PRRI Rice-based farm household survey, 1996/7, 2001/2, 2006/7 rounds

Source of area and yield data: Bureau of Agricultural Statistics (BAS)

1.5.4 Focal traits

The analysis for Bangladesh focuses on the effects of specific dominant varieties, due to the varietal concentration in the Boro season, which is the only season with substantial adoption of post 1989 MVs. With such a small number of dominant varieties, decomposition of effects into individual traits for econometric analysis is not possible, because trait adoption becomes multi-collinear.

In Indonesia and the Philippines, this study focuses on five sets of traits introduced through modern varietal replacement: host plant resistance to Brown Planthopper, host plant resistance to Leaf and Neck Blast, host plant resistance to Bacterial Leaf Blight, host plant resistance to Rice Tungro Disease and attainable yield. Attainable yield is the major focus of most conventional rice breeding efforts, while the resistances included reflect the major pest and diseases for which genetic resistance has been successfully identified and incorporated in many varieties.

Brown Planthopper (BPH, Nilaparvata lugens) is an insect pest that inflicts damage to the rice crop by feeding at the base of rice tillers, causing plants to yellow and shrivel. The insect also acts as a vector for rice ragged stunt virus and rice grassy stunt virus. It attacks primarily in intensive irrigated systems during the dry season, and can cause extensive yield loss. Host plant resistance was initially incorporated in IR26 in 1973, but quickly broke down. More durable sources of resistance were first identified in the 1980s at IRRI and incorporated in subsequent varieties (Khush and Virk, 2005).

Blast, or rice blast fungus, (Magnaporthe grisea) is a plant pathogenic fungus, which causes lesions on plant leaves and nodes. Infestation is more common during the wet season, and is often associated with more stressed environments. The use of blast nurseries at IRRI and in national institutes allows for screening for resistance from the F2 generation during the breeding process, based on polygenic resistance (Khush and Virk, 2005).

Bacterial Leaf Blight (BLB, Xanthomonas oryzae) is a proteobacterium that causes wilting and rolling of leaves after infestation. It more commonly infests during the wet season, when humidity is higher. A single source of BLB resistance was incorporated in the IR varieties from the 1970s through the 1980s, and was considered to give durable partial resistance. As of the mid 2000s, IRRI had identified 20 genetic loci associated with BLB resistance (Khush and Virk, 2005).

Tungro, or Rice Tungro Disease is actually composed of two viruses, rice tungro bacilliform virus (RTBV) and rice tungro spherical virus, transmitted by the Green Leafhopper vector. It is especially prevalent in the Philippines. Tungro infestation causes stunting and reduced numbers of tillers. Tungro resistance was an explicit emphasis of the IR breeding program, where incorporated resistances were primarily to the Green Leafhopper vector. In the 1990s, genetic sources of direct resistance to the virus were identified (Khush and Virk, 2005).

A proxy for genetically defined attainable yield is the yield identified during the process of varietal release. Within each country there exists a national body that coordinates a multiple year and multi-site process of varietal evaluation under trial conditions. Varieties that exceed the yield of a check variety, which reflects the contemporary best performing variety available to farmers, by a threshold amount, and which contain certain levels of host plant resistance can be nominated and selected for “release”. This “release” is an official designation which allows government agencies to produce the seed for official sale to farmers. The trials that underpin the release process are conducted under controlled conditions, but are expected to be reflective of farm level yields. The average yield of the released varieties across years of testing and locations is recorded as its release yield. Provided that check varieties are updated, release yields should be increasing over time based on the nature of the release process, but the rate of increase will depend upon the rate of genetic gain.

During the release process, varieties are subjected to standard screening procedures for resistance to specific pests and diseases, and a rating is accorded for the resistance of the variety. These standard procedures are consistently applied for the host plant resistances investigated in this study. During the varietal development process, standard screening procedures have also been incorporated to ensure some level of resistance to these pathogens, as well. However, there are physiological tradeoffs among traits, so not all resistances may be present in all released varieties.

Initially, this study also intended to assess the effects of drought and flood tolerance. However, this was not feasible to include, as a result of the nature of how the traits are embodied and adopted. In the case of drought tolerance, there is strong correlation between release yield and presence of the trait for popular varieties. As a result, the effects of drought tolerance are difficult to separate in the absence of precise data on drought exposure. In the case of flood tolerance, adoption rates are very low during the periods for which data are available (<1%), so that there is little ability to assess impact.

2. Methodology

The present study takes a multi-stage approach to identify the diffusion of new varieties and traits, estimate their yield effects, translate this into yield shocks, and model the welfare implications of yield shocks for different groups, with special emphasis on the poor and food insecure in Bangladesh, Indonesia and the Philippines. The first step is characterization of progress in the outputs of genetic improvement process – varieties, taking into account that some traits of varieties, such as resistances, are changing over time (Element 1). Next, varietal adoption data are assembled from primary and secondary data sources over space and time, and are used to identify the diffusion of traits attributable to new varieties and IRRI contributions to those varieties (Element 2). After this, econometric methods that address deficiencies of prior approaches are used to identify the effects of trait and varietal diffusion (Element 3). This is accompanied by a bio-economic modeling approach to identify the yield effects of one host plant resistance for which the econometric method cannot estimate a significant coefficient (Element 4). Finally the econometric and bioeconomic results are subsequently used with the diffusion data to estimate supply shocks, which are modeled in a new partial equilibrium framework to identify welfare and distributional impacts (Element 5).
Study Elements:

1. Varietal characterization
2. Quantification of adoption
3. Econometric identification of yield effects
4. Bio-economic modeling of host plant resistance effects
5. Partial equilibrium welfare modeling

2.1 Varietal characterization

Varietal release lists have been compiled from the national rice research institutes of each respective country. Each varietal release list includes year of release, basic varietal characteristics, such as release yield, resistance scores for major pests and diseases (blast, bacterial leaf blight, tungro, sheath blight, and brown planthopper), designated target ecologies and parental lines. Abiotic stress tolerances are indirectly characterized by reference to stresses in target environments.

Basic trends and patterns in research productivity and research contributions were compiled to contextualize the analysis. To understand whether release yields are comparable over time (and accurately reflect genetic gain), detailed records of varietal release yields have been obtained for popular mega-varieties.

To supplement this information, expert consultations were held in each of the covered countries. A major focus of these consultations was to reflect the current effectiveness of host plant resistances, as resistances may become ineffective as pest and pathogen populations adapt in response to selection pressures imparted by resistance. The consultations characterized the most popular varieties in each country over the period from 1990 to the present.

The consultations included 20 to 50 experts per country from a range of disciplines, institutions and areas of expertise, including extension staff, breeders, pathologists and entomologists. In Bangladesh, three consultations were held regionally before a national consultation, whereas in Indonesia and the Philippines national consultations were held. In each consultation, resistances from the varietal release lists were reviewed and augmented by expert opinion and the results of other trials to provide an enhanced appraisal of each resistance at release. Subsequently, the current status of each host plant resistance for each popular variety was appraised, and the basis for appraisal of current status was noted. In the cases where the current status of resistance is lower than at varietal release, the approximate date of resistance change was also elicited. In the cases of Bangladesh and the Philippines, subnationally disaggregated resistance characterization was performed to reflect differences in resistance performance in regions within the countries. In Indonesia, resistance was nationally characterized, as most rice cultivation environments within the country are relatively favorable and homogenous. In addition, varieties were systematically explicitly characterized in terms of tolerance to drought, flooding, salinity and cold stress.

2.2 Quantification of adoption

2.2.1 Bangladesh

In the case of Bangladesh, an array of data sets is used for characterizing varietal effects and adoption. For varietal effects, as described in section 2.3.4.1, a nationwide survey conducted in collaboration with the Bangladesh Institute of Development Studies every four years from 2000 through 2008 and covering 2000 households in 62 villages is used, with one village included per district. While these data are sufficient for identifying representative “treatment effects” when varieties are adopted, a single village is not sufficient to represent adoption patterns over an entire district, which contains thousands of villages. Thus, alternative larger survey datasets were used to characterize adoption at the Division level for the two dominant Boro season varieties – BRRI dhan 28 and BRRI dhan 29. These adoption estimates are used in bio-economic modeling and in calculation of supply shifts based on varietal effects, but are not part of the econometric analysis of varietal effects.

Adoption data for the Boro Season have been generated on the basis of a 14000 household, 600 block, 1800 village, survey conducted in 2004-2005 by the Bangladesh Department of Agricultural Extension in collaboration with IRRI (described in Hossain et al., 2012) and a Bangladesh Integrated Household Survey of 6000 households 325 blocks, and 325 villages conducted in 2010-2011 by IFPRI (described in Ahmed et al., 2013). To create a comparable time-series, only observations for the 230 shared blocks between the two surveys were retained (representing 5400 households for 2004-2005 and 4000 households in 2010-2011), and were aggregated to Division level adoption statistics for the two time periods. A third set of 1994 values has been generated based on the 1994 release year for the two varieties, in which adoption is assumed to be zero for all divisions.

Based on the three years of adoption parameters (1994, 2004-05 and 2010-11) per division, annual varietal adoption values for 1994-2011 are interpolated. Where each successive observation represents a higher level of adoption than the previous, a Gompertz asymmetric sigmoidal adoption curve has been fit to the data (Eqs. 2.-1 and 2-2). It has been observed that the Gompertz function can better describe many agricultural adoption process, compared with the typically used logistic curve (Binet and Richefort, 2010).

$$a(t) = \alpha_1 e^{\alpha_2^{e^{\alpha_3 t}}}$$

Equation 2-1

Alternatively this is specified as:

$$a(t) = \alpha_1 * \exp(\alpha_2 * \exp(\alpha_3 * t))$$

Equation 2-2

Where a(t) is the adoption rate; $\alpha_1 > 0$ is the upper asymptote, α_2 and α_3 are negative growth parameters; and t is time (year).

In the Divisions for which adoption peaks in 2004-05, a quadratic curve is fit between the individual observations (Eq. 2-3.).

$$\boldsymbol{a(t) = \alpha_0 + \alpha_1 t + \alpha_2 t^2}$$

Equation 2-3

2.2.2 Philippines

Adoption data by province have been generated for 1991/92, 1996/96, 2001/02, 2006/07, and 2011/12, based on a 2500 household Rice-Based Farm Household Survey (RBFHS) conducted every five years by the Socioeconomics Division (SED) of PhilRice. For each survey round, both wet and dry seasons are covered.

The 1992-93 round covered 15 major rice-producing provinces comprising around 50% of the country’s total rice area, while the 1996-97 covered 30 provinces, and the subsequent 2001-02, 2006-07, and 2011-12 surveys covered 33 provinces. The province served as sample frame and all barangays in the province served as sampling population. This study used a two-stage sampling selection. The first stage is the barangay, selected by using systematic random sampling, and the second stage unit is the rice farm household. The percentage distribution of respondents by specific variety planted, and share to total area planted by variety were used to describe the recent diffusion adoption of specific rice varieties.

Provincial areas of varietal adoption between the years of sampling have been estimated for the top 60 varieties in the period using cubic spline interpolation over time. This interpolation method was chosen because it provides a smooth adoption curve without imposing assumptions regarding the functional form of adoption progression. While sigmoidal curve assumptions are probably appropriate for slow continuous adoption processes such as have been observed in Bangladesh, the rapid and diverse turnover of varieties in the Philippines suggests that more flexibility in functional forms is needed.

Under cubic spline interpolation, given an adoption function a(t) defined over time (year) t_i for i=1, … , n, a set of observable data points such as year and the corresponding adoption rates are identified $[t_i, a_i]$. In years where adoption data is absent, two adoption data points defining an interval or a segment enable the absent data to be spline interpolated. The cubic spline interpolation is a piecewise continuous curve passing through each point of an interval. Splines are as many as the intervals in the function a(t). By definition, splines[1], S(t), are cubic polynomials with unique coefficients estimated for each interval (Eq. 2-4):

$$S_i(t) = \alpha_0 + \alpha_1(t - t_i) + \alpha_2(t - t_i)^2 + \alpha_3(t - t_i)^3 \ldots .for\ x \in [t_i, t_{i+1}]$$

Equation 2-4

2.2.3 Indonesia

Varietal adoption data have been obtained from the Seed Directorate (Direktorat Perbenihan) of the Ministry of Agriculture. These data are available by province and season annually for 1976-2011, with the exception of 1998 and 1999. The basis of these estimates is a village level agricultural planning process entitled "the Definitive Plan for Group Needs" (Rencana Definitif Kebutuhan Kelompok) in which farmers declare varieties to be cultivated, areas to be cultivated and input needs. Farmer participation is mandatory for eligibility to receive subsidized inputs, and the stated plans form the basis for seed distribution planning. Within Indonesia, 23 provinces are covered by these data, with more limited temporal coverage for recently created provinces. To add coverage for 1998 and 1999, cubic spline interpolation has been performed to estimate varietal area by variety in each province during the missing years, as described for the Philippines. For supply shift estimation area data on the top 20 varieties were used, which collectively cover 93% of paddy area over the period.

2.3 Econometric identification of yield effects

2.3.1 Approach to causal inference

Traditional methods used to identify the effects of the adoption of modern varieties may conflate confounding factors with varietal impacts. Index of Varietal Improvement approaches may conflate changes in factors that condition or covary with varietal adoption, such as irrigation, with the consequences of adoption, and assume an implicit release yield elasticity of 1 to actual farm yield, without empirical substantiation. Such an assumption of similarity of between experimental and actual effects is unlikely to be reliable (de Janvry et al., 2010). Similarly, pooled ordinary least squares regressions with varietal characteristics as independent variables may be susceptible to selection bias, as more progressive or better endowed farmers or regions may be more likely to adopt better varieties. As a result, the effects of differences in these characteristics may be conflated with the consequences of adoption.

The approach used here to identify varietal effects on yields and unit production costs consists of a series of fixed effects models, which often better control for selection bias. In principle, the use of a fixed effects model is similar to a "differences in differences" approach, while allowing for continuous variables for "treatment". This essentially means that changes in the dependent variable are regressed on changes in the independent variables, including the independent variable of interest, to identify "treatment effects".

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[1] See http://banach.millersville.edu/~BobBuchanan/math375/CubicSpline/main.pdf and http://www.physics.utah.edu/~detar/phys6720/handouts/cubic_spline/cubic_spline/node1.html for easier reference.

Fixed effects models allow for time-invariant characteristics to be eliminated from the estimated effects of independent variables of interest (Wooldridge, 2002). This is important because many determinants of varietal adoption that also may determine productivity are likely to be relatively static over time while varying over space. Thus, fixed effects models allow for elimination of "fixed" time invariant factors that may be confounded with varietal improvement impacts, so as to obtain productivity effect estimates that are less subject to selection bias.

The panel unit varies according to data availability among the countries, while independent variables for input use depend upon the significance of the model results and coefficients for individual parameters. In this analysis, the fixed effects models are specified in Cobb-Douglas form, with log transformations applied both to the dependent variable (yield) and major independent variables. All regressions have been performed such that heteroskedasticity-consistent standard errors are reported.

2.3.2 Genetic yield gain

Genetic yield impacts are estimated directly by specifying a Cobb Douglas functional form within a fixed effects model (Eq. 2-5).

$$\ln(y) = \sum_{j=1}^{J} \beta_j \ln(x_j) + \sum_{i}^{n-1} \alpha_i D_i + e. \qquad \textbf{Equation 2-5}$$

The outcome variable, paddy yield, is natural log transformed.

There are two terms on the right hand side. The first term is the regular Cobb Douglas specification of inputs—the natural log of each continuous variable input, x_j, j=1, 2, ⋯, k. The coefficient β_j is output elasticity; this is interpreted as the percent increase in paddy yield per 1% increase in x_j. It is rather usual for x_j to have binary values of either 0 or 1 instead of being continuous; in which case, log transformation cannot be done. In such a case, the coefficient β_j measures percent increase/decrease in paddy yield when the value of x-dummy equals 1.

The second term is the fixed effects component which uses a set of dummy D to control for unobservable time-invariant heterogeneity which would have biased estimates of β_j had these been not explicitly included in the model. Possible sources of heterogeneity are unobserved farmer and location characteristics.

2.3.2.1 Bangladesh

The study initially intended to use a trait based approach to assess varietal improvement impacts in Bangladesh. However, Boro season adoption is heavily concentrated on two varieties – BRRI dhan 28 and BRRI dhan 29, so that the effects of other varieties are more minor. Furthermore, the IRRI 62 village survey sampling design is based on population, so it has greater representation of Dhaka and other regions in which BRRI dhan 28 and 29 adoption is even more concentrated, so that 80% of 2008 Boro season observations are of these two varieties. Given that many varieties make up the remaining 20%, there are not sufficient observations to draw conclusions about other varieties, and from the two dominant varieties, there is not enough trait variation to draw conclusions about traits. For this reason, the approach in Bangladesh relies on the varieties directly as independent variables, rather than traits, as in the other countries.

The regression approach applied is to include dummy variables for the dominant varieties—BRRI dhan 28 and BRRI dhan 29. Damage dummies for pest, flood, drought, hail, and other sources are also included in the model. The source of fixed effects is farm-household, as panel household observations are available for the regression.

$$\begin{aligned}\ln(y) = {} & \beta_0 + \beta_1 \ln(fertilizer) + \beta_2(BRRI\ dhan\ 28 dummy) + \beta_3(BRRI\ dhan\ 29\ dummy) \\ & + \beta_4(pest\ damage\ dummy) + \beta_5(flood\ damage\ dummy) \\ & + \beta_6(drought\ damage\ dummy) + \beta_7(hail\ damage\ dummy) \\ & + \beta_8(other\ damage\ dummy) + \beta_9(irrigation\ dummy) + \sum\nolimits_i^{n-1} \alpha_i D_i + e.\end{aligned}$$

Equation 2-6

2.3.2.2 Indonesia

To evaluate the genetic yield trait effect of adopted varieties, a measure of yield potential is expressed in terms of weighted attainable yield—this is done by multiplying the attainable yield potential of adopted varieties by the proportion of area adoption. Other inputs specified to explain variation in paddy yield are fertilizer (kg urea/ha), irrigation (proportion of area irrigated), dry harvested area (proportion of dry season area to total rice area), flooding (proportion of area damaged by flood), and drought (proportion of area damaged by drought). The province is the panel variable for location fixed effects.

$$\begin{aligned}\ln(y) = {} & \beta_0 + \beta_1\ ln(yield\ trait) + \beta_2 ln(fertilizer) + \beta_3\ ln(irrigation) \\ & + \beta_4\ ln(dry\ harvested\ area) + \beta_5\ (flood) + \beta_6\ (drought) \\ & + \sum\nolimits_i^{n-1} \alpha_i D_i + e.\end{aligned}$$

Equation 2-7

2.3.2.3 Philippines

The model for the Philippines is the same as Indonesia in terms of varietal yield trait, irrigation, drought, and flood. The three variables specified differently are—fertilizer (kg N/ha), certified seed (proportion of area planted to certified seeds), and farm size (ha). Municipality is the panel variable for location fixed effects over three rounds of observations. The regressions are run separately for the dry and wet seasons, as all observations for all variables are available by season (Eq. 2-8).

$$\ln(y) = \beta_0 + \beta_1 \ln(yield\ trait) + \beta_2\ ln(fertilizer) + \beta_3\ ln(irrigation) + \beta_4\ ln(certified\ seed) + \beta_5\ ln(farm\ size) + \beta_6(drought) + \beta_7(flood) + \sum_i^{n-1} \alpha_i D_i + e.$$

Equation 2-8

2.3.3 Rice varietal pest resistance trait effects

In the prevailing production function estimation approaches employed prior to the mid 1980s, all production factors including inputs to reduce biotic yield losses, as well as inputs to increase productive potential, are treated symmetrically, and are thus assumed to contributed to production in the same manner. However, Lichtenberg and Zilberman (1986) suggested that this is not appropriate as a functional form, as productive inputs define productive potential, while damage abating inputs mitigate loss of that productive potential and thereby only indirectly contribute to yield. They proposed a “damage abatement” framework with asymmetrical treatment of productive and damage abating inputs, which has become the accepted modeling approach for assessing the effects of crop protection inputs (e.g. Qaim & Zilberman, 2003; Shankar & Thirtle, 2005; Mutuc et al., 2011, de Mey et al., 2012).

In this framework, “damage abating” inputs are modeled in a function that multiplicatively scales the production function, so as to represent the proportion of productive potential retained after abatement. Crop growth is modeled by f(x,β), which is continuous and twice-differentiable in x. HPR traits along with sister inputs, herbicides and insecticides, are modeled by a damage abatement specification of g(z,γ,δ) which is characteristically a cumulative distribution that generates values within the interval [0,1]. It is assumed that x and z are weakly separable so that their marginal productivities are independent of each other (Eq. 2-9).

$$y = f(x, \beta) * g(z, \gamma, \delta).$$

Equation 2-9

The first term is the production or attainable yield[2] in the absence of damage which is specified in this study in Cobb-Douglas form (Eq. 2-10).

$$\ln(y) = \sum_{j=1}^{J} \beta_j \ln(x_j).$$

Equation 2-10

The dependent variable, y, is paddy yield and the growth stimulating inputs, x, that directly affect yield are fertilizer, irrigation, and certified seeds. To net out the adverse effects of abiotic stresses on yield, drought and flooding indicators were also specified. This is similar

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[2] Potential yield as defined in rice literature pertains to the genetic potential of a variety under the best environment (absence of abiotic and biotic stresses) and management (no input is limiting) conditions. Attainable yield is second best to potential where abiotic stresses impose a limit to the genetic potential. Actual yield runs third best where yield is constrained by nonnegative prices and presence of biotic stresses such as pests and diseases.

in principle to using the production function to estimate what is termed abiotic “limited yield” in the production ecology literature, from which “yield reductions” occur, due to biotic stresses (Van Ittersum and Rabbinge, 1997). Time is added to the production function to capture the effects of exogenous technological progress, including improvements in the release yield of adopted varieties, which is multi-collinear with year. The second term is the damage abatement component which gives the proportion of biotic damage and damage abated by an otherwise special set of inputs Z. This is specified in two (of many possible[3]) ways for Indonesia and the Philippines.

The specifications for the two countries differ, as a result of differing information availability. In most of the damage abatement literature, pest pressure is unobserved, and is not incorporated as an exogenous variable in the abatement specification. For Indonesia, where pest pressure information is available, the abatement specification that allows adding a biotic dummy, b, is adapted from a framework first proposed by Feder (1979) to assess the effects of insecticide use (Eq. 2-11).

$$g(z,\gamma,\delta) = \left\{exp\left[\delta b\left(1 - \sum\nolimits_{k=1}^{K} \gamma_k\, z_k\right)\right]\right\}^{-1}.$$

Equation 2-11

$$where{:}\ 0\ \le \delta\ \le 1;\ b = (0{,}1);\ and\ \delta d\ \le\ \sum\nolimits_{k=1}^{K} \gamma_k z_k.$$

In the damage abatement specification above the dummy variable, *d* serves as a switch that turns off the damage abatement function in the absence of pest pressure. When d=0 then production is equal to attainable yield (even though z is nonzero[4]). Where pest pressure is present and abatement inputs are not used, the proportionate yield loss without abatement or instituting control is given by δ. Damage abatement inputs are k-dimensional and given by z_{kit}; in this study, these inputs include pesticides and rice varietal resistance traits. In the presence of pest, input k proportionately reduces damage inflicted by γ_k.

The model for Indonesia becomes (Eq. 2-12):

$$\ln(\mathrm{y}) = \sum\nolimits_{j=1}^{J} \beta_j \ln(x_j) - \delta b\left(1 - \sum\nolimits_{k=1}^{K} \gamma_k\, z_k\right) + e.$$

Equation 2-12

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[3] Results of damage abatement models are sensitive to their specification. Of the four specifications suggested by Lichtenberg and Zilberman (1986) the three most popularly used are Exponential, Weibull, and Logistic distributions. Examples of empirical applications to rice are found in Huang et al. (2003) for logistic and de Mey et al. (2011) for Weibull.

[4] It is easy to conceive farmers choosing plant varieties with resistance to a particular pest and where pest population remained low and posed no threat or yield loss even in the absence of such HPR trait. The marginal product of that trait is zero.

Under this specification, the marginal effect z_k on y is (Eq. 2-13)

$$\frac{\partial y}{\partial z_k} = \exp\left[\sum_{j=1}^{J} \beta_j \ln(x_j)\right] * \frac{\gamma_k \delta b * \exp[(\delta b) * (1 - \sum_{k=1}^{K} \gamma_k z_k)]}{\{\exp[(\delta b) * (1 - \sum_{k=1}^{K} \gamma_k z_k)\}^2}.$$

Equation 2-13

Note that in the above equation (Eq. 2-14):

Equation 2-14

$$y = X^{\beta} = \exp\left[\sum_{j=1}^{J} \beta_j \ln(x_j)\right].$$

In the case of two interacting damage abatement inputs, z_k and z_l such as insecticides and BPH trait in this study, the marginal effect is (Eq. 2-15):

$$\frac{\partial y}{\partial z_k} = \exp\left[\sum_{j=1}^{J} \beta_j \ln(x_j)\right] * \frac{(\gamma_k + \gamma_{kl} z_l) \delta b * \exp[(\delta b) * (1 - \sum_{k=1}^{K} \gamma_k z_k)]}{\{\exp[(\delta b) * (1 - \sum_{k=1}^{K} \gamma_k z_k)\}^2}.$$

Equation 2-15

The ability to apply this framework is contingent upon having a variable that can accurately capture the presence of pest pressure abated by input *k.* While such data are available for Indonesia (under the assumption that abatement measures are partial such that the presence of a low threshold level of damage after abatement correlates with a threshold level of pressure in the absence of abatement), based on provincial annual statistics on damage by individual pests and diseases, similar data are not available for the Philippines.

In the absence of pest pressure information, other functional forms are used in the damage abatement literature, with logistic functional forms observed as offering flexibility and plausible results (e.g. Quaim and Zilbermann, 2003). Among common damage abatement models applied without pest pressure data, only the logistic model includes an internal intercept, which accounts for the proportion of yield that can be retained in the absence of the included abatement inputs (Fox and Weersink, 1995). Other models are formed under a framework in which the damage abatement function scales productivity to 0 in the absence of abatement, which may lead to the overestimation of abatement effects when damage will only be partial when not abated. Given that many agronomic operations (such as tillage) and inputs (such as flood irrigation) are both growth stimulating and damage abating, partial damage in the absence of inputs that only serve a damage abatement function is more likely than total damage. Thus, a logistic damage abatement function is applied for the Philippines (Eq. 2-16; Lichtenberg and Zilbermann, 1986):

$$g(z,\gamma,\mu) = [\,1 + \exp\left(\mu\ - \sum\nolimits_{k=1}^{K} \gamma_k\, z_k\ \right)]^{-1}.$$

Equation 2-16

The model for the Philippines becomes (Eq. 2-17):

$$\ln(y) = \sum\nolimits_{j=1}^{J} \beta_j \ln\left(x_j\right)\ + \ln\,[\,1 + \exp\left(\mu\ - \sum\nolimits_{k=1}^{K} \gamma_k\, z_k\ \right)]^{-1}\ + e.$$

Equation 2-17

The marginal effect of damage abatement input, $z_{k,}$ on y is (Eq. 2-18):

$$\frac{\partial y}{\partial z_k} = \exp\left[\sum\nolimits_{j=1}^{J} \beta_j \ln\left(x_j\right)\right] * \frac{\gamma_k[\exp(\mu - \sum_{k=1}^{K} \gamma_k\, z_k)]}{[1 + \exp(\mu - \sum_{k=1}^{K} \gamma_k\, z_k)]^2}.$$

Equation 2-18

In the case of two interacting damage abatement inputs, z_k and z_l, the marginal effect is (Eq. 2-19):

$$\frac{\partial y}{\partial z_k} = \exp\left[\sum\nolimits_{j=1}^{J} \beta_j \ln\left(x_j\right)\right] * \frac{(\gamma_k + \gamma_{kl} z_l) * [\exp(\mu - \sum_{k=1}^{K} \gamma_k\, z_k)]}{[1 + \exp(\mu - \sum_{k=1}^{K} \gamma_k\, z_k)]^2}.$$

Equation 2-19

Note that the second term above is the *pseudo elasticity* of damage abatement input since it measures the damage abated as a proportion of output, y, per one unit increase in the damage input z_k.

For the damage abatement models, locational fixed effects are included through a least squares dummy variable approach, since within panel demeaning does not eliminate fixed effects from non-linear models. In the case of the Philippines dummies, D_i, were created for municipalities and for Indonesia, provinces. To make the model approximate a full two-way fixed effects approach, year is included as a variable in the production function. Because year is covariant with the average release yield of adopted varieties, this means that release yield cannot be included in the production function with the damage abatement model. The estimating models after incorporating the location dummy variables for Indonesia and the Philippines become as specified by Eq. 2-20 for Indonesia and Eq. 2-21 for the Philippines:

$$\ln(\mathrm{y}) = \sum\nolimits_{j=1}^{J} \beta_j \ln\left(x_j\right) - \delta b\left(\,1 - \sum\nolimits_{k=1}^{K} \gamma_k\, z_k\,\right) + \sum\nolimits_{i}^{n-1} \alpha_i D_i + e.$$

Equation 2-20

$$\ln(y) = \sum_{j=1}^{J} \beta_j \ln(x_j) + \ln\left[1 + \exp\left(\mu - \sum_{k=1}^{K} \gamma_k z_k\right)\right]^{-1} + \sum_{i}^{n-1} \alpha_i D_i + e. \qquad \text{Equation 2-21}$$

2.3.4 Data sources for econometric models

2.3.4.1 Bangladesh

The fixed effects production function for Bangladesh is specified on the basis of household level observations from a 62 village panel survey carried about by the Bangladesh Institute of Development Studies (BIDS), the Bangladesh Rice Research Institute (BRRI) and IRRI during 1987, 2000, 2004 and 2008, but only the 2000, 2004 and 2008 observations were utilized in this study, since the 1987 survey round did not collect data by season. The original survey sampling was performed by randomly sampling unions/blocks from a comprehensive list for the country reported in the 1981 Population Census. For all villages in the selected unions, the number of households, land area, total population and literacy rates were compiled. One village was selected per union which had between 100 and 250 households, literacy rates closest to the union median and land to population ratios closest to the union median. . Thus, the sampling is more based on population characteristics than agricultural or rice system characteristics.

In each village approximately 20 households were randomly selected in the initial round, to which another 10 randomly selected households were added in the 2000 round. The same households were included in successive rounds where possible, and were replaced when successive inclusion was not possible, so that approximately 1900-2000 households were surveyed per utilized survey round. To make use of the fixed effects model, only households with multiple rounds of observations were included in the data pool for the econometric analysis.

Of the surveyed households, only a subset cultivated rice and were surveyed on cultivation characteristics. The household survey for the utilized rounds includes separate input output data for each production season (where production occurs) for each household. Only Boro season observations were utilized, as this is the only season in which substantial post 1989 varietal adoption has occurred, and Boro season observations are a minority of the rice observations. The collected input output data for Boro rice includes household characteristics, variety, area, production, yield, chemical inputs, irrigation, labor, and perceived crop damage.

2.3.4.2 Data sources for the Philippines

In the Philippines, regressions are based on observations from the 1996/96, 2001/02 and 2006/07 rounds of 2500 household Rice-Based Farm Household Survey (RBFHS) conducted every five years by the Socioeconomics Division (SED) of PhilRice (surveys described previously). The 1991/92 round was not utilized, due to differences in sampling, while the complete data from the 2011/12 round were not yet available that the time of analysis.

Although sampling in the survey was repeated in the same municipalities and provinces for each successive round, only a minority of individual households is shared across rounds, and in some cases, villages were replaced. To use the data in a fixed effects approach, panel observations are needed. To translate these observations into quasi-panel data, municipal means of observations were utilized rather than household observations. To ensure that the same villages are represented across rounds, only municipal means that included a minimum number of observations, and which did not differ substantially in the number of observations across rounds were included in the data pool for regressions.

The survey data include separate observations for wet and dry seasons, and contain information on varietal adoption, area, production, yield, certified seed, chemical inputs, irrigation, labor, and perceived crop damage due to flooding and drought. With the use of municipal means categorical household variables are translated into proportions.

Municipal proportions of areas under varieties are translated into proportions of areas under resistance based on the resistance status of the variety in the location and year, as identified in the release list and further characterized in the expert consultations. The areas of varieties are also used with the average release yields of varieties as indicated in national varietal release lists to calculated weighted average varietal release yields per municipality and year.

2.3.4.3 Data sources for Indonesia

In Indonesia, nationally representative primary household panel data for rice producing households are unavailable. However, detailed secondary data are available at the provincial level, which enable implementation of the regression approach described.

Annual provincial data were sourced from the Badan Pusat Statistik for area, yield, proportion of physical area irrigated and dry season proportion of harvested area. Annual provincial data on area under specific varieties were sourced from the Seed Directorate (Direktorat Perbenihan) of the Ministry of Agriculture. Data on fertilizer and pesticide use by province were sourced from regular surveys of the “Cost Structure of Paddy and Secondary Food Crops” published by the BPS. Given that these are not conducted annually, linear time series interpolation was performed to fill missing values. Annual provincial data on crop area damaged and destroyed due to flooding, drought, and pests and diseases were sourced from the Directorate of Food Crop Protection.

To generate the pest damage dummy variable, yield loss was approximated by taking half the annual area reported damaged by tungro, BLB, blast and BPH by the Directorate of Food Crop Protection, adding it to the area reported destroyed, and dividing this by the harvested area for the province and year. When this value exceeded .03 (approximately the mean value), the dummy variable was set to 1, otherwise it was 0.

2.4 Bio-economic modeling of host plant resistance effects

When estimating the yield effects of damage abatement inputs, such as host plant resistance, econometric approaches are vulnerable to simultaneity bias, because damage abatement adoption may be conditioned by pest pressure, an unobserved variable that also affects yields. The usage of a fixed effects approach helps to mitigate this potential problem by eliminating selection effects that are time invariant. Thus, abatement actions for pest problems represented by locationally and temporally fixed “hotspots” are freed from this source of bias. However, if pest pressure is time and location variant, and pest pressure conditions abatement responses, simultaneity bias cannot be fully eliminated through fixed effects methods. The general consequence of such bias will be to cause resistance effects to be underestimated, because the negative yield effects of unobserved pest/disease pressure will be correlated and conflated with the positive effects of abatement actions. To address this potential econometric deficiency, bio-economic modeling approaches were applied to bacterial leaf blight resistance, which did not return significant results econometrically.

Two models were linked to predict the effects of varietal resistance on yield savings due to reduced disease – EPIRICE, which models the disease severity expected under a set of growing conditions and RICEPEST, which models the yield effects expected from the disease severity predicted by EPIRICE. Both models are applied in a Geographic Information System (GIS) allowing for spatial mapping and analysis of the data. By combining the two models, the effects of BLB on yields for the Philippines and Indonesia were estimated for the individual diseases, incorporating the effect of weather on crop and disease development. Both models historical use weather data observations from the same data source, ensuring that they coincide with each other spatially and temporally (Fig. 2.1).

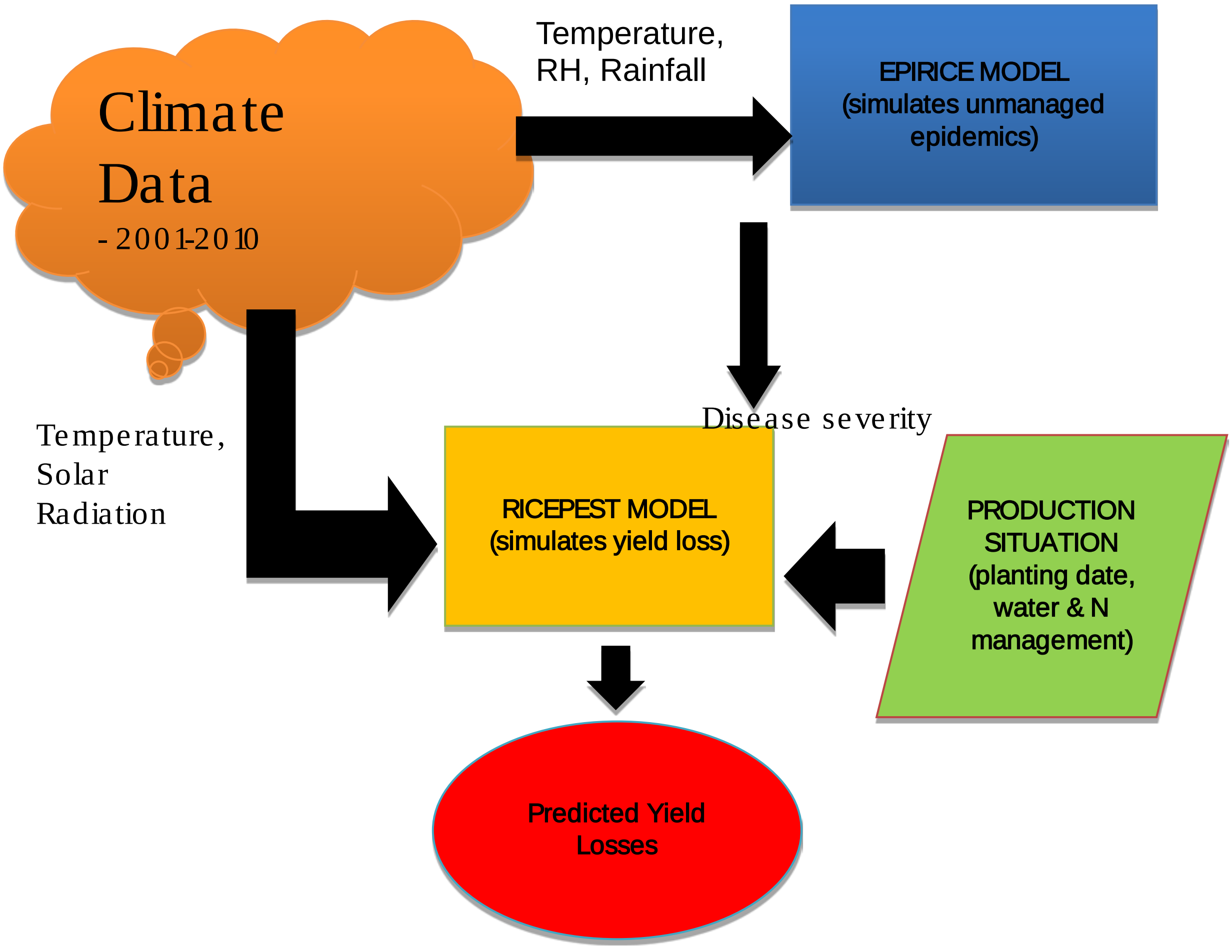

Figure 2.1. An overview of the coupled models and input data (C. Duku, AfricaRice Center).

2.4.1 EPIRICE Model

EPIRICE is a generic statistical model that simulates potential unmanaged epidemics in a susceptible variety for five diseases, including leaf blast and bacterial leaf blight (Savary et al., 2012). The system considered is 1m^2 of a rice crop stand with epidemics being simulated over a 120-day duration using a daily time step, corresponding to the RICEPEST simulation. In order to generate daily percentage values of disease severity for use in RICEPEST a disaggregation function was incorporated into the original EPIRICE model. With this function, the EPIRICE model produced daily representative and non-cumulative percentage disease severity data. Inputs to the model are daily precipitation, minimum and maximum temperature and relative humidity.

The EPIRICE model was run, generating disease severity for a susceptible variety. These data were then used to generate severity values for a resistant variety by assuming resistance would decrease disease severity by at least 90% (Willocquet et al., 2004) in the selected RICEPEST Generic Production Situation (GPS)).

2.4.2 RICEPEST Model

The RICEPEST model step (Willocquet et al., 1998, 1999a, 1999b, 2000, 2002 and Zhu et al., 2001) is a simple mechanistic crop growth model that simulates rice yield losses due to bacterial leaf blight and leaf blast (as well as other rice pests and diseases) that has been validated under a range of specified production situations and with multi-site validation involving several data sets (Willocquet et al., 1998, 1999a, 1999b, 2000, 2002 and Zhu et al., 2001). It runs on a daily time-step with simulation beginning 14 days after crop establishment, in this case, 14 days after transplanting. The system considered is 1m2 of a rice crop stand with the growing season being simulated over a 120-day duration.

2.4.3 Data sources and parameterization

2.4.3.1 Growing seasons and production situation

The weather for the primary rice-growing season was selected from a database of weather data using a raster file of planting dates indicating the commencement of the primary growing season (i.e. the season with the greatest area identified for a given geographic locale; Cuerdo et al. 2013). The production situation, i.e., the farmers' practices used when growing a crop, directly affect the intensity of yield reduction for a given injury profile (Savary et al., 1997, 2000a, 2000b and Willocquet et al., 2000, 2002). For this study, production situation is defined as the combination of socioeconomic, environmental and biophysical factors excluding pests that define the attainab1e yield and was characterized using the following parameters; rice cultivar, crop establishment type, fertilizer input or nitrogen management and water management. Because the countries of interest were the Philippines and Indonesia, GPS1 was chosen as it represents the predominant system of irrigated rice-rice production in South East Asia (Willocquet et al., 2002) with high fertilizer input and good water management.

2.4.3.2 Weather Data

Daily weather data observations from an improved and downscaled set of weather data (Sparks unpublished) based upon NASA/POWER (Chandler et al., 2004) and the Tropical Rainfall Measuring Mission (TRMM) data were used in these models. Daily maximum temperature, minimum temperature and relative humidity, from NASA/POWER, with daily precipitation, from TRMM, were used in EPIRICE to generate daily disease severity values to be used in RICEPEST. The corresponding bias-corrected average daily temperature and solar radiation values from the downscaled NASA/POWER dataset were used in the RICEPEST model.

2.4.3.3 Spatial modeling of yield loss

Simulation runs of both EPIRICE and RICEPEST were made at a spatial resolution of 15 arc minutes for the primary growing season (Cuerdo et al., 2013) for the years 2001-2010. Simulation of potential epidemics of bacterial leaf blight and leaf blast was achieved using the EPIRICE model implemented in the R statistical programming language (R Core Team, 2013) using the following packages: raster (Hijmans, 2013), cropsim (Hijmans et al., 2009), rgdal (Bivand et al., 2013) and rodbc (Ripley, 2013).Outputs of daily non-cumulative percentage disease intensity were then produced for each country, year and disease combination.

To map and quantify the spatial distribution of rice yield loss as a result of the two diseases the RICEPEST model was linked to climate data (temperature and solar radiation) and daily disease severity outputs from the EPIRICE model using a Python script (Duku unpublished) employing spatial extensions from ArcGIS Desktop Software v10 SP5 (ESRI, 2011). The Python script ran the RICEPEST model using the daily weather and disease severity data, calculating the yield for a resistant and susceptible rice cultivar.

The output from the EPIRICE-RICEPEST runs consists of annual conditional relative yield effects from host plant resistance adoption per spatial unit and year for the period 2001-2010 in the main production season. These were translated into annual values by assuming the yield effect as 0 in the secondary production season, and weighting the main season values by the proportion of production in the main season.

2.5 Economic surplus modeling of welfare impacts of yield shocks

The econometric and bio-economic modeling approaches employed provide measures of yield and yield protection effects of traits introduced by newer modern varieties of rice. However, actual economic benefits are conditioned by the nature of agricultural production systems affected, as well as market price interactions that redistribute benefits from increased productivity to consumers, laborers and other groups. An explicit welfare framework is needed to assess how increased productivity translates into production cost shifts, supply increases, changes in equilibrium price, and increases (or decreases) in producer and consumer surplus, and how those effects accrue to the poor. It should be noted that such a welfare framework generates approximations of implications expected based on economic theory, rather than estimates rooted purely in empirical analysis of observed behavior. However, given the importance of these conditioning interactions to distributional outcomes, such approximation is difficult to avoid in poverty analysis.

As described in more detail below, such a framework starts with spatially disaggregated quantification of adoption of varietal traits, which is used in conjunction with econometric and bio-economic estimates of trait yield effects on farm to estimate production shocks. Those production shocks are used to estimate shocks to rice supply functions by spatial unit and year. Shocked supply functions are used with national rice demand functions to estimate effects expected on domestic rice prices and on consumer surplus, and are used in conjunction with subnational supply shifts to estimate gross producer surplus. Gross producer surplus is adjusted for the share of rice self-consumed by farmers to give net producer surplus (with concomitant reductions to net consumer surplus).

The model is further extended to capture environmental, food security and poverty considerations in a somewhat simplistic but illustrative manner. Cropped area changes are approximated based on shifts to equilibrium quantities produced, and are used to approximate environmental effects in terms of greenhouse gas emissions, water use and pressure on forests. Increases in hired labor demanded (based on shifts to yields and cropped area) are approximated and used to derive welfare effects for labor. Subnational welfare effects for labor and producers are weighted based on poverty characteristics in each spatial unit to approximate benefits to the poor, and are approximated for poor consumers based on the share of rice consumed by poor populations. Increased caloric intake and reduced protein energy malnutrition are approximated based on increased rice consumption as a result of reduced rice prices.

2.5.1 Yield shock estimation

2.5.1.1 Total effects of new varieties

2.5.1.1.1 BRRI dhan 28 and 29 in Bangladesh

In the case of Bangladesh, the production function regression identifies yield effect coefficients for the adoption of BRRI dhan 28 and 29 directly. When these dummy variable coefficients are translated into marginal effects, they represent the yield effects of replacement of antecedent varieties. These yield effect coefficients then are adjusted according to the adoption rates of the two varieties in each division and year among inbred modern varieties planted in the Boro season (as described earlier), the proportion of inbred modern varietal production in Boro season production (according to national statistics), and the proportion of Boro season production among total production in each region and year to generate supply shocks for each.

2.5.1.1.2 Release yield improvement in Indonesia and the Philippines

The coefficients generated by the econometric and bio-economic analyses of release yield and host plant resistance effects in Indonesia and the Philippines allow for the identification of yield effects per hectare based on adoption of traits and varieties with higher release yields. The approach employed to quantify overall changes in release yield attributable to post 1989 varieties relies on the development of a counterfactual scenario in which only pre 1990 varieties are adopted. This is accomplished by removing the area shares occupied by 1990 and later varieties in each subnational unit and year, and reweighting the area shares of the pre 1990 varieties such that they sum to 1. In cases where adoption of pre 1990 varieties is no longer observed, adoption is held constant from the most recent observation in the spatial unit containing pre 1990 varieties. A weighted average counterfactual varietal release yield is then calculated by using these counterfactual area shares to weight release yields. The difference between this counterfactual average release yield of adopted varieties and the actual average release yield of adopted varieties (without hybrids) is multiplied by the econometrically derived coefficient for the effect of release yield on actual yield to estimate changes in actual yield attributable to the improved release yield of 1990 and later varieties.

2.5.1.1.3 Host plant resistances of 1990 and later varieties in Indonesia and the Philippines

Resistance progress is more complicated to assess than release yield, because there is no obvious index of incremental genetic progress, and the trait may change substantially over time (if the pest or pathogen population evolves). Thus, the approach here is to identify how area under resistant germplasm is affected by the introduction of newer varieties. Each resistance status for each variety in each year, country and/or subnational unit is translated into a 0-1 dummy variable to reflect if resistant or not. The counterfactual adoption scenarios developed for assessing the overall contributions of post 1990 varieties to the average release yield of adopted varieties are used to determine counterfactual resistance diffusion. Each area share of each variety in the counterfactual scenario is multiplied by each respective dummy variable for resistance in the spatial unit and year to identify the counterfactual proportion of area under resistance. The actual area under resistance is calculated on the basis of the actual varietal area share and resistance in the spatial unit and year. For econometric resistance estimates, the effect of new varieties is evaluated as the proportional difference between the production function evaluated at the actual level of resistance adoption in the spatial unit and year and the counterfactual level of resistance adoption. For bio-economic resistance estimates, the conditional yield effect from resistance is multiplied by the difference between actual and counterfactual resistance adoption in each spatial unit and year.

2.5.2 IRRI attribution

Modern varieties generated and disseminated to date are the product of collaboration between IRRI, national partners and advanced research agencies. Dividing credit for collective outputs from such a partnership is an imperfect science, as it is largely unknown what outputs would have been generated in the absence of a particular partner. At the same time, some level of attribution is needed to ascertain whether institutes, such as IRRI, are actually adding value. To this end, this analysis applies a system of weighting based on the origin of genetic content to give an approximate picture of contributions.

2.5.2.1 IRRI attribution weights

To apply the coefficients so as to estimate yield effects attributable to international research, counterfactual scenarios of trait adoption in the absence of international efforts need to be defined. Previous rice varietal impact studies devised procedures to account for the contributions of international research to the MV development process, in terms of direct release or breeding material provision. An accepted approach in the previous literature is based on what Pardey et al (2002) term the “last cross rule” and “geometric rule”, which attribute varieties based on share of genetic pedigree. Under the last cross rule, direct releases of international crosses are given an absolute IRRI attributable weight of 100%. If the released variety is from a NARS cross without the use of IRRI materials, it is entirely NARS attributable. Varieties resulting from NARS crosses that utilize IRRI sourced germplasm are counted as 50% NARS attributable for the cross, with the remaining 50% of “credit” allocated according to share of pedigree. This is determined via the “geometric rule”, which is based on proportion of pedigree with diminishing weights the further back the lineage goes and where the total weights sums to 1. The method traces the lineage of each variety from parents to great grandparents to assign a weight to each generation traced backwards (Table 2.1). The output of this analysis is an IRRI and NARS attribution weight per variety.

2.5.2.2 IRRI trait contributions

2.5.2.2.1 BRRI dhan 28 and 29 in Bangladesh

In Bangladesh, attribution of IRRI contributions is performed by multiplying the yield shocks attributable to BRRI dhan 28 and 29 adoption by the IRRI attribution weight for each variety. For the other countries and traits, however, the approach involves more steps.

Table 2.1. Pedigree weights and pedigree contribution of parents up to the great grandparents of a breeding line under three breeder-material contribution scenarios.

	Generation level	**Total number of ancestors under consideration**	**Weights**		**Pedigree contribution**	
	A	B	**C**	**D**	**B*C**	**B*D**
Breeding contribution weight, B			**0**	**0.5**	**0**	**0.5**
Material contribution weight, M			**1**	**0.5**	**1**	**0.5**
Parent (generation) weight	2	2	0.25000	0.125000	0.500	0.250
Grandparent (generation) weight	3	4	0.06250	0.031250	0.250	0.125
Great grandparent (generation) weight	4	8	0.03125	0.015625	0.250	0.125
Total pedigree contribution					1.000	0.500

2.5.2.2.2 Release yield improvement in Indonesia and the Philippines

For Indonesia and the Philippines, the analysis uses the attribution weights to develop counterfactual scenarios of traits and trait adoption in the absence of international contributions after 1989. The focus is on identifying the international contribution to trait advancement in 1990-2010, so traits are benchmarked relative a period centered on 1990. To do so, the average release yield for varieties released in the period of 1987 to 1991 is calculated per country. Changes in the release yield relative to this value for individual varieties released after this period are multiplied by the IRRI attribution weight to remove the IRRI contribution to yield. The average release yields for varieties weighted by adoption area are subsequently recalculated with the counterfactual release yields (excluding post 1989 IRRI crosses from the denominator) to develop counterfactual estimates. The difference between this counterfactual average release yield of adopted varieties and the actual average release yield of adopted varieties (without hybrids) is multiplied by the econometrically derived coefficient for the effect of release yield on actual yield to estimate changes in actual yield attributable to international contributions to the release yield of 1990 and later varieties.

2.5.2.2.3 Host plant resistances of 1990 and later varieties in Indonesia and the Philippines

For host plant resistances, the approach is similar, but is adapted to reflect the way in which new varieties contribute to trait diffusion. The approach taken is to attribute the effects of the adoption of 1990 and later varieties on resistance adoption to IRRI varietal contributions. To do so, the difference between the 0-1 dummy variable for the resistance status of each variety in each spatial unit and year and the counterfactual scenario of resistance diffusion in the absence of post 1989 MVs in the spatial unit and year is multiplied by the IRRI attribution weight for each post 1989 variety. These “without IRRI” counterfactual varietal contributions to resistance diffusion are then weighted by varietal area shares in the spatial unit and year and aggregated to reflect aggregate effects on resistance diffusion. The aggregated values are then subtracted from actual resistance diffusion values in the spatial unit and year to reflect resistance diffusion in the absence of

IRRI contributions for each. For econometric resistance estimates, the effect of new varieties is evaluated as the proportional difference between the production function evaluated at the actual level of resistance adoption in the spatial unit and year and the counterfactual level of resistance adoption. For bio-economic resistance estimates, the conditional yield effect from resistance is multiplied by the difference between actual and counterfactual resistance adoption in each spatial unit and year.

2.5.2.3 IRRI attributable yield shocks

To generate yield shocks in the absence of IRRI trait contributions, each counterfactual value for trait adoption in the spatial unit and year is used along with each respective significant regression coefficient to calculate yield contributions. The difference between this value and the value for trait contributions using the regression coefficients with actual adoption values reflects the counterfactual yield shock in the absence of IRRI contributions to the trait.

The counterfactual yield shocks for elimination of positive IRRI attributable trait contributions to yield are negative, and represent a leftward contraction of the supply function. However, the attributable effects are calculated as the area between the leftward shifted supply function and the actual supply function, which are positive.

Yield shocks are calculated using the seasonally disaggregated trait effect regression coefficients for the Philippines and overall trait effect regression coefficients for Indonesia. Each coefficient is used in conjunction with the adoption level of the trait in each province, year, and in the Philippines, season, to estimate yield effects. Shocks are subsequently aggregated to annual values based on the share of production per season for the Philippines, using Bureau of Agricultural Production statistics.

To identify how changes in rice supply attributable to newer modern varieties have generated welfare effects, two functional forms for supply are used to model research induced supply shocks and changes to producer and consumer surplus: 1) constant elasticity and 2) near constant elasticity with a positive shutdown price. In the following presentations of the surplus framework, it should be noted that the initial “without shock” supply function represents the counterfactual leftward shifted supply, while the “with shock” function represents the actual supply function.

2.5.3 Economic surplus under constant elasticity supply and demand curves

Following Ayer and Schuh (1972), the baseline constant elasticity functional form for the relationship between the quantity supplied by a rice producer and price is a power function with a zero intercept of the form specified in Eq. 2-22.

$$Q_{S0} = BP^{\varepsilon}, \varepsilon > 0$$

Equation 2-22

Where: Q_{s0} is baseline quantity supplied, *P* is the domestic price, *B* is a constant and *ε* is the own price elasticity of supply.

The initial quantity demanded is specified similarly as a constant elasticity function (Eq. 2-23):

$$Q_{D0} = AP^{\eta} = AP^{\eta}, \eta < 0$$ **Equation 2-23**

Where: Q_{D0} is quantity demanded, *P* is the domestic price, *A* is a constant and η is the own price elasticity of demand.

As a consequence of the adoption of new technologies that affect output, there is a proportional shift in supply at any given price, so that the quantity supplied proportionally stretches under an output increase to Q_{S1}. With the proportionate shift *j*, the shocked supply function becomes as follows (Eq. 2-24)

$$Q_{S1} = BP^{\varepsilon}(1 + j)$$

Equation 2-24

In addition, there is a proportionate change in variable production costs resulting from changes in input use accompanying the adoption of a new technology, which must be considered, as well. This effectively stretches the supply curve along the price axis. Incorporating the proportionate cost shift as *c*, the shocked supply equation thus becomes as per Eq. 2-25. In the case of yield effects due to genetic enhancement, the cost effect is approximated as a concomitant increase in the share of harvesting costs to changes in yield, divided by the proportional change in output.

$$Q_{S1} = B(\frac{P}{1 + c})^{\varepsilon}(1 + j)$$ **Equation 2-25**

For simplicity, the vertical and horizontal proportionate shocks can be reconciled to a single shift multiplier to the original supply function, here termed L via the following equation (Eq. 2-26).

$$L = \frac{(1 + j)}{(1 + c)^{\varepsilon}}$$ **Equation 2-26**

By setting the shocked supply function equal to the original demand function, under closed economy assumptions, the shocked supply function will intersect the demand function at a new price P_1 specified by the following equation (Eq. 2-27).

$$P_1 = P_0 L^{\frac{1}{(\eta - \varepsilon)}}$$ **Equation 2-27**

In developing Asia, most major rice consuming countries are near self-sufficiency and trade is minor. However, there are a few countries where a significant share of production is currently exported (Thailand, Vietnam and Pakistan), and comparative trends in consumption and production suggest that there may be more trade in the future. In the case of exporters considered individually, the above equation overestimates domestic price shocks from supply shifts, as part of the supply shock is not absorbed domestically. Following Alston et al. (1995) for major exporters, the domestic price implications of trade can also be incorporated into the comparative static estimates of price effects without spillovers by replacing the domestic own price demand elasticity η_{dom} with an average of the domestic and export demand elasticities η_{exp}, weighted by the share of production consumed domestically ς and exported, respectively.

$$P_1 = P_0 L^{\frac{1}{((\eta_{dom}\varsigma - \eta_{exp}(1-\varsigma)) - \varepsilon)}}$$

Equation 2-28

For importers, in the absence of spillovers, the effect of linkages to the world market can be approximated by replacing the domestic supply curve with an aggregate supply curve that incorporates imports, and shocking only the portion of that curve that represents domestic supply in the equation. This is approximated in Eq. 2-29.

$$P_1 = P_0(1 + (L-1)\vartheta)^{\frac{1}{(\eta - (\varepsilon_{dom}\vartheta + \varepsilon_{imp}(1-\vartheta)))}}$$

Equation 2-29

Where: ϑ is the share of domestic consumption that is domestically produced, ε_{dom} is the domestic supply elasticity and ε_{imp} is the elasticity of import supply (excess supply from the world market).

The original supply function and equilibrium price combined with the shocked supply function and consequent equilibrium price enable the calculation of changes to producer and consumer surplus. To depict this graphically in the simple closed economy case, in Figure 2.2, the baseline producer surplus is the area below the baseline equilibrium price and above the baseline supply curve shaded as *abc*. The post shock producer surplus is the area below the new equilibrium price and above the shocked supply curve shaded as *ade*. The change to consumer surplus as a result of the new price equilibrium is area *dbce.*

The areas of producer surplus are calculated as the definite integral of the supply function with respect to quantity between 0 and the equilibrium price. Changes to producer surplus, ΔPS, as a result of a supply shock are thus the difference between the definite integral of the shocked supply function between 0 and the shocked equilibrium price and the definite integral of the original supply function between 0 and the initial equilibrium price, via the following equation (Eq. 2-30).

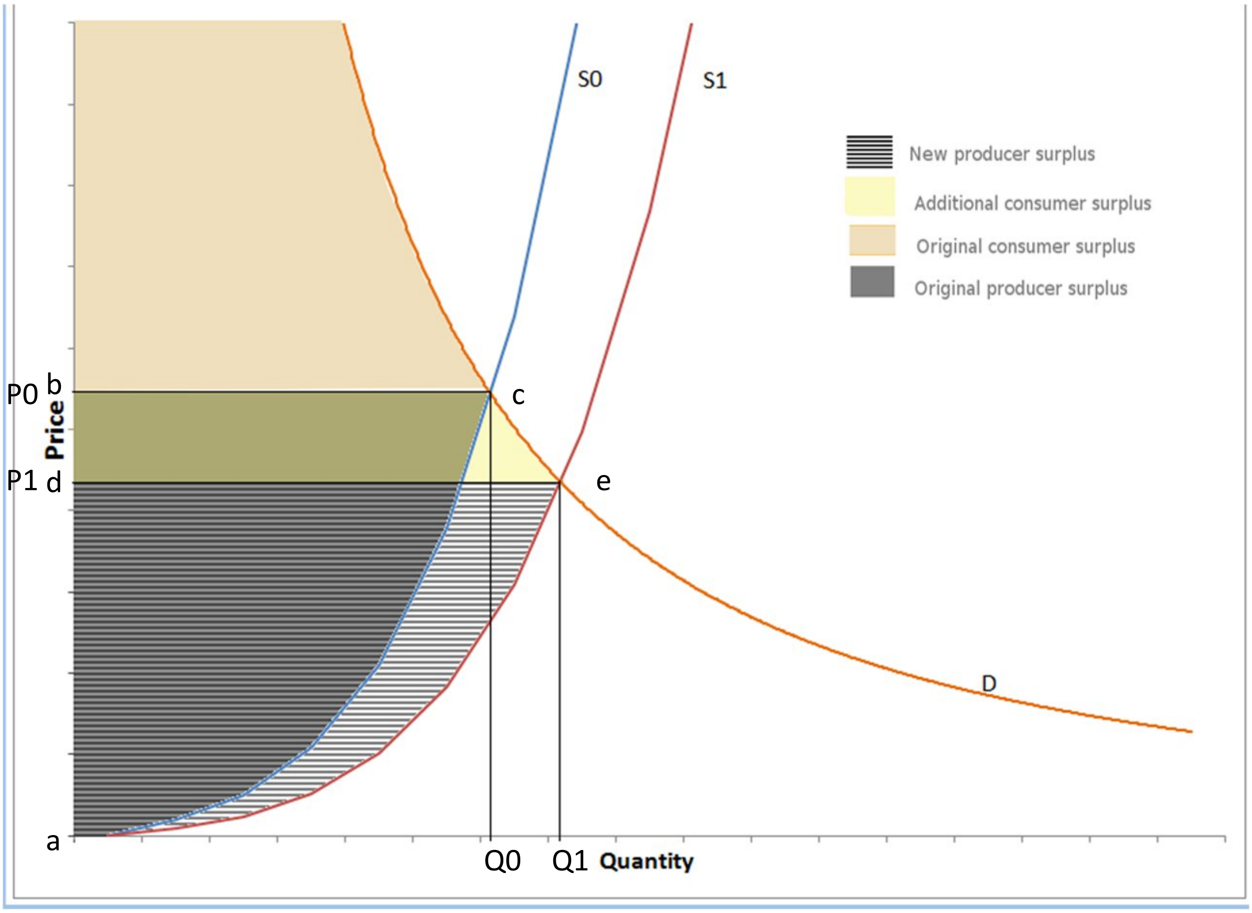

Figure 2.2. Producer and consumer surplus effects of a supply shift under constant elasticity supply and demand curves.

$$\Delta PS = \int_0^{P_1} LBP^{\varepsilon}\, dQ - \int_0^{P_0} BP^{\varepsilon}\, dQ \;=\; \frac{LP_1^{(\varepsilon+1)}\frac{Q_0}{P_0^{\varepsilon}} - P_0 Q_0}{\varepsilon + 1} \qquad \text{Equation 2-30}$$

Similarly, changes to consumer surplus, ΔCS, the area under the demand function and above the equilibrium price, are calculated as the difference in the definite integrals of the demand function before and after the shock. As only the equilibrium price is shifted due to the supply shock, this is expressed as the following (Eq. 2-31)

$$\Delta CS = \int_{P_1}^{P_0} AP^{\eta}\, dQ \;= \frac{\frac{Q_0}{P_0^{\eta}}}{\eta+1}\left({P_0}^{(\eta+1)} - {P_1}^{(\eta+1)}\right) \qquad \text{Equation 2-31}$$

2.5.3.1 Data sources for constant elasticity surplus model

In this framework, the prices applied represent average national rice prices for the 1990-2010 period from the IRRI World Rice Statistics, as expressed in 2005 Purchasing Power Parity Dollars (PPP$). The quantities produced per province and year are derived from national statistical databases, while the quantities consumed and traded are sourced from statistics from the U.S. Department of Agriculture “World Markets and Trade” database.

Own price elasticities are obtained from an inventory of rice demand and supply literature for the countries of interest. Credible demand elasticity estimates are sourced from studies that employed established estimation techniques that utilized income-expenditure data collected through national surveys. The leading demand models are Almost Ideal Demand System (AIDS) and its variant Quadratic Almost Ideal Demand System (QUAIDS). Only the Marshallian (uncompensated) own price elasticity estimates are used in this study, and these were sourced from Llanto (1998), Pangaribowo and Tsegai, 2011, and Alam, 2011..

The intention in the identification of supply elasticities was to make use of the best existing estimates, while incorporating subnational disaggregation where possible. Subnational own price supply elasticities have been recently identified for parameterizing the IRRI Global Rice Model (IGRM, described in detail in IRRI-SSD, 2011) using a double log specification with 10 years of data. At the same time, the IGRM estimates reflect lower supply responses than other literature, with own price supply elasticities between 0.06 and 0.15 in the study countries, while robust recent estimates from econometric studies range between 0.2 and 0.6. For Indonesia and the Philippines, to reconcile these two sources of information and preserve subnational disaggregation, IGRM subnational estimates were nationally adjusted, so that national supply responses are consistent with the most reliable estimates from studies of price response available in the literature (Edison et al., 2011, Estudillo, 1989, Warr, 2005). For Bangladesh, given the very low supply elasticities generated for the IGRM, Boro and Aman/Aus own price supply elasticities consistent with the literature (Dorosh et al., 2001) were used and weighted by the average share of production in the Boro and Aman/Aus season in each Division.

The general equations presented above describe aggregate surplus measures. To explore distributional effects, and consider temporal tradeoffs, the equations are applied with disaggregation over space and time. As a result, these equations are separately applied for each of the spatial units in the analysis, with distinct shock values applied for each year and spatial unit. Domestic price effects under closed economy assumptions are calculated nationally via a production weighted average of subnational L shocks, and are fed into separate surplus equations for each subnational spatial unit, year, technology, and scenario combination.

2.5.4 Economic surplus under a supply curve with a positive shutdown price

The previous surplus equations apply under the assumption that the supply curve intersects the price axis from the origin, and that there is rice supplied at any positive price. This is an arbitrary assumption, which may appear to be a theoretical consideration. However, it becomes important in the context of welfare quantification, because economic surplus is measured over the entire supply curve.

While the origins of the supply curve are not observed, economic theory suggests that there is minimum production cost for outputs, including rice, below which production would cease over the long term, because producers cannot recover production costs. To reflect this means that the supply curve should start from a positive shutdown price, rather than from the origin, but that it should exhibit observed elasticities when at values near the observed market equilibrium.

Incorporation of a shutdown price requires a modified form of the supply function presented previously, drawing on the work of Pachico and Borbob (1986). The modified form is below (Eq. 2-32).

$$Q_{S0} = g\ (P - m)^{\ d}$$

Equation 2-32

Where: m is the shutdown price, g is essentially a modified version of the constant B from the constant elasticity case and d is a modified form of the supply elasticity ε.

$$d = \frac{\varepsilon(P_0 - m)}{P_0}$$

Equation 2-33

$$g = \frac{Q_0}{(P_0 - m)^{d}}$$

Equation 2-34

In the constant elasticity, zero intercept case presented previously, it does not matter whether the combined technology induced supply shift resulting from cost and output changes is considered as vertical or horizontal, because the geometric consequences are identical. However, with a positive shutdown price, this is no longer the case, because a vertical proportionate shift is operating against a function that originates from a positive value, while a horizontal proportionate shift is operating against a value that originates from zero. In other terms, a proportionate vertical shift now modifies the shutdown price intercept, whereas a horizontal shift does not change any intercepts.

In this case, so as to fully encompass the possible changes resulting from this more sophisticated functional form assumption, the horizontal and vertical shifts at the equilibrium are reconciled to an overall vertical shift of the supply function. This is analogous to considering that new technologies change the shutdown price of the supply curve. The combined vertical supply function shift parameter K is calculated, as per the below (Eq. 2-35).

$$K = \frac{(1+j)^{\frac{1}{d}}\ (P_0 - m) + m}{P_0} - \mathrm{c}$$

Equation 2-35

This gives a post shock supply equation as follows (Eq. 2-36).

$$Q_{S1} = g\ (KP - m)^{d}$$

Equation 2-36

There is not a closed form equation to identify the exact solution for the new price domestic price equilibrium under closed economy assumptions. However, Eq. 6, 7, and 8 provide a close approximation for supply shocks that are not drastic. To apply those equations, the L shock is calculated as the following (Eq. 2-37).

$$L = (\frac{KP_0 - m}{P_{0-m}})^{d}$$

Equation 2-37

As under the constant elasticity case, the baseline producer surplus is represented by the area above the supply curve and below the price, here represented graphically as abc in Fig. 2.5.4. However, the difference here is that the supply curve starts at a positive shutdown value, reducing the baseline surplus. The post shock producer surplus is represented by area fde, which has an additional gain compared to the constant elasticity case because the intercept moves from a to f, whereas it remains at the origin in the pure constant elasticity case. The change in consumer surplus area represented by dbce is essentially the same as the constant elasticity case.

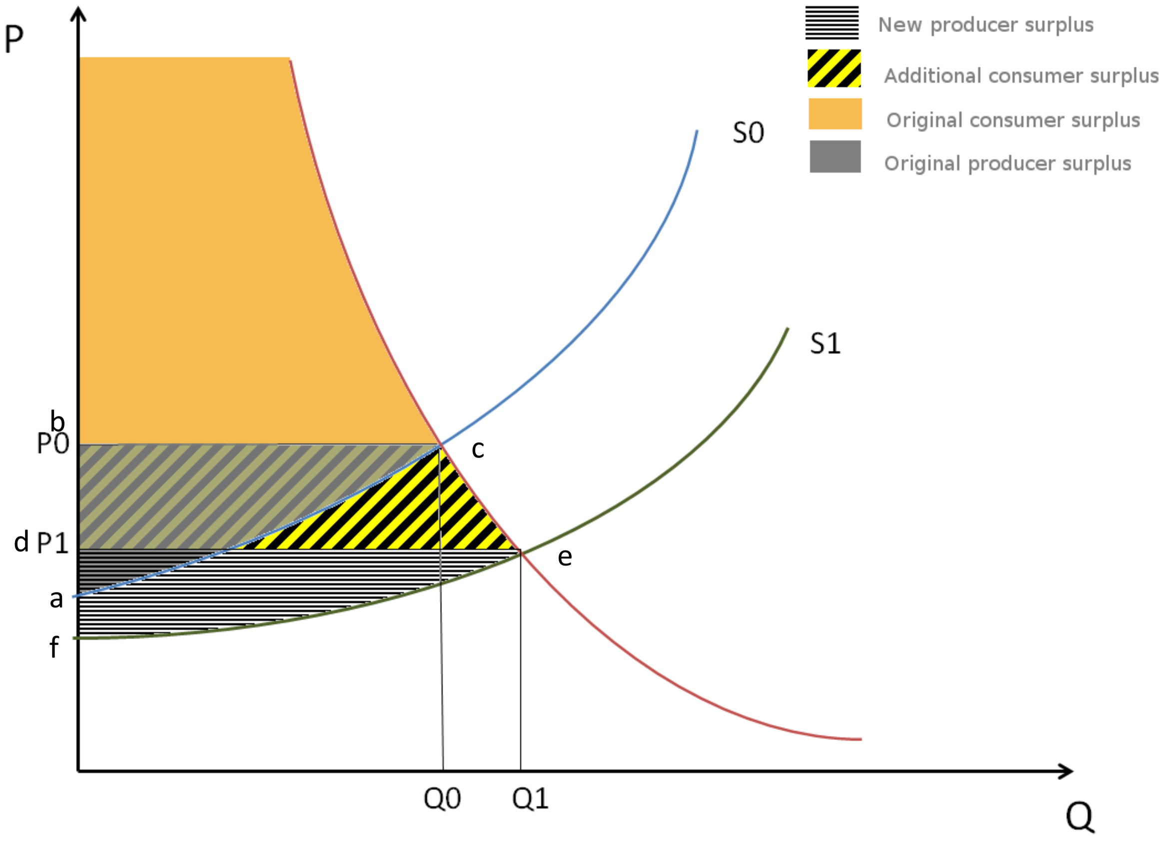

Figure 2.3. Producer and consumer surplus effects of a supply shift under a supply curve with a positive shutdown price.

To calculate the change in producer surplus, the difference between the integral of the shocked supply function from the shifted shutdown price to the new price equilibrium and the integral of the original supply function between the original shutdown price and price equilibrium is taken (Eq. 2-38).

$$\begin{aligned}\Delta PS &= \int_{\frac{m}{K}}^{P_1} g\,(K(P-m))^d\,\mathrm{d}P - \int_{m}^{P_0} g\,(P-m)^d\,\mathrm{d}P \\ &= \frac{g}{d+1}\left(\frac{1}{K}(KP_1-m)^{(d+1)} - (P_0-m)^{(d+1)}\right)\end{aligned}$$

Equation 2-38

2.5.4.1 Data sources for positive shutdown price surplus model

The same data are used in this framework as in the constant elasticity case, except for an additional parameter on shutdown prices. This analysis approximates the shutdown price as the sum of harvesting costs, 50% of variable material input costs and 10% of all other labor costs. The intention is to capture conditional on production but invariable to output. Calculation of consumer surplus changes is the same as previously presented, as the consumer surplus function form is unchanged.

2.5.5 Adjustment of consumer and producer surplus to reflect producer self-consumption

Rice is a commodity that is produced both for self-consumption, as well as for marketed surplus sold to consumers. The previously presented distributions of welfare between consumers and producers ignore this fact, and represent consumer benefits accruing to producers themselves as part of consumer surplus. If the objective is to identify benefits for farmers, compared with other consumers who purchase rice, some of the consumer surplus needs to be reallocated to producers to reflect self-consumption. This is done by apportioning the portion of consumer surplus that accrues on production that is self-consumed back to producers via the equation below (Eq. 2-39).

$$\Delta PS_{net} = \Delta PS + (\Delta CS(\frac{\bar{Q}_{producer\ consumed}}{\bar{Q}_{produced}}))$$

Equation 2-39

Where: PS_{net} is net producer surplus, adjusted for self consumption, $\bar{Q}_{produced}$ is the average quantity of rice production per farm in the spatial unit and $\bar{Q}_{producer\ consumed}$ is the average quantity of rice self consumed by rice farmers in the spatial unit.

To avoid double counting consumer benefits, research induced changes to net surplus for purchasing consumers Δ 〖CS〗 _net become the following (Eq. 2-40)).

$$\Delta CS_{net} = \Delta CS - (\Delta CS(\frac{\bar{Q}_{producer\ consumed}}{\bar{Q}_{produced}})$$

Equation 2-40

2.5.5.1 Data sources for incorporating producer self-consumption

Primary household survey data on crop disposal (IFPRI, 2011) are utilized for Bangladesh to estimate the proportion of production retained for household consumption. For Indonesia, BPS statistics on the number of rice farming households per province, data on provincial production and estimates of milling recovery rates are utilized to estimate average household production of rice for the 1990-2010 period. Provincial household consumption is estimated on the basis of average provincial household size statistics from BPS for the period multiplied by average per capita consumption of rice, and this is divided by average provincial household production to estimate the average proportion of household production self-consumed. Similarly, for the Philippines, average household production is estimated by dividing regional milled rice production reported by BAS by the regional number of rice farming households identified in the 2000 Agricultural Census. Average rural household rice consumption is estimated on the basis of BAS statistics on rural regional per capita consumption multiplied by average regional household size reported in the 2000 Population Census, and this is divided by average regional household production to estimate the proportion self-consumed.

2.5.6 Economic surplus implications of research induced shifts in hired labor demand

The adoption of new rice production technologies may affect benefits to the poor and to the environment via effects on input markets, as well as output markets, and this needs to be considered as part of expected impacts, where relevant. Given that labor is the most valuable input utilized in rice production in most of Asia, and that most hired laborers are poorer than the general or farmer population, the welfare implications of changes in hired labor use should be considered to fully assess the poverty implications of new technologies.

New rice production technologies have differential effects on labor use. For example, mechanization of crop management operations is expected to reduce the labor utilized for those operations, in order to reduce production costs. Technologies that increase yields, on the other hand, may increase the labor needed for harvesting on a per area basis. Meanwhile, if the equilibrium rice area declines as a result of the price effects of yield enhancing technologies, labor demand is eliminated for the area that comes out of production.

Each change in labor use can be considered to have a concomitant effect on labor demand, which affects, in turn, the hired portion of labor for each operation. This change in labor demand, when extrapolated over the area of adoption, becomes a shift in an input demand curve for hired labor.

Under a constant elasticity functional form, the initial labor demand curve is as specified previously for rice demand, although here N_{D0} refers to the baseline quantity of hired labor, w refers to the wage of hired labor), α is a constant and β is the own price elasticity of demand for hired labor (Eq. 2-41).

$$N_{D0} = \alpha w^{\beta}$$ **Equation 2-41**

The initial hired labor supply curve is similar to the rice supply, as well. Here, γ refers to the own price elasticity of supply for hired labor, and $\phi$is another constant (Eq.2-42).

$$N_{s0} = \phi w^{\gamma}$$ **Equation 2-42**

In this case, the demand curve is horizontally shifted proportionately by *z* as a result of increased or reduced need for hired labor under new technologies (Eq. 2-43).

$$N_{D1} = \alpha w^{\beta}(1 + z)$$ **Equation 2-43**

The shift in hired labor demand is taken as the yield effect multiplied by the proportion of hired labor used for harvesting ב (under the assumption that harvesting labor use per area covaries with yield) minus the relative change in equilibrium production area due to the new technology (as aggregate hired labor covaries with production area). This is illustrated in Eq. 2-44, using the positive shutdown price equation for the latter. Note that here the supply elasticity used in calculating *d* is reduced (by an assumed 30%) to represent an area elasticity.

$$z = (1 + j) * \beth + (1 - \frac{(KP_1 - m)^d}{(KP_0 - m)^d})$$

Equation 2-44

The new price (wage) equilibrium after the demand shift is given as the following (Eq. 2-45), assuming a closed market for labor supply (more will be discussed on this later).

$$w_1 = \frac{w_0}{(1 + z)^{\frac{1}{\beta - \gamma}}}$$

Equation 2-45

The proportional reduction in demand changes producer (laborer) surplus as the difference between the area between the wage rate and the labor supply curve at the new and original wage equilibria, denoted as area *abcd* in Figure 2.4.

This area can be calculated as the definite integral of the supply curve between the baseline and shocked equilibrium prices, with respect to the *N* axis (Eq. 2-46). The loss in producer surplus when the wage changes is:

$$\Delta PS = \int_{w_0}^{w_1} \phi w^{\beta} \, dN = \frac{\phi(w_1^{\beta+1} - {w_0}^{\beta+1})}{\beta + 1}$$

Equation 2-46

Senso stricto, this form of surplus calculation is under the assumption that the unskilled labor market for rice is closed and distinct from other labor markets. As a result, it exaggerates the wage effects of a given labor demand shift, relative to assumptions incorporating unskilled labor mobility between sectors. However, by the same measure, this is restricting the effects of the wage shift to a much smaller population than would be the case under more open labor market assumptions, which countervails the magnified effect on prices/wages. This is evident in the equation. Inclusion of a broader labor supply pool than for rice labor alone would reduce the difference between w_1 and w_0 by the same proportion as the labor pool is increased. At the same time, parameter ϕ would increase by essentially the same proportion as the size of the labor pool, so that the reduction in price effect is countered in the calculation of changes in producer surplus. As a result, this approach is a reasonable approximation of welfare effects for laborers under a broader range of labor market assumptions.

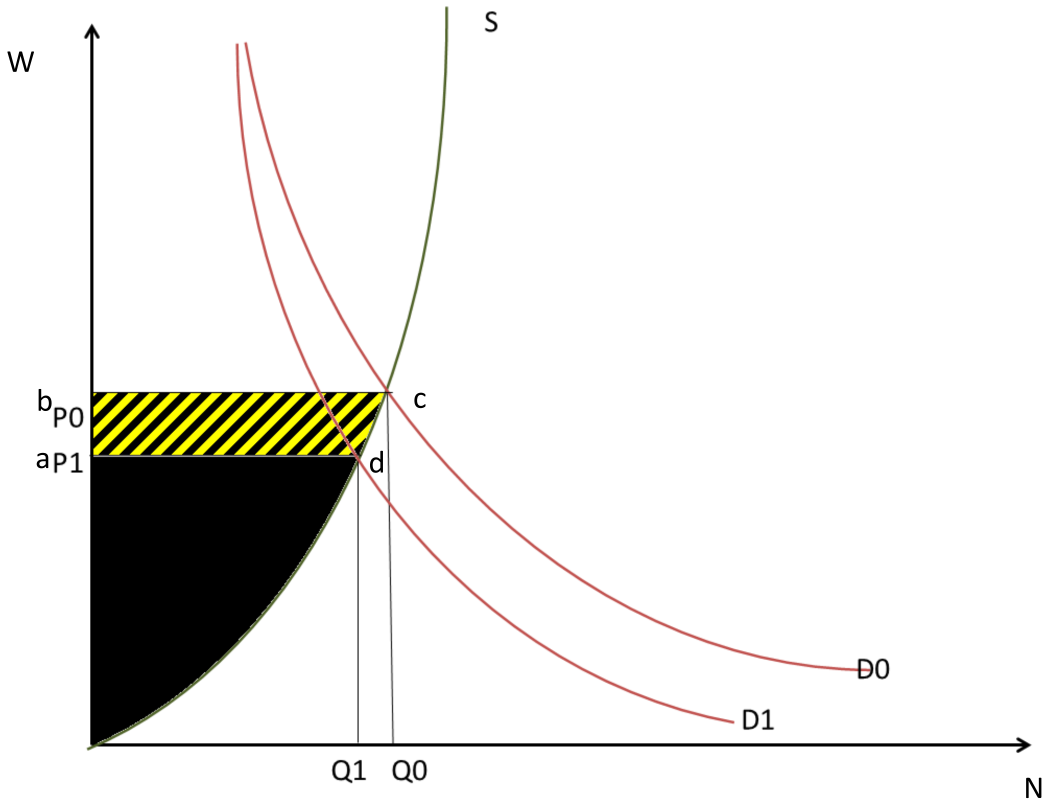

Figure 2.4. Economic surplus implications for producers of a proportionate negative demand shift.

These changes to producer surplus welfare are estimated separately for each of the spatial units in the analysis, with distinct shock values applied for each year and spatial unit. Price/wage effects under closed economy assumptions are calculated separately for each subnational spatial unit, year, technology and scenario combination and are then used in surplus changes equations for each.

2.5.6.1 Data sources for labor welfare model

Quantities of hired labor used in rice production and wage rates paid are approximated based on statistics regarding hired man days per harvested hectare from IRRI household surveys. These hired man days per hectare are multiplied by annual values of harvested areas per province from national agricultural statistical databases to approximate total quantities of hired labor.

To interpolate wages, two data time series are assembled: 1) the trend in the average wage of the population; 2) the trend in the deviation between average wages and wages for unskilled agricultural labor. National historical average agricultural wages at different points in time from 1995 to 2010 have been obtained from the ILO (ILOSTAT), and have been deflated according to each national Consumer Price Index to reflect trends in real wages. Where ILO data are missing, the trend in mean per capita income from PovCalNet (World Bank, 2013) has been used instead. Historical trends in real wages/income are then applied to reflect wage changes for the general population (under Eq. 2-47 with slope ѧ and intercept җ).

$$\bar{w}_{general\,ϗt} = ѧ_{ϗ}t + Җ_{ϗ}$$ **Equation 2-47**

To reflect the trend in wages for agricultural labor, it is assumed that unskilled agricultural wages generally fall in the bottom two deciles of national income distribution. PovCalNet provides historical estimates of the share of income held by decile, and division of the income share held by a decile and its respective shares of population (.1) provides an estimate of mean income/wages within the decile as a fraction of average income/wages. The fractions of mean income held by the bottom two deciles have been averaged for each country and year as ԉ, (under Eq. 2-48 with slope Ψ and intercept Ꙩ).

$$ԉ_{ϗt} = Ψ_{ϗ}t + Ꙩ_{ϗ}$$ **Equation 2-48**

The product of the mean fraction of income held by the bottom two deciles and the average wage/income in each country and year is used to approximate the unskilled agricultural wage. The ratio of the average wage in each year and country divided by the wage in the year of household survey is used as a multiplier on the survey derived wage to adjust it for exogenous changes over time (Eq. 2-49).

$$w_{ag\ labor\ ϗt} = w_{ag\ labor\ ϗ0} * (\frac{\bar{w}_{general\ ϗt}}{\bar{w}_{general\ ϗ0}}) * (\frac{ԉ_{ϗt}}{ԉ_{ϗ0}})$$ **Equation 2-49**

Annual adjustments are performed to reflect increasing real wage trends. To approximate this effect, the shift in labor supplied can be approximated based on the shift in the wage equilibrium by solving Eq. 2-41 for a horizontal shift factor that reflects the contraction of labor availability that drives the equilibrium wage increase. The baseline labor quantity in each spatial unit is thus adjusted for each year by multiplying it by the national shift value for the year.

$$N_{ϗt} = N_{ϗ0}(\frac{\bar{w}_{ag\ labor\ ϗt}}{\bar{w}_{ag\ labor\ ϗ0}})^{\gamma_{ϗ}-\beta_{ϗ}}$$ **Equation 2-50**

2.5.7 Approximation of benefits to the poor

2.5.7.1 Poor producers

The spatial and temporal disaggregation of the model enables approximation of benefits to poor populations based on the congruence of patterns of welfare generation and poverty. To do so, net producer surplus generated under a scenario and research output in a spatial unit and year is multiplied by the baseline portion of the rice cultivating population under a particular poverty threshold φ and the ratio of the average rice area for the population under the poverty line $\bar{h}_{poor}$ to the average rice area of the general population$\bar{h}$ (to take into account inequity in land distribution) (Eq. 2-51).

$$\Delta PS_{poor} = \Delta PS_{net} * \varphi * \frac{\bar{h}_{poor}}{\bar{h}} \qquad \textbf{Equation 2-51}$$

This calculation is performed annually at the first level subnational administrative unit against baseline poverty rates disaggregated by spatial unit and adjusted over time. Given the prevalence of rice production in the focal countries, as well as the lack of more detailed poverty data, the poverty rate among rice producers is assumed to be the same as the rural poverty rate in a particular location.

The implicit assumption in such an approach is that there is equal propensity for the poor and non-poor to adopt varietal traits within specific agro-ecologies in a spatial unit.

2.5.7.1.1 Data sources for producer surplus poverty adjustments

Ratios of rice areas held by those under the poverty line to the general population are calculated on the basis of IRRI household survey datasets from the 2000s. The portion of the rice cultivating population under the poverty line is approximated as the rural poverty rate in a spatial unit and year. The 2005 poverty rate is sourced from poverty maps complied by Wood et al. (2010). To incorporate changes over time, poverty rates reported by the World Bank's PovCalNet (World Bank, 2013) have been compiled, and annual values have been linearly interpolated between the periods reported. The ratios of these annual national values relative to the 2005 national poverty rate are multiplied by the values from Wood et al (2010) to incorporate exogenous changes in poverty rates over time.

2.5.7.2 Poor consumers

Net consumer benefits to the poor are calculated as the product of national gross consumer surplus changes calculated using a demand elasticity reflective of the poor population and the portion of rice consumption τ by those under the poverty line, with the sum of consumer surplus accruing to poor producers in each of the country's spatial units netted out, as identified earlier[5] (Eq. 2-52).

$$\Delta CS_{poor} = \Delta CS * \frac{\tau_{poor}}{\tau} - \sum(\Delta CS(\frac{\bar{Q}_{producer\ consumed}}{\bar{Q}_{produced}})\ \varphi(\frac{\bar{h}_{poor}}{\bar{h}})) \qquad \textbf{Equation 2-52}$$

2.5.7.2.1 Data sources for consumer surplus poverty adjustments

National consumption of rice by those under the poverty line is approximated based on household income and expenditure survey data from the 2000s, which have been compiled by the World Bank. Aggregate annual rice expenditure by the poor is estimated as the annualized poverty line multiplied by 1 minus the poverty gap (assuming that income equals expenditure), the proportion of household expenditure for rice, and the number of poor (as described earlier). This aggregate expenditure is then divided by the domestic rice price in PPP$ to estimate quantities consumed by the poor, and the national proportion of

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[5] In cases where the consumer surplus accruing to poor producers through self-consumption is greater than the product of national gross consumer surplus changes and the portion of rice consumption by those under the poverty line, net consumer benefits to the poor are taken as zero.

consumption by the poor is estimated by dividing aggregate consumption by the poor by aggregate total national consumption.

2.5.7.3 Poor hired labor

The effects of changes in hired labor demand on the poor are modeled taking the product of the changes in labor producer surplus in in a particular spatial unit and year and the poverty rate among hired labor providers in the same unit and period. The poverty rate among hired labor providers, who tend to be landless or smaller farmers than average, is approximated as twice the general rural poverty rate in the period and unit (Eq. 2-53).

$$\Delta PS_{poor\ hired\ labor} = \Delta PS * \varphi * 2$$ **Equation 2-53**

2.5.8 Approximation of food security and health impacts

Estimated price effects, in conjunction with the demand equations, enable the calculation of changes in the quantity of rice consumed due to research induced supply shifts. The relative consumption change $\dot{q}$ of a price change is a simple ratio of Q_{D1} to Q_{D0}, which is equivalent to Eq. 2-54.

$$\dot{q} = \frac{P_1^{\eta}}{P_0^{\eta}}\text{-}1$$ **Equation 2-54**

Changes in the quantity of rice consumed, in turn, lead to nearly concomitant changes in caloric intake, given that rice has low cross price elasticities with other foods. These changes in caloric intake can then be translated into reductions in the prevalence of caloric insufficiency and the burden of disease risk attributable to it.

The baseline per capita caloric intake from rice for the caloric insufficient population is approximated as ɋ , the baseline proportion of calories from rice for the population, multiplied by the average caloric intake of the caloric deficient population (which is the minimum recommended caloric intake ϖ minus the average caloric gap for the deficient population ɤ). This is multiplied by the caloric deficient population ɘ to obtain the total baseline calorie pool from rice for the caloric deficient population (Eq 55.).

$$cal_{rice} = \text{ɋ}(\varpi - \text{ɤ})\text{ɘ}$$ **Equation 2-55**

The additional caloric intake available to the food insecure from price declines is modeled by taking the proportional change in rice quantity consumed and multiplying it by the baseline rice caloric intake of the caloric insufficient population. Assuming that there is a normal distribution of caloric insufficiency, additional caloric intake is divided by twice the average per capita caloric gap for the caloric insufficient population to approximate the number of people lifted out of caloric insufficiency in a particular year and country[6] (Eq. 2-56).

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[6] Under a normal distribution of caloric insufficiency, the mean caloric gap is the median of caloric gap values, with a symmetric distribution such that 50% of the caloric insufficient population has a caloric gap between 0 and the average, and 50% has a caloric gap between the average value and twice the average value.

$$\Delta POP_{caloric\ insufficient} = \frac{(\frac{P_1^{ƞ}}{P_0^{ƞ}} - 1)(ɋ(ɷ - ɤ))ɵ}{2 * ɤ}$$

Equation 2-56

Another measure of food security impact can be captured via health implications. Child underweight status is the foremost risk factor associated with disease burden, according to the WHO (2008), and underweight status has an important association with protein energy malnutrition and caloric insufficiency. In addition, protein energy malnutrition also poses direct disease burden.

Disability Adjusted Life Years (DALYs), an indicator of the years of productive life lost due to disability and premature mortality, offer a standardized means to capture the health effects of disease burden and changes thereof. For this analysis, the baseline disease burden attributable to energy insufficiency $DALYS_{energy\ def}$ is approximated as the annual underweight risk factor attributable DALYs ɹ, adjusted to reflect the prevalence of chronic energy deficiency (by the ratio of chronic energy deficiency prevalence ɘ to unweight prevalence ɠ), plus additional disease burden DALYs for protein energy malnutrition ʮ (Eq 2-57.).

$$DALYS_{energy\ def} = ɹ(\frac{ɘ}{ɠ}) + ʮ$$

Equation 2-57

Carbohydrate insufficiency associated DALYs are then attributed as the maximum carbohydrate share of energy intake for a balanced diet ʌ multiplied by the energy insufficiency DALYs. To approximate health effects of reductions in carbohydrate insufficiency attributable DALYs, they are multiplied by proportional reductions in the number of people with caloric insufficiency in each year and country (Eq. 58).

$$\Delta DALYs = \frac{\Delta POP_{caloric\ insufficient}}{POP_{caloric\ insufficient}} * (ʌ(ɹ(\frac{ɘ}{ɠ}) + ʮ))$$

Equation 2-58

2.5.8.1.1. Data sources for health impact model

Time series historical national annual estimates of the number of people with caloric insufficiency and average caloric intake gaps among the insufficient are provided by the "Hunger Statistics" of FAO. The former is divided by national population estimates to obtain headcount prevalence rates. Based on historical patterns, the trends in the headcount prevalence rates and caloric intake gaps for each country are then calculated annually (Eq. 2-59 and Eq. 60, respectively).

$$п_{ķt} = ᴖ_{ķ}t + æ_{ķ}$$

Equation 2-59

Where: п reflects headcount prevalence of caloric deficiency, ᴖ is the slope of the caloric deficiency trend and æ is the intercept.

$$ɤ_{ķt} = ฿_{ķ}t + ʊ_{ķ}$$

Equation 2-60

Where: ฿ is the slope of the caloric intake gap trend and ʊ is the intercept.

FAO has also developed “Minimum Dietary Energy Requirements” estimates, of which the 2004-2006 data are used. The WHO has estimated two sets of disease burden estimates that reflect the effects of caloric insufficiency (plus other associated factors) on annual Disability Adjusted Life Years in 2004. One is a set of estimates of the broader disease risks and effects thereof stemming from the “underweight” risk factor for children, which is reported on a subregional basis (WHO, 2009). The second is the direct disease burden associated with protein energy malnutrition, which is reported nationally (WHO, 2008). To approximate the national DALYs attributable to the underweight risk factor, subregional aggregate estimates are allocated in proportion to the distribution of protein energy malnutrition attributable DALYs within the subregion (Eq. 2-61).

$$ɹ_{ϗ} = ɹ_{region} * \left(\frac{ч_{gross\,ϗ}}{ч_{gross\,region}}\right) \qquad \textbf{Equation 2-61}$$

To approximate the underweight risk factor DALYs attributable to chronic energy deficiency, they are multiplied by the ratio of the prevalence of chronic energy deficiency (which is measured among adults) and the prevalence of underweight status (which is measured among children), under the assumption that chronic energy deficiency is similar among different age groups[7], which are directly drawn from the WHO. The portion of chronic energy deficiency that carbohydrates can alleviate is fixed at 0.65, as per the maximum share of recommended calories from carbohydrates.

Although protein energy malnutrition DALYs for early childhood are largely quantified by the WHO as attributable to the underweight risk factor, there are additional disease burden DALYs for adult protein energy malnutrition, which are included nationally after subregional adjustment to eliminate double counting of protein energy malnutrition DALYs attributable to the childhood underweight risk factor (Eq. 2-62).

$$ч_{ϗ} = ч_{gross\,ϗ} - \left(ɹ_{ϗ} * \frac{ч_{region\ underweight}}{ч_{region}}\right) \qquad \textbf{Equation 2-62}$$

To incorporate population changes, UN population data are obtained and multiplied by headcount prevalence rates (Eq. 2-63).

$$ϑ_{ϗt} = \pi_{ϗt}\,ϼ_{ϗt} \qquad \textbf{Equation 2-63}$$

So as to adjust 2004 chronic energy deficiency associated DALYs, the 2004 DALYs national estimate is multiplied by the ratio of the caloric insufficient population in a particular year

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[7] This is a less than ideal assumption, but there are no data currently available on chronic energy deficiency, *per se*, among children in most Asian countries, as underweight or associated anthropometric measurements, such as stunting, are used as a proxy measure. However, these capture the effects of other deficiencies and syndrome, as well. The ratio is capped at 0.7 in cases where chronic energy deficiency prevalence exceeds child underweight prevalence.

and country and the 2004 caloric insufficient population. This is applied both to underweight risk factor DALYs (Eq. 64) and net protein energy malnutrition DALYs (Eq. 2-65.).

$$\text{ɹ}_{\text{ϗ}t} = \text{ɹ}_{\text{ϗ}0} * \left(\frac{\text{ƍ}_{\text{ϗ}t}}{\text{ƍ}_{\text{ϗ}0}}\right) \qquad \text{Equation 2-64}$$

$$\text{ɥ}_{\text{ϗ}t} = \text{ɥ}_{\text{ϗ}0} * \left(\frac{\text{ƍ}_{\text{ϗ}t}}{\text{ƍ}_{\text{ϗ}0}}\right) \qquad \text{Equation 2-65}$$

2.5.9 Environmental benefits

The price effects attributable to supply shocks from productivity enhancing technologies affect the equilibrium area under production. This area response can be conceptualized as the difference between the quantity/area reflected at the intersection of the shocked supply curve with the pre-shock equilibrium price and the quantity/area reflected at the new price-quantity equilibrium, if the elasticity that defines the supply curve is adjusted to reflect an area response to price.

The difference in area under production has concomitant environmental effects. For example, reduced harvested rice area eliminates methane emissions. The usage of irrigation water is also eliminated if irrigated areas fall out of production. This is calculated in Eq. 2-66 under the supply curve with a positive shutdown price, where $\wp$ is environmental benefits, $\mathfrak{I}_{C02}$ is the marginal unit value of avoided CO2 equivalent greenhouse gas emissions, $\mathfrak{I}_{water}$ is the marginal unit value of reduced irrigation water withdrawls, Å is the CO2 equivalent emissions per hectare of irrigated and rainfed rice, ∀ is the proportion of area irrigated, rainfed and in the irrigated dry season , ∄ is the baseline production area, and the remaining terms are as defined in the producer surplus equations.

$$\begin{aligned}\wp = {} & \mathfrak{I}_{C02}(\text{Å}_{Ir}\forall_{ir} + \text{Å}_{rf}\forall_{rf})\nexists\left(1 - \frac{(KP_1 - m)^d}{(KP_0 - m)^d}\right) \\ & + \mathfrak{I}_{water}(\mathfrak{H}\forall_{ir_{dry}})\nexists\left(1 - \frac{(KP_1 - m)^d}{(KP_0 - m)^d}\right)\end{aligned} \qquad \text{Equation 2-66}$$

Reduced physical rice area may reduce land pressure and deforestation, with attendant preservation of environmental benefits of forested areas. As illustrated in Eq x, the analysis captures this by dividing the change in harvested area according to cropping intensity Ξ to reflect physical area, and multiplying this physical area by the proportion of the spatial unit covered by forest $\mathfrak{R}$, under the assumption that reduced area affects all other land use similarly. This change in forested area is then multiplied by the value of carbon sequestered annually per hectare of forest Θ, plus the annualized value of averted carbon release from cleared forest biomass Ⅎ (Eq. 2-67).

$$\wp = \nexists \left(1 - \frac{(KP_1 - m)^d}{(KP_0 - m)^d}\right)\frac{1}{\Xi}\Re(\Theta + \Finv)$$ **Equation 2-67**

In the case of constant elasticity supply curves, the same formulas are applied with the substitution of

$\left(\frac{{P_1}^{\mathcal{E}}}{{P_0}^{\mathcal{E}}}\right)$ for $\left(\frac{(KP_1 - m)^d}{(KP_0 - m)^d}\right)$. However, the divergence in estimates generated by the functional forms is not large.

These calculations are performed annually by subnational spatial unit in the analysis.

2.5.9.1 Data sources for environmental benefit model

Greenhouse gas emissions coefficients for rainfed and irrigated rice have been sourced from scaling factors recommended by IPCC guidelines (Lasco et al., 2007), converted to CO2 equivalent emissions. Irrigation water usage is assumed to be 7000 cubic meters per hectare in the dry season, and savings are valued at .02PPP$ (2005 price) per cubic meter. Cropping intensity is approximated based on the share of area double-cropped, according to IRRI rice agro-ecological zone statistics per spatial unit. Forest cover data per spatial unit are derived by overlaying administrative boundaries on GlobCover data from the European Space Agency. Forest carbon sequestration values are derived from IPCC guidelines (Penman et al., 2003), and the annualized release of carbon from forest biomass is taken by multiplying the national average natural forest biomass reported by the IPCC by the average carbon content of biomass, and a conversion factor from carbon to CO2, divided by the 23 years covered in the analysis. Averted CO2 equivalent emissions are converted into values by using a (2005) price of PPP$10 per ton.

2.5.10 Aggregation and discounting

Each estimate of net consumer, poor consumer, producer, poor producer, hired labor and poor hired labor surplus change for each scenario and technology in each spatial unit and year is discounted and subsequently aggregated to give summary measures of each type of welfare change over space and time, as per Eq. 2-68.

$$\Delta surplus_{sr_{population}} = \sum \Delta surplus_{itsr_{population}} \; (1 + \text{Ɍ})^t$$ **Equation 2-68**

Effects on DALYs, as non-monetary measures without clear opportunity costs, are aggregated without discounting across years (Eq. 2-69).

$$\Delta DALYs_{sr} = \sum \Delta DALYs_{itsr_{population}}$$ **Equation 2-69**

3 Results

3.1 Characteristics of released varieties

3.1.1 Bangladesh

3.1.1.1 Trends in release

In Bangladesh, the number of varietal releases is relatively small, and appears to have fallen in recent years, as 11 varieties were released in the 2000s, compared with 16 in the 1990s and 13 in the 1980s. Even more surprisingly, with rapidly rising Boro area, the number of Boro releases has fallen from seven in the 1980s, to four in the 1990s and 3 in the 2000s (Table 3.1).

Table 3.1. Trend in releases of inbred rice varieties: Bangladesh, 1970—2009.

Period	Boro	Aman	Aus	All Season
		*Number of releases**		
1970-74	3	1	3	3
1975-79	4	2	4	6
1980-84	4	2	4	6
1984-89	3	2	2	7
1990-94	2	4	3	9
1995-99	2	5	---	7
2000-04	---	2	2	4
2005-09	3	3	1	7
All period	21	21	19	49
		Average release yield, t/ha		
1970-74	5.67	4.00	4.00	4.71
1975-79	5.25	4.00	4.50	4.70
1980-84	5.75	6.50	4.88	5.55
1984-89	6.00	5.25	3.25	5.00
1990-94	6.25	4.88	3.83	4.83
1995-99	5.00	3.90		4.21
2000-04	---	4.50	3.50	4.00
2005-09	6.17	5.23	5.50	5.67
All period	5.71	4.72	4.21	4.90

* Some varieties are recommended for two or all seasons, thus, "All Season" total may be less than the sum.
Source of Data: BRRI Varietal release database

3.1.1.2 Trends in yields of released varieties

There is also little indication of progress in yield over time, as reflected in yield at release (Table 3.1). The highest average period of yields in the Boro season is the early 1990s, while the highest for the Aman season occurs in the late 1980s.

However, there is some indication that unobserved changes in the production environment in Bangladesh may be counteracting genetic gains. In the Aman season, check yield information from the release process was assembled for BR11, the dominant mega-variety, and used to generate a yield trend with variety held constant. The trend is clearly downward, which indicates a growing differential with subsequent releases that maintain the same yield in successive years where BR11 yield falls (Figure 3.1).

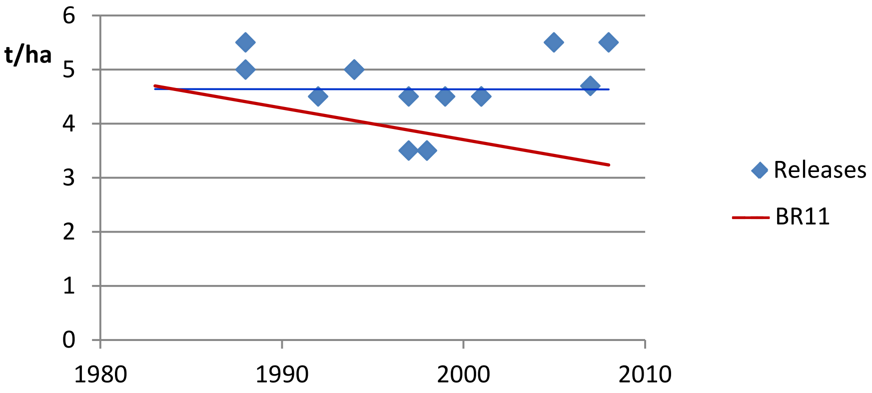

Figure 3.1. Yield releases versus check variety (Aman), Bangladesh.

For the Boro season, check yield information for BR14, the dominant mega variety up until the early 2000s, was assembled for the period from 1983 to 1997, and was used to generate a linear yield trend, which is then compared with release yield. There is a slight downward trend for BR14, compared with a slight upward trend in subsequent releases, which illustrates a possible growing gap over time (Figure 3.2). Much of this is due to the effect of BRRI dhan 29, which is a 1994 release with a yield of 7.5 tons per hectare.

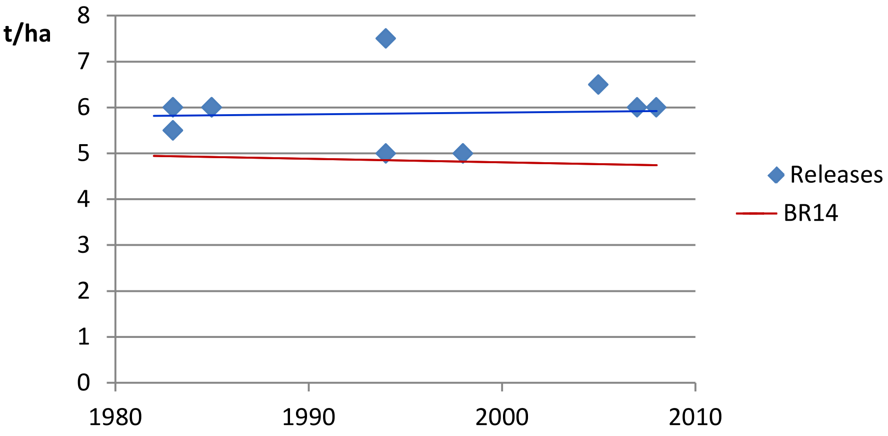

Figure 3.2. Yield of releases versus check variety (Boro), Bangladesh.

3.1.1.3 Resistance of released varieties

Figures 3.3 to 3.6 present the proportion of released varieties with resistance to brown planthopper, blast, bacterial leaf blight and rice tungro disease. There are slight downward trends in the resistant proportions of released varieties to all four pathogens. BPH resistance dips during the mid to late 1990s, before being present again in most varieties. Similarly, blast resistance falls in frequency during the late 1990s. Bacterial leaf blight resistance is fairly flat, with a slight downward trend. Tungro resistance is also more often present in varieties released during the mid 1980s to mid 1990s than thereafter.

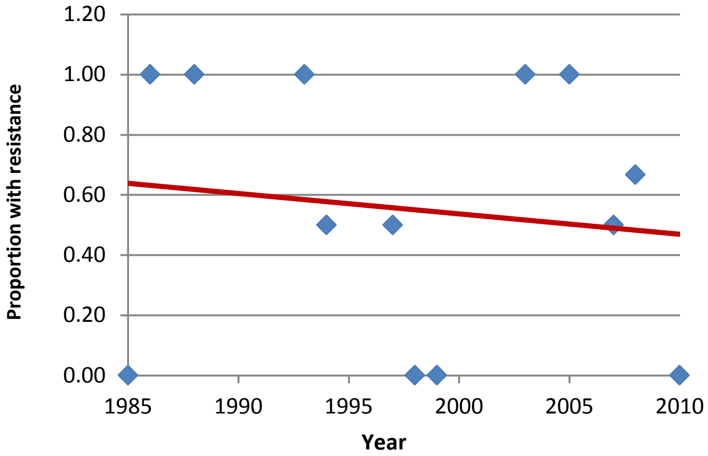

Figure 3.3. Proportion of varieties released with resistance to BPH in Bangladesh, 1985-2010.

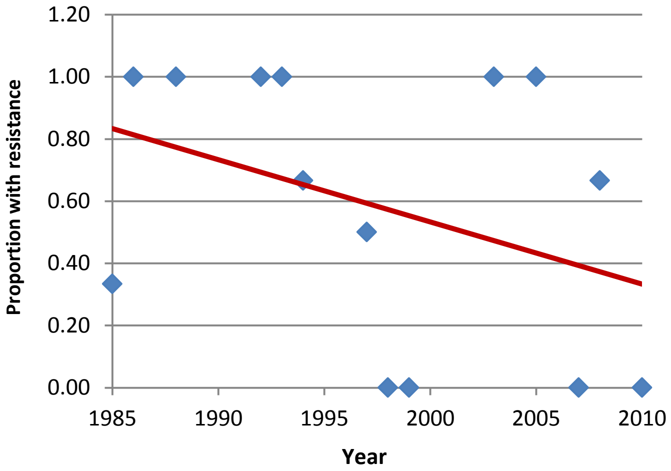

Figure 3.4. Proportion of varieties released with resistance to blast in Bangladesh, 1985-2010.

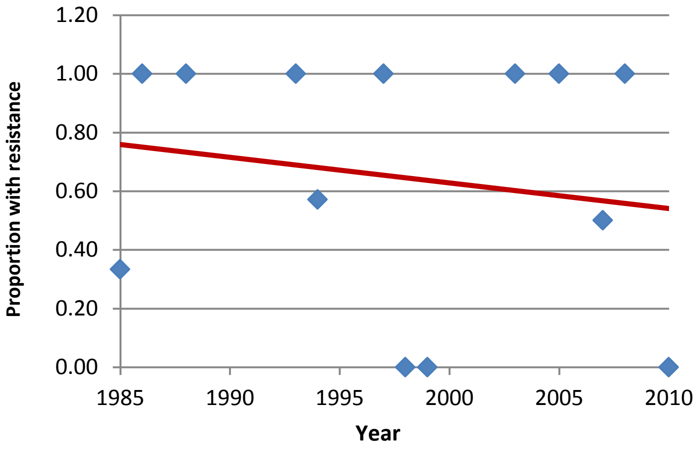

Figure 3.5. Proportion of varieties released with resistance to BLB in Bangladesh, 1985-2010.

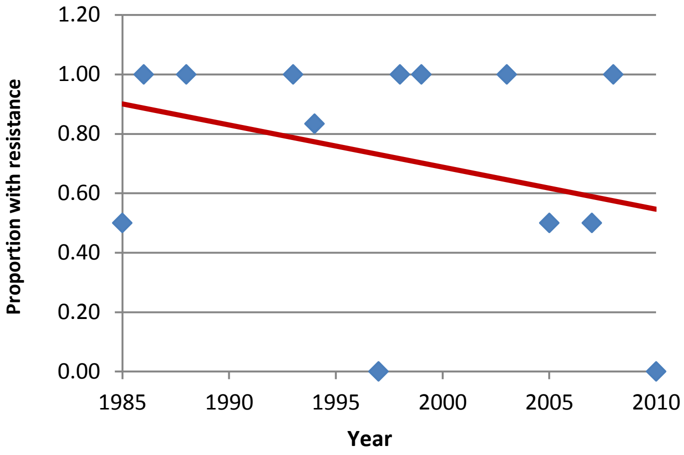

Figure 3.6. Proportion of varieties released with resistance to tungro in Bangladesh, 1985-2010.

3.1.1.4 Trend in IRRI contributions

From the 1970s to the mid 1980s, there was extensive usage of IRRI germplasm, as direct releases as was as parental material (Table 3.2). From the late 1980s, the IRRI genetic contribution began to fall, with increasing usage of national system parents. However, almost all varieties continued to have some usage of IRRI material through the 2000s, primarily as parents.

It should be noted that the genetic contributions presented here are entirely based on the share of pedigree, and do not reflect weighting based on ancestry or give credit for the institution performing the final cross resulting in the variety. Thus, the numbers are not the same as the IRRI credit used in the attribution of benefits in this study, which reflect those factors.

Table 3.2. IRRI genetic material contribution to inbred lowland rice variety released from 1970-2009,Bangladesh.

Period	Number released	IRRI cross	NARES cross IRRI parent(s)	NARES cross IRRI ancestor(s)	NARES cross no IRRI ancestor	IRRI genetic contribution, % (parents)	IRRI genetic contribution, % (GG-parents)
				Bangladesh			
1970-74	3	2	1			83	83
1975-79	6	2	3		1	83	83
1980-84	6	2	4			83	92
1984-89	7	1	5		1	43	61
1990-94	9	2	6	1		28	64
1995-99	7	1	6			14	32
2000-04	4		4			25	69
2005-09	7	2	5			36	65
All period	49	12	34	1	2	46	66

Sources of data:
Bangladesh: BRRI released rice varieties from 1970 to 2010. Bangladesh Rice Research Institute website http://brri.gov.bd/publications/leaflets.htm (last accessed 18 Apr 2013).

3.1.2 Indonesia

3.1.2.1 Trends in release

Indonesia has had a relatively large number of varietal releases per year, compared with Bangladesh (Table 3.3). However, it appears that the varietal output of the national system dipped during the 1990s. In the 1980s, 63 varieties were released, whereas in the 1990s only 18 were released. However, by the 2000s, output recovered with 58 releases. During the 1990s, the breeding focus appeared to be principally on unfavorable environments, whereas the focus became more on irrigated environments in the 2000s.

3.1.2.2 Trends in yields of released varieties

Yields at release have shown strong growth in the 1990s and 2000s in irrigated environments, although they were flat in the 1980s (Table 3.3). Upland varietal yields showed very rapid rates of increase, as well.

To assess whether changes in production conditions may be affecting the rate of gain, check yield information was obtained for IR64, which has many years of observations for the same evaluation sites used in the release process, and was regressed to develop a trend (Figure 3.7). In this case, IR64 check yield is also increasing over time, at roughly 60% of the rate of new varieties. This indicates that changes in weather or management, rather than genetics may be playing a role in the rapid rate of gain in release yield.

Table 3.3. Trend in releases of inbred varieties: Indonesia, 1970-2009.

Period	Irrigated	Upland	Tidal swampy	Plateau	Rainfed	All Ecosystem
			Number of releases			
1970-74	3					3
1975-79	11	2		3		16
1980-84	20	5	3	2		30
1984-89	20	7	3	2	1	33
1990-94	5	6	3			14
1995-99	8	3	3			14
2000-04	28	3	7	2	1	41
2005-09	11	1	5			17
All period	106	27	24	9	2	168
			Average release yield, t/ha			
1970-74	4.88					4.88
1975-79	4.08	*		5.38		4.41
1980-84	4.76	2.75	4.44	4.75		4.40
1984-89	4.87	4.23	4.50	3.70	5.10	4.72
1990-94	5.58	4.13	5.50			5.08
1995-99	6.03	5.25	5.50			5.91
2000-04	6.66	*	*	5.54	*	6.57
2005-09	6.48	*	*			6.48
All period	***5.52***	***3.72***	***4.75***	***5.05***	***5.10***	***5.26***

*Release yield data not available.
Source of Data: ICRR varietal release database

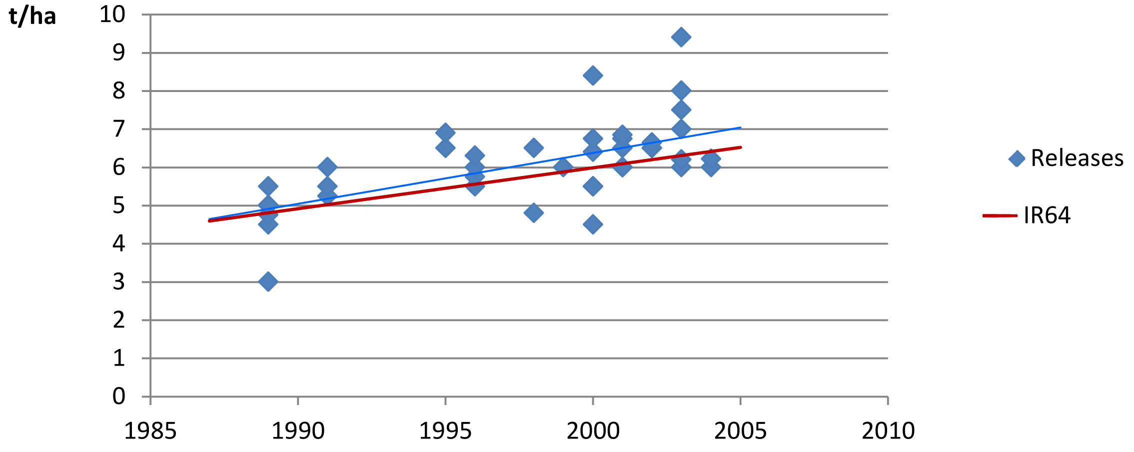

Figure 3.7. Yield of releases versus check variety, Indonesia.

3.1.2.3 Resistance of released varieties

Figures 3.8 to 3.11 present the proportion of released varieties with resistance to brown planthopper, blast, bacterial leaf blight and rice tungro disease. The trend in BPH resistance is flat, with almost all varieties appraised as having resistance at release. The proportion of released varieties with blast resistance has fallen somewhat, largely due to the absence of resistance in varieties released around year 2000, which turn out to be some of the most popular varieties in Indonesia. Bacterial leaf blight resistance is fairly flat, with most varieties resistant over the period. Tungro resistance exhibits a slight decline from a somewhat higher share of (including a majority of popular) resistant released varieties in the 1980s to only a small share of resistant releases in the 2000s.

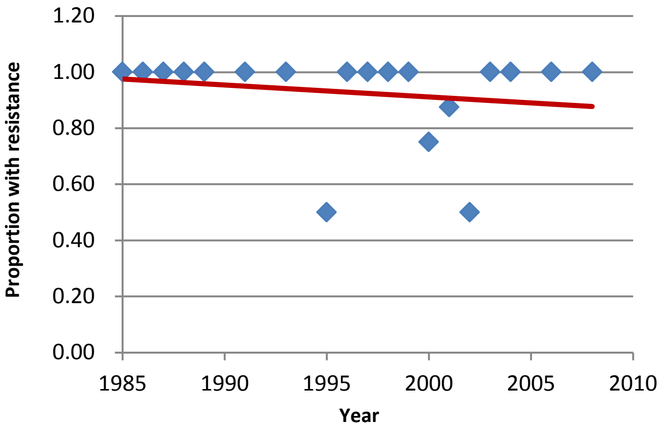

Figure 3.8. Proportion of varieties released with resistance to BPH in Indonesia, 1985-2008.

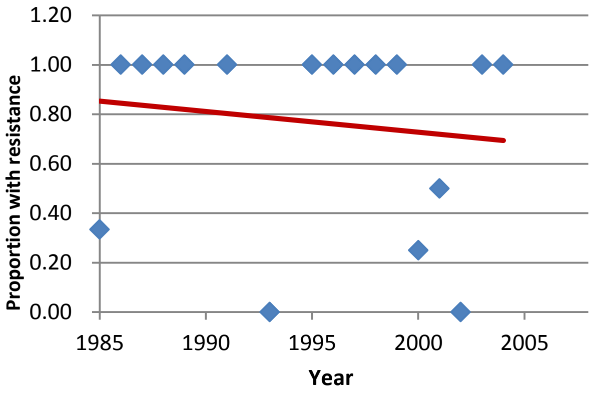

Figure 3.9. Proportion of varieties released with resistance to blast in Indonesia, 1985-2008.

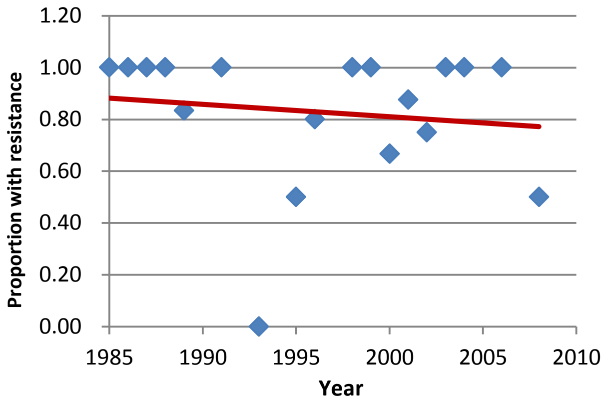

Figure 3.10. Proportion of varieties released with resistance to BLB in Indonesia, 1985-2008.

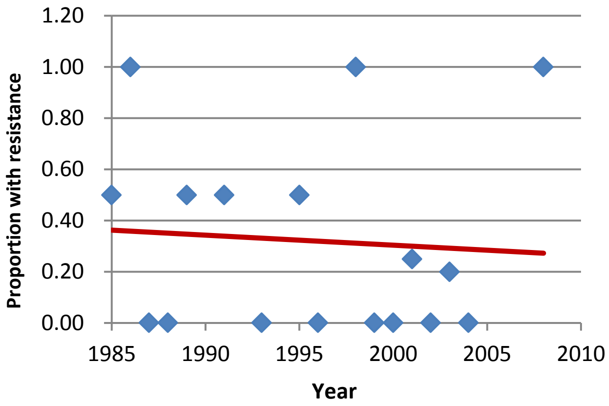

Figure 3.11. Proportion of varieties released with resistance to tungro in Indonesia, 1985-2008.

3.1.2.4 Duration of resistance after release

Expert characterization of the resistance of popular varieties since release to BPH, blast, BLB and tungro was performed, and is summarized in Table 3.4. Tungro resistance is appraised to have the shortest average duration of effectiveness at less than six years, whereas the other resistances have average effective durations of 15 to 17 years.

Table 3.4. Average number of years resistances remain effective in Indonesia in specific popular varieties.

Trait	Duration (year)
Blast	15.69
Bacterial leaf blight	17.36
Tungro	5.64
Brown planthopper	16.06

3.1.2.5 Trends in IRRI contributions

The IRRI genetic contribution to released varieties appears to be relatively stable from the 1980s through the 2000s (Table 3.5). During the late 1990s and early 2000s, there was a dip in the proportion of IRRI crosses released, and there is a slight trend towards increased usage of IRRI materials as ancestors, rather than parents in more recent periods. However, the trends are not strong.

Table 3.5. IRRI genetic material contribution to inbred lowland rice variety released from 1970—2009, Indonesia.

Period	Number released	IRRI cross	NARES cross IRRI parent(s)	NARES cross IRRI ancestor(s)	NARES cross no IRRI ancestor	IRRI genetic contribution, % (parents)	IRRI genetic contribution, % (GG-parents)
1970-74	3	1	2			67	67
1975-79	16	8	4	2	2	72	78
1980-84	30	9	10	9	2	49	69
1984-89	33	14	13	2	4	61	73
1990-94	14	3	7	2	2	43	58
1995-99	14	1	11	2		58	74
2000-04	41	7	21	12	1	50	70
2005-09	17	7	4	6		50	51
All period	168	50	72	35	11	55	68

Sources of data:
Rice germplasm information system. Balai besar penelitian tanaman padi. Available online at http://bbpadi.litbang.deptan.go.id/plasma/index.php?main=unggul_daftar (last accessed 18 Apr 2013).
Suprihatno et al. 2010. Deskripsi varietas padi. Subang: Balai Besar Penelitian Tanaman Padi. 105 p.

3.1.3 Philippines

3.1.3.1 Trends in releases

Among the countries in this study, the Philippines has the greatest number of releases per unit rice area (Table 3.6). Moreover, the number of releases per year is growing over the period, aside from during the late 1980s. Prior to the 1990s, no varieties were released for rainfed lowand systems. However by the late 1990s, more varieties were released for rainfed and upland systems than irrigated environments. In the 2000s, the focus became again on irrigated environments.

3.1.3.2 Trends in yields of released varieties

Release yields were largely flat from the 1970s to the 1980s (Table 3.6). However, in the 1990s yields started to grow, with the fastest growth realized in the late 2000s in irrigated environments. Rainfed yields appear to be flat over the period. When rainfed yields are included, average yields of released varieties falls in the 1990s, before growing in the 2000s.

To help determine if changes in production conditions may be affecting the rate of yield gain, check yield information was obtained for PSBRc18, a popular 1996 irrigated release which has many years of observations for the same evaluation sites used in the release process, and this is used to develop a trend (Figure 3.12). In this case, the PSBRc 18 check yield is very slightly decreasing over time, whereas there is a clear upward trend in the yields of later irrigated varietal releases. This suggests that changes in genetics, rather than weather or environmental conditions, are responsible for the upward trend in release yield.

Table 3.6. Trend in releases of inbred varieties: Philippines, 1970-2009.

Period	Irrigated	Rainfed	Upland	All Ecosystem
		Number of releases		
1970-74	6		1	7
1975-79	15		3	18
1980-84	10		2	12
1984-89	8			8
1990-94	9	3	1	13
1995-99	13	5	2	20
2000-04	21	3	3	27
2005-09	27	2		29
All period	109	13	12	134
		Average release yield, t/ha		
1970-74	*		*	
1975-79	4.88		*	4.88
1980-84	4.80		*	4.80
1984-89	4.80			4.80
1990-94	4.96	3.55	*	4.64
1995-99	5.13	3.13	*	4.58
2000-04	5.19	*	*	5.19
2005-09	5.77	*		5.77
All period	5.16	3.30		4.98

*Release yield data not available
Source of Data: PhilRice varietal release database

The proportion of released varieties with resistance to brown planthopper, blast, bacterial leaf blight and rice tungro disease is presented in Figures 3.13 through 3.16.

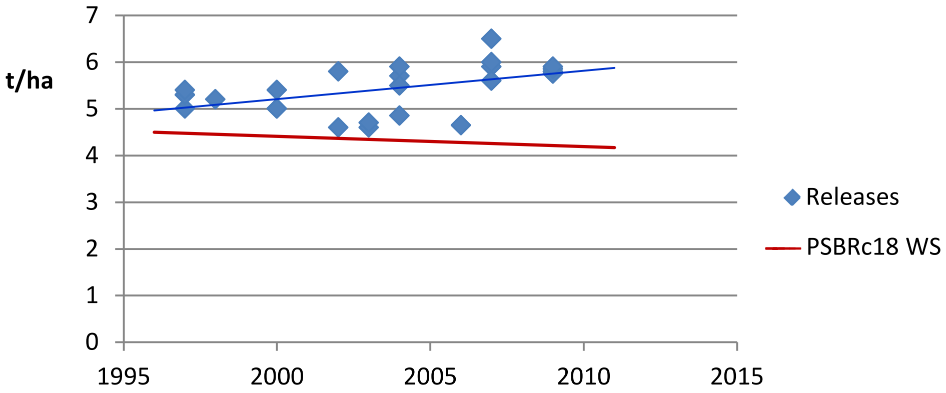

Figure 3.12. Yield of releases versus check variety, Irrigated, Philippines.

The trend in BPH resistance is flat from the early 1990s onward. After nearly universal resistance in varieties released in the 1980s and 1990s, blast resistance becomes much more intermittent in subsequent periods. Bacterial leaf blight resistance is present in all varieties until the late 1990s, after which it starts to be absent from some released varieties, causing a downward trend, particularly in the late 2000s. Tungro resistance exhibits a marked decline from a majority of resistant released varieties in the 1980s to only a small share of resistant releases in the 2000s.

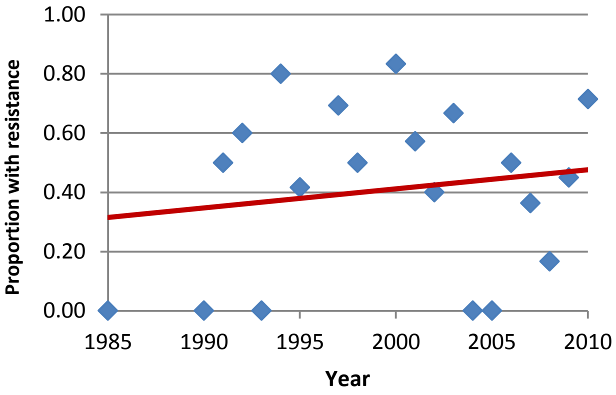

Figure 3.13. Proportion of varieties released with resistance to BPH in the Philippines, 1985-2010.

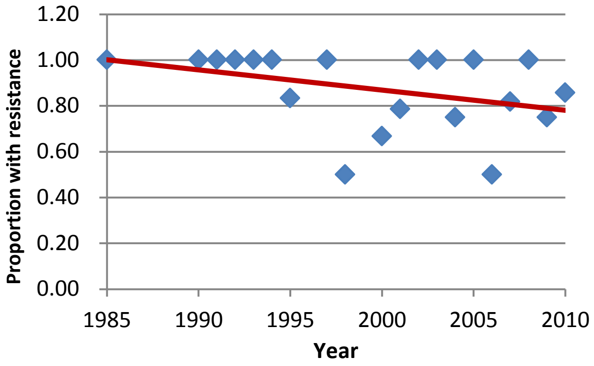

Figure 3.14. Proportion of varieties released with resistance to blast in the Philippines, 1985-2010.

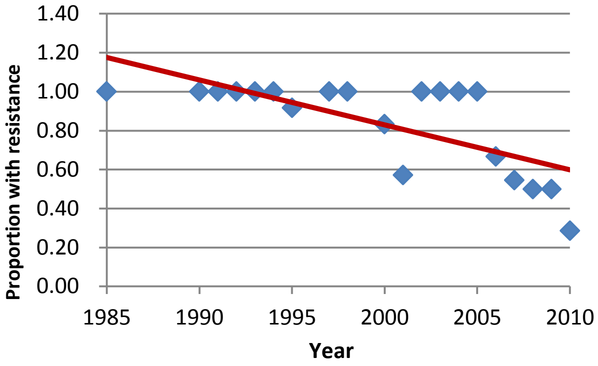

Figure 3.15. Proportion of varieties released with resistance to BLB in the Philippines, 1985-2010.

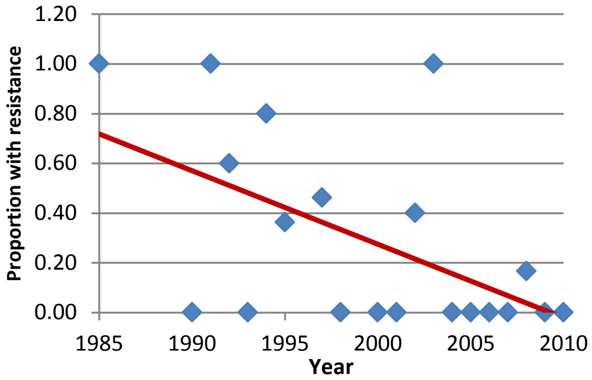

Figure 3.16. Proportion of varieties released with resistance to tungro in the Philippines, 1985-2010.

3.1.3.3 Duration of resistance after release

Expert characterization of the resistance of popular varieties since release to BPH, blast, BLB and tungro was performed, and is summarized in Table 3.7. Tungro resistance is appraised to have the shortest average duration of effectiveness at six years, whereas the other resistances have average effective durations of 10 to 15 years.

Table 3.7. Average number of years resistances remain effective in the Philippines in specific popular varieties.

Trait	Duration (year)
Blast	12.56
Bacterial leaf blight	14.99
Tungro	6.13
Brown planthopper	9.93

3.1.3.4 Trends in IRRI contributions

There is considerable stability in IRRI's genetic contribution to new varieties released in the Philippines from the 1970s through the 2000s (Table 3.8). In the 1990s and 2000s, there is a trend towards using IRRI varieties more as parental and ancestral materials, with a smaller share of releases directly from IRRI. However, a higher share of varieties is derived from IRRI materials over time, counteracting this trend to keep the IRRI genetic share stable.

Table 3.8. IRRI genetic material contribution to inbred lowland rice variety released from 1970-2009, Philippines.

Period	Number released	IRRI cross	NARES cross IRRI parent(s)	NARES cross IRRI ancestor(s)	NARES cross no IRRI ancestor	IRRI genetic contribution, % (parents)	IRRI genetic contribution, % (GG-parents)
1970-74	7	3			4	57	57
1975-79	18	14	3		1	75	75
1980-84	12	7		1	4	58	60
1984-89	8	7	1			94	94
1990-94	13	7	6			77	74
1995-99	20	11	7		2	75	76
2000-04	27	14	10	3		63	64
2005-09	29	11	11	5	2	53	61
All period	134	74	38	9	13	67	69

Sources of data: Crop variety database. National Seed Industry Council, Bureau of Plant Industry, Department of Agriculture. Available online at http://skyapp.koding.com/cropdbase/display.php?sort=all (last accessed 18 Apr 2013).

Pedigree data: International Rice Information System. Philippines: International Rice Research Institute. Available online at www.iris.irri.org/germplasm/# (last accessed 18 Apr 2013).

3.2 Adoption

3.2.1 Varietal adoption in the Bangladesh Boro season

To represent Boro adoption nationally, two larger survey datasets were used, compared with the econometric analysis. As the datasets from 2004 and 2010, the progression of adoption prior to 2004 is based on the year of varietal release. In addition, the varietal classification for other major varieties differs between the 2004 and 2010 surveys. As a result, it is not possible to determine the adoption progression of individual other varieties over time, but it is possible to assess progression of the two dominant varieties – BRRI dhan 28 and 29. Adoption of these varieties progresses rapidly until the mid 2000s, with BRRI dhan 29 rising more rapidly until 28 catches up with to have equal areas shares in the late 2000s, at which point 2/3 of Boro area is covered by the two varieties (Figure 3.17).

3.2.2. Varietal adoption in Indonesia

Adoption is relatively stagnant in Indonesia from 1990 until the early 2000s, with more than half of area covered by IR64 (Figure 3.18). However, in 2003 Ciherang rapidly expands to displace IR64, and an array of other new varieties occupies large portions of area, including Cigeulis, Mekongga, and Ciliwung. By the late 2000s, Ciherang occupies more than half of paddy area in Indonesia.

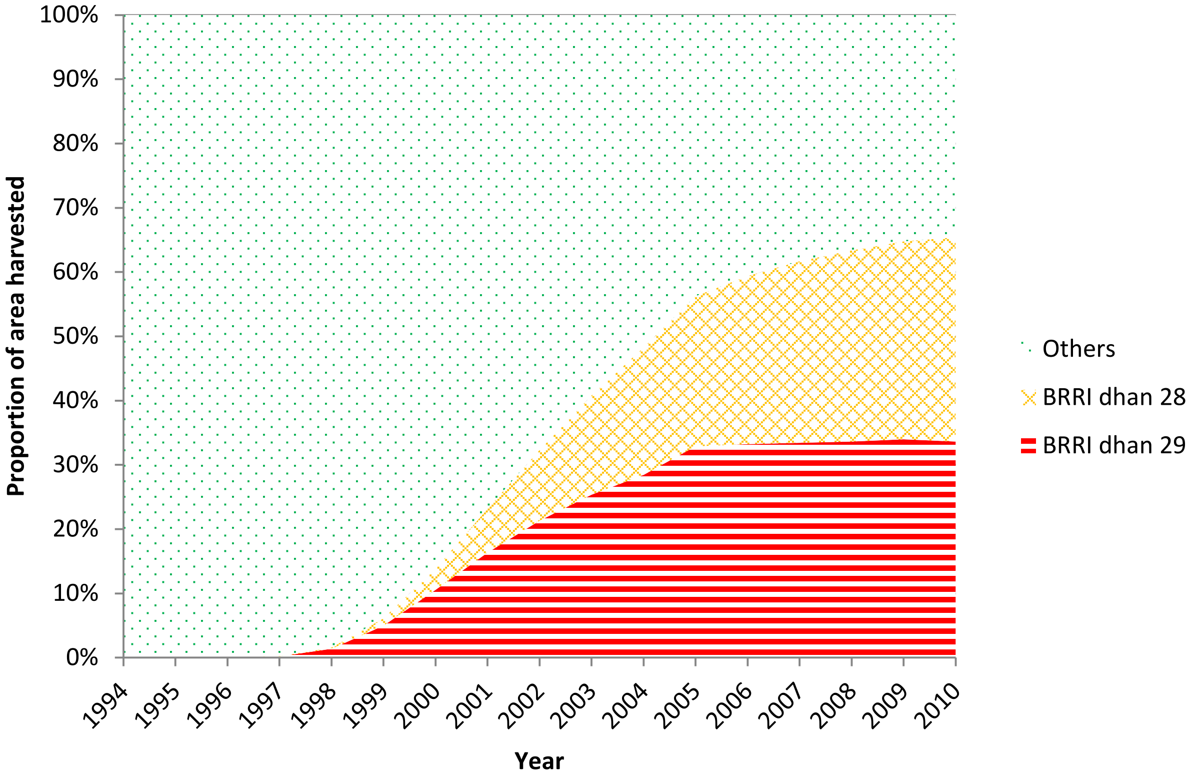

Figure 3.17. Proportion of area planted to BRRI dhan 28 & 29 in Bangladesh, 1994-2010.

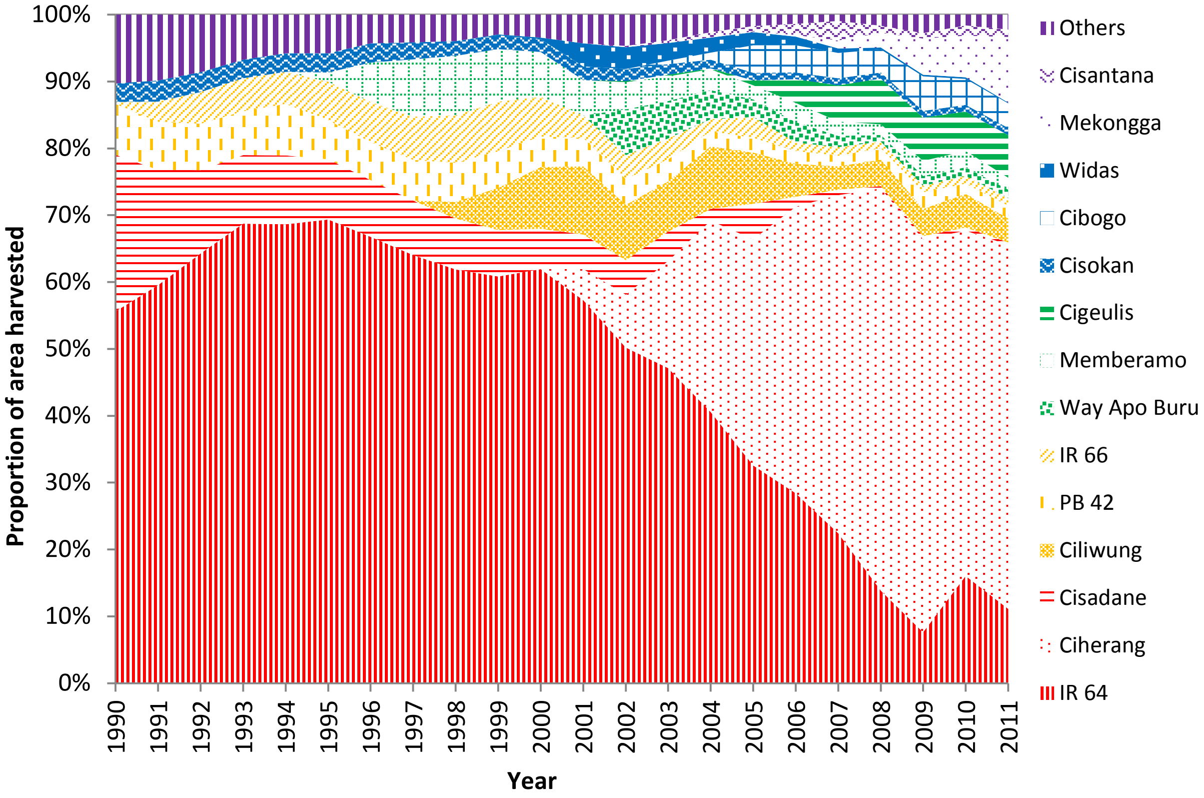

Figure 3.18. Proportion of modern varietal harvested area planted to specific varieties during 1990 to 2011 in Indonesia.

3.2.2.1 Release yield of adopted varieties in Indonesia

The stagnation of varietal replacement in the 1990s, followed by rapid turnover in the 2000s is mirrored in the weighted release yield of adopted varieties (Figure 3.19). Here, the average release yield of adopted varieties changes little between 1990 and 2000, then rapidly rises in the 2000s. By the late 2000s, the average release yield of adopted varieties had risen by nearly 20%, compared with the early 1990s. This increase is almost entirely driven by the adoption of 1990 and later varieties. When those varieties are eliminated in the "no 1990 and later MV" counterfactual, the average release yield of adopted varieties is not changing over time. The 1990 and later varieties that have driven the rise in adopted release yield have substantial IRRI genetic contributions, as nearly half of the gain is eliminated under a counterfactual scenario in which those contributions are removed.

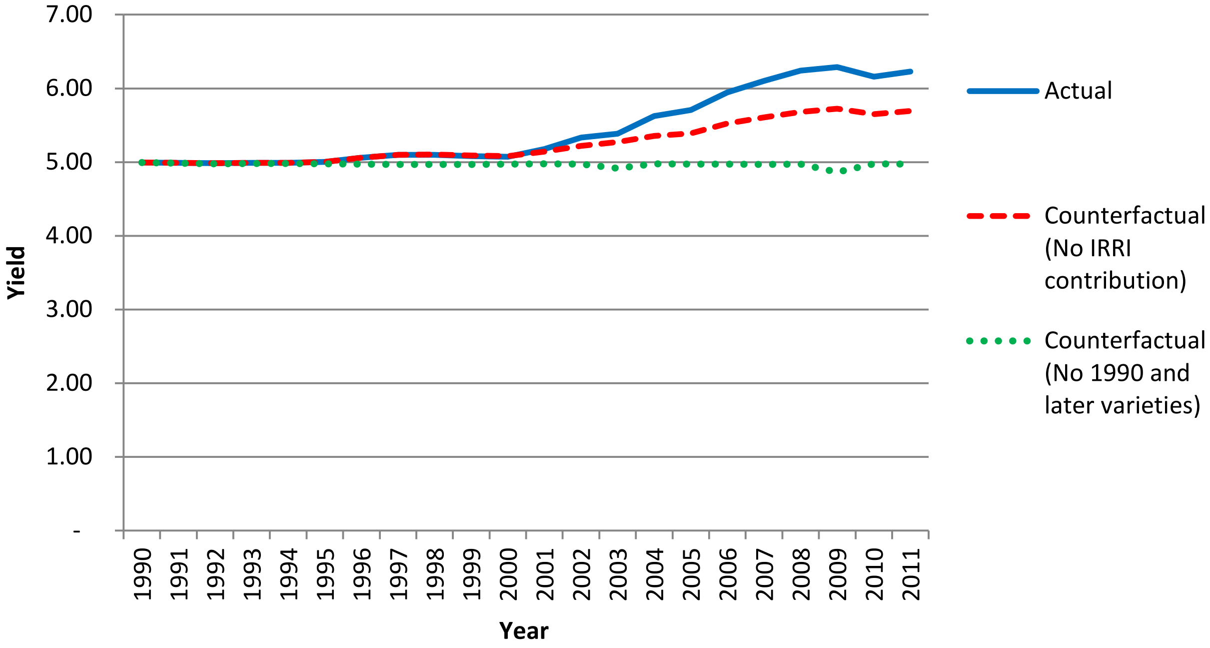

Figure 3.19. Average weighted release yields of adopted varieties during 1990 to 2011 in Indonesia.

3.2.2.2 Adoption of varieties with brown planthopper resistance in Indonesia

The adoption of varieties with BPH resistance is similar in the late 2000s to the early 1990s (Figure 3.20). However, in the period there is considerable fluctuation in adoption rates. In the late 1990s, the leading varieties in Indonesia lost effective BPH resistance, according to expert characterization of resistances. As a result, resistance dramatically declines from a majority of rice area to a very small share in only a few years. However, the diffusion of varieties in the 1990s and 2000s appears to have restored resistance coverage. In the counterfactual scenario in which post 1989 varieties are eliminated, resistance diffusion remains at 10 to 20% of area, rather than rising to over 80% by the late 2000s. Approximately half of the gain in resistance coverage due to newer varieties appears to be attributable to IRRI genetic contributions.

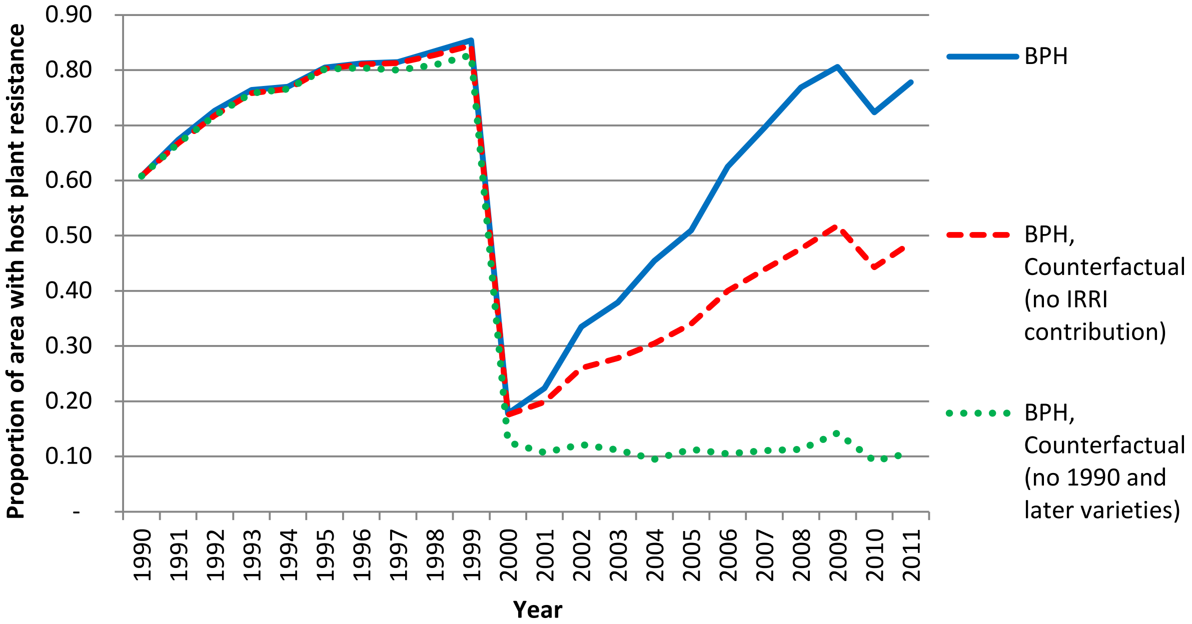

Figure 3.20. Proportion of harvested area under BPH resistant varieties during 1990 to 2011 in Indonesia.

3.2.2.3 Adoption of varieties with blast resistance in Indonesia

The pattern is very different in the case of blast host plant resistance, where the actual area under resistant varieties declines by nearly 60% from the early 1990s to the late 2000s (Figure 3.21). Here, the older varieties that remain popular, even when taking changes in resistance effectiveness into account since release, are more resistant than the varieties released after 1989. Thus, if the latter are eliminated, the area under blast resistance remains at above 90% in the late 2000s, rather than at the actual level of 35%. Approximately half of the decline is attributable to IRRI, according to the IRRI contribution share to the newer varieties.

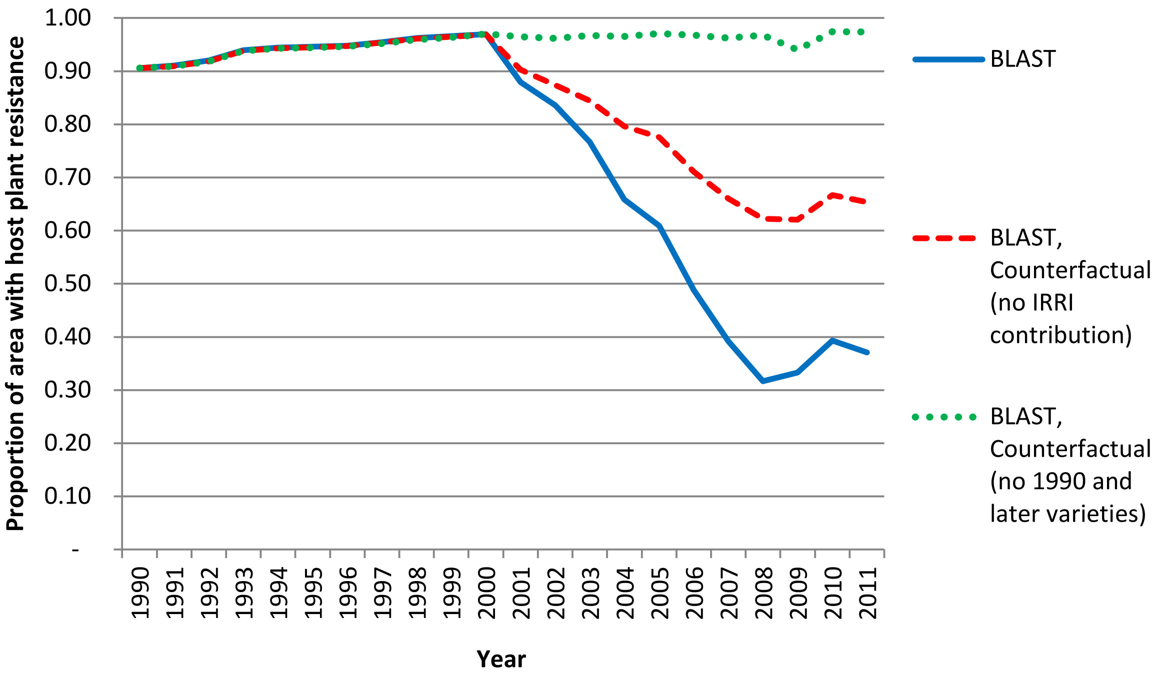

Figure 3.21. Proportion of harvested area under blast resistant varieties during 1990 to 2011 in Indonesia.

3.2.2.4 *Adoption of varieties with bacterial leaf blight resistance in Indonesia*

In the early 1990s, nearly all of Indonesian paddy area falls under BLB resistant varieties. However, BLB resistance became ineffective for leading varieties in the mid 1990s, according to the expert consultations, leading to a dramatic decline in area under resistance. From the mid 1990s until the mid 2000s, the diffusion of newer resistant varieties replenished the area under resistance. However, in the mid 2000s, the resistance in leading varieties again became ineffective, such that less than 30% of paddy area has effective resistance (Figure 3.22).

Accordingly, there is a period from the mid 1990s to the mid 2000s in which there is a large difference between the actual area under resistance and the counterfactual in which the post 1989 varieties are eliminated. However, by the late 2000s, this difference disappears, and the counterfactual actually has slightly lower area under effective resistance. The no IRRI counterfactual again here reflects about half of the difference between the actual and the no 1990 and later MV counterfactual.

3.2.2.5 Adoption of varieties with tungro resistance in Indonesia

In the mid 1990s, the most popular varieties in Indonesia have been characterized as no longer having effective resistance to rice tungro diseases. As a result, the actual area under resistance declines dramatically from over 70% of area to 20% (Figure 3.23). Post 1989 varieties adopted in the late 1990s cause resistance to rise again to nearly 30% by year 2000, before declining again. Under the counterfactual no post 1989 MV scenario, resistance coverage remains at approximately 15% of area from the mid 1990s onward. The without IRRI scenario is similar to the actual scenario, indicating little IRRI contribution to resistance diffusion through post 1989 varieties.

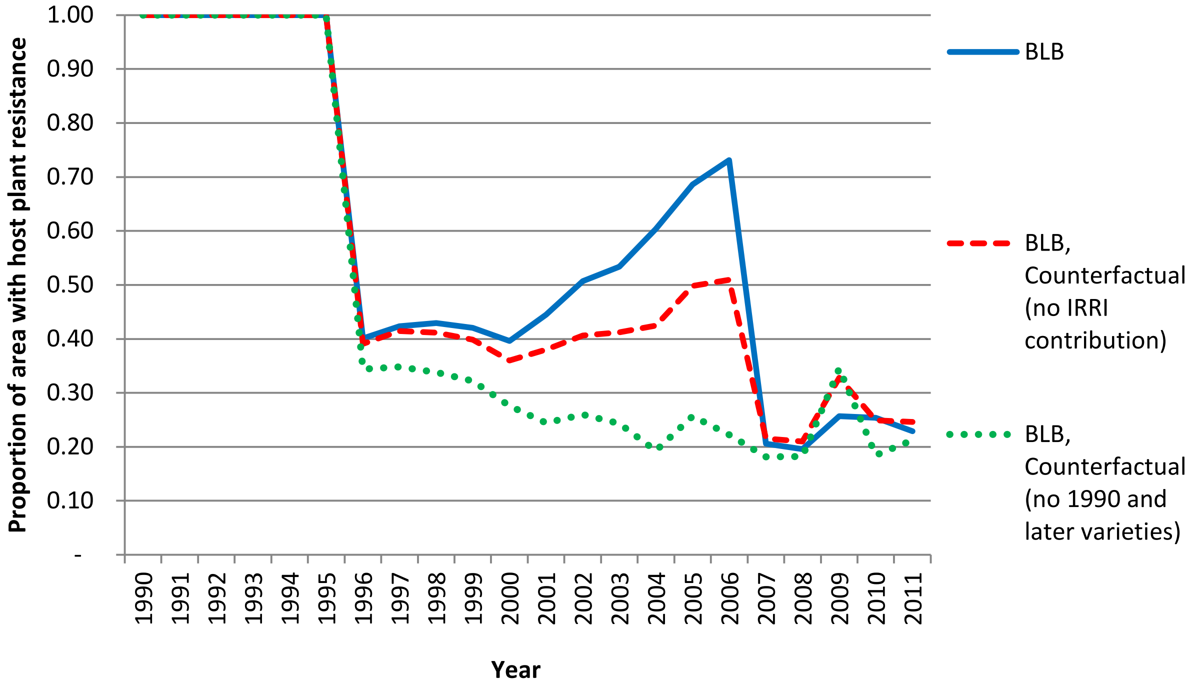

Figure 3.22. Proportion of harvested area under BLB resistant varieties during 1990 to 2011 in Indonesia.

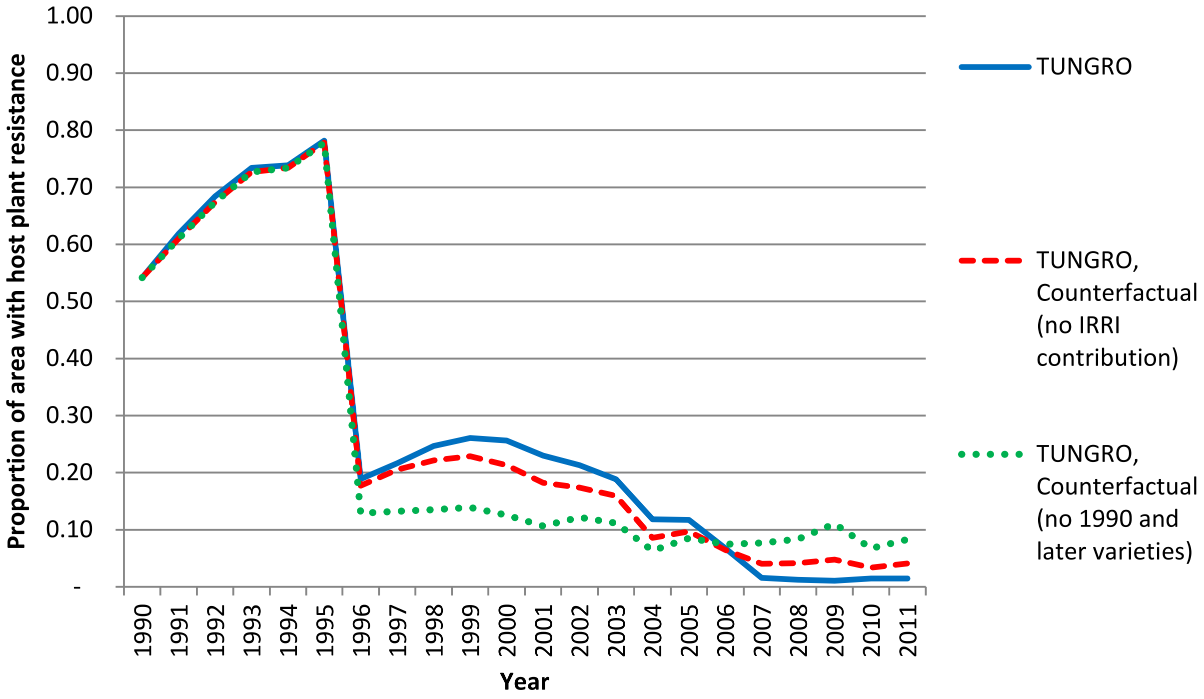

Figure 3.23. Proportion of harvested area under tungro resistant varieties during 1990 to 2011 in Indonesia.

3.2.3 Varietal adoption in the Philippines

The Philippines exhibits the highest level of varietal diversity among the countries in the study, as well as the most rapid varietal replacement (Figure 3.24). In the span of 20 years, the leading varieties change from IR64 to PSBRc18 to PSBRc82 and by the dry season of 2012, NSIC 222. Moreover, the varietal diversity is increasing over the period.

Surprisingly, however, the rapid turnover does not translate into rapid rise in the average release yield of adopted varieties (Figure 3.25). The average varietal release yield climbs slowly but steadily over the period, with an 8% increase from the early 1990s to late 2000s. In the no 1990 and later MV counterfactual, the average release yield of adopted varieties changes very little but with a slight decrease in the late 2000s compared with the early 1990s. The average release yield in the no IRRI contribution scenario is almost the same with the actual in the early 1990s. It declines and remains stable in the late 1990s to mid 2000s then rises in the late 2000s.

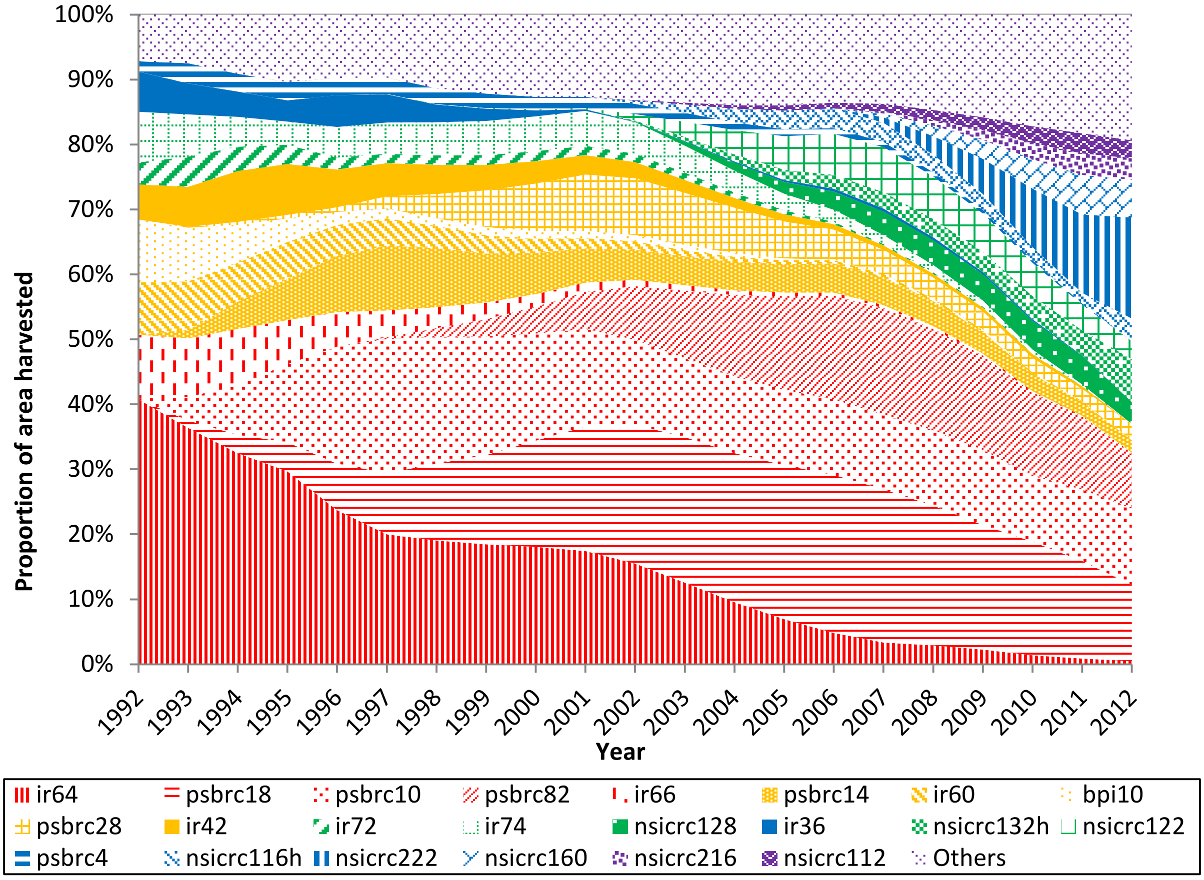

Figure 3.24. Proportion of modern varietal harvested area planted to specific varieties during 1992 to 2012 in the Philippines.

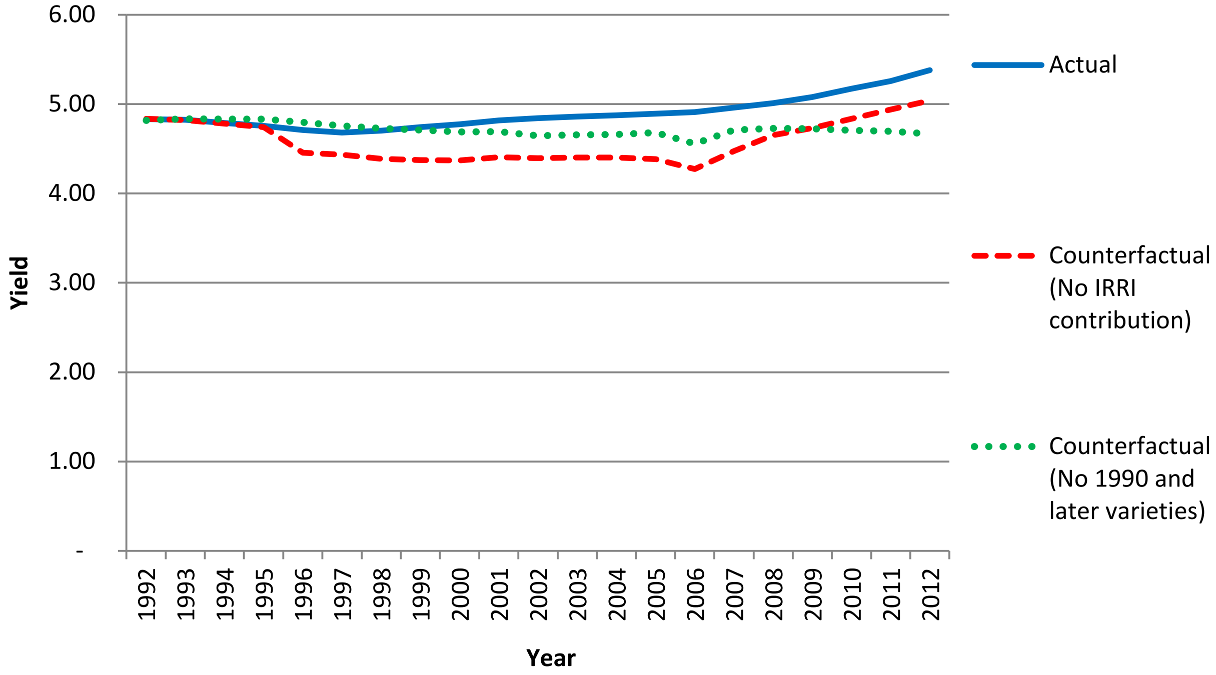

Figure 3.25. Average weighted release yields of adopted varieties during 1992 to 2012 in the Philippines.

3.2.3.1 Adoption of varieties with brown planthopper resistance in the Philippines

The Philippines appears not to exhibit the dramatic changes in resistance area presented previously for Indonesia, probably as a result of greater varietal diversity, such that the change of resistance status for an individual variety has less effect on total area under resistance. For BPH resistance, the actual area covered by resistant varieties is relatively stable over the period, with a slight decline over the 2000s (Figure 3.26). In the absence of post 1989 varieties, resistance is also fairly stable over the period, although at a slightly lower level of coverage. In the absence of IRRI germplasm contributions, resistance cover would be slightly reduced over the period, with the greatest change in the early 2000s.

3.2.3.2 Adoption of varieties with blast resistance in the Philippines

Actual area under blast resistant varieties remains fairly stable from the early 1990s to the mid 2000s, with a minor decline afterward (Figure 3.27). In the absence of 1990 and later varieties, the area under blast resistant varieties would have fallen from 70% to 50% by the early 2000s. The without IRRI scenario has almost the same trend with the no 1990 and later varieties counterfactual although slightly higher from the early 1990s to mid 2000s and lower in the late 2000s.

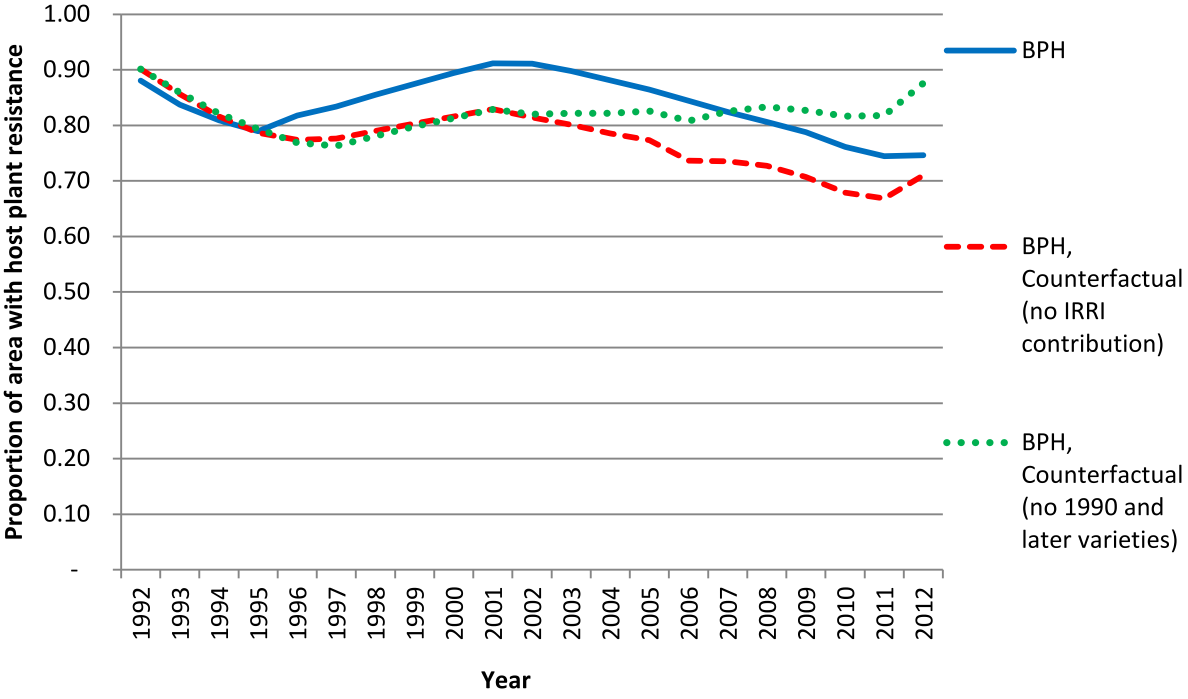

Figure 3.26. Proportion of harvested area under BPH resistant varieties during 1992 to 2012 in the Philippines.

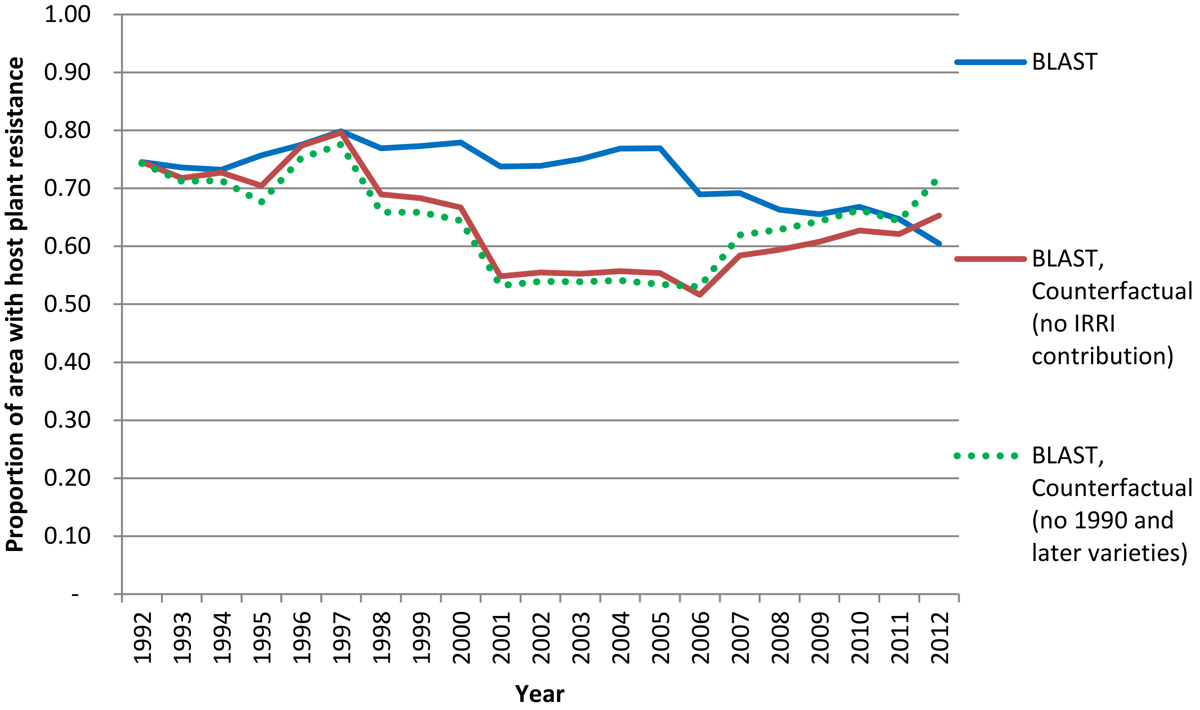

Figure 3.27. Proportion of harvested area under blast resistant varieties during 1992 to 2012 in the Philippines.

3.2.3.3 Adoption of varieties with bacterial leaf blight resistance in the Philippines

The actual adoption levels for BLB resistant varieties are relatively stable over the period, but decline slightly in the late 2000s from initial values near 100% to about 90% of area (Figure 3.28). In the absence of the adoption of post 1989 varieties, resistance coverage is only slightly reduced in the 2000s. The counterfactual in the absence of IRRI contributions to the post 1989 varieties is similar to the no post 1989 MV counterfactual during the early to mid 2000s, after which it is close to the actual values in the late 2000s.

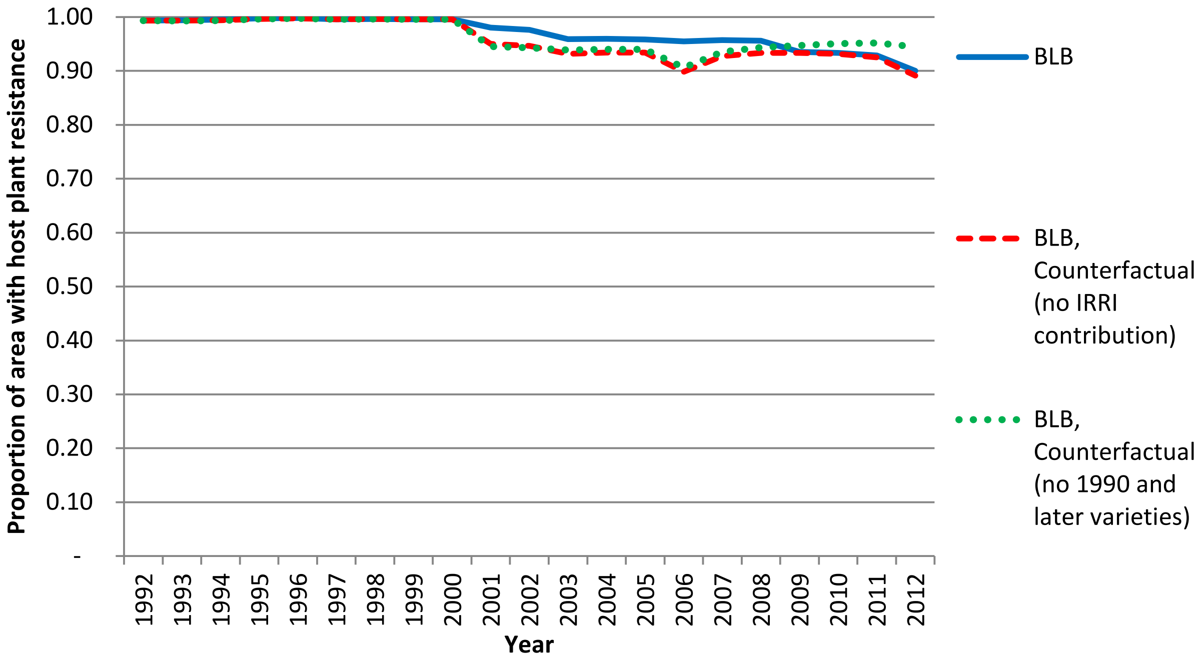

Figure 3.28. Proportion of harvested area under BLB resistant varieties during 1992 to 2012 in the Philippines.

3.2.3.4 Adoption of varieties with tungro resistance in the Philippines

In a similar manner to Indonesia, the actual area under tungro resistant varieties declines dramatically over the period from nearly all of area to less than 10% of area (Figure 3.29). In the absence of post 1989 varieties the resistance area also declines, but not as rapidly, which indicates that the area decline is a largely function of absence of resistance in new varieties, rather than only existing resistance becoming ineffective. The no IRRI contribution to post 1989 varieties counterfactual has higher area under effective resistance compared to the actual in the 1990s, after which it jumps up to near the no post 1989 varietal counterfactual. This indicates a lower prevalence of tungro resistance in IRRI related varieties than non-IRRI varieties.

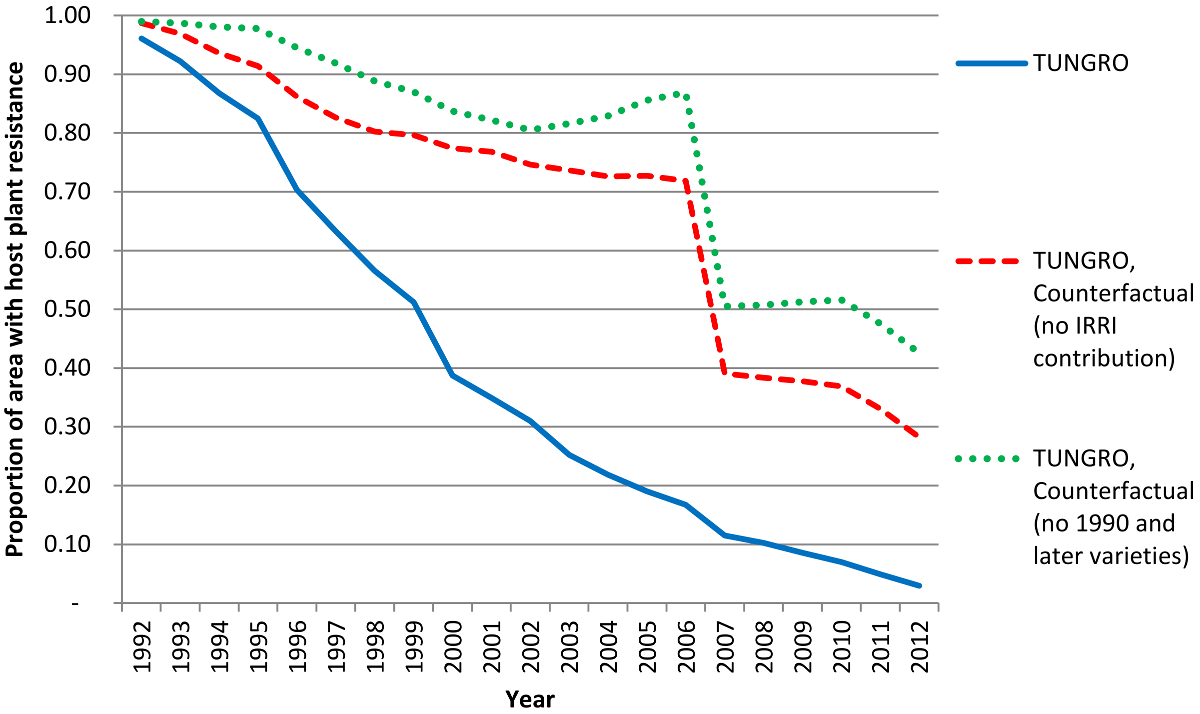

Figure 3.29. Proportion of harvested area under tungro resistant varieties during 1992 to 2012 in the Philippines.

3.3 Econometric identification of yield effects

3.3.1 Bangladesh

In Bangladesh, the Cobb Douglas fixed effects production function with dummy variables for BRRI dhan 28 and 29 find significant yield contributions relative to the varieties that they replace. Interpretation of these coefficients against the log transformed yield dependent variable suggests that BRRI dhan 29 has an attributable yield advantage of 8.31%, while BRRI dhan 28 increases yields by 6.54%, relative to replaced varieties (Table 3.9).

Table 3.9. Rice varietal yield trait effect: A fixed-effects model, Bangladesh.

Dependent variable: Paddy yield	**Coefficient**	**t-statistic**
Fertilizer	0.0222 ns	0.64
BR28 dummy	0.0637 **	2.32
BR29 dummy	0.0800 ***	3.73
Pest	-0.2451 ***	-5.32
Flood	-0.2225 ns	-1.38
Drought	-0.1706 **	-2.66
Hail	-0.2308 **	-2.08
Others	-0.2521 ***	-4.42
Irrigation	-0.3931 ns	-1.58
Intercept	1.9050 ***	6.20
N	*1271*	
R^2 *(within)*	*0.163*	
F(df)	*8.87 ****	*df(9,754)*

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3.9b. Description of variables used in Table 3.9 model, Bangladesh, boro season, 2000-2008

	No of farmers	**Mean/ Freq**	**Std. Dev./ %**	**No of farmers**	**Mean/ Freq**	**Std. Dev./ %**	**No of farmers**	**Mean/ Freq**	**Std. Dev./ %**
		2000			***2004***			***2008***	
Dependent variable:									
Yield, t/ha	375	5.27	1.40	421	5.25	1.35	475	5.50	1.29
Independent variables:									
Fertilizer, kg/ha	375	234.64	81.99	421	241.68	79.06	475	236.14	66.94
BRRI dhan 28 dummy = 1	375	55	14.67%	421	95	22.57%	475	137	28.84%
BRRI dhan 29 dummy = 1	375	31	8.27%	421	144	34.20%	475	253	53.26%
Pest dummy = 1	375	22	5.87%	421	32	7.60%	475	18	3.79%
Flood dummy = 1	375	19	5.07%	421	3	0.71%	475	4	0.84%
Drought dummy = 1	375	4	1.07%	421	29	6.89%	475	3	0.63%
Hail dummy = 1	375	0	0.00%	421	5	1.19%	475	9	1.89%
Others dummy = 1	375	6	1.60%	421	51	12.11%	475	27	5.68%
Irrigation source dummy = 1	375	369	98.40%	421	417	99.05%	475	466	98.11%

Source of data: BIDS-IRRI 62 village panel survey data

3.3.2 Indonesia

3.3.2.1 Changes in release yield of adopted varieties

In Indonesia, the Cobb Douglas fixed effects production function finds a significant coefficient of 0.43, indicating a 0.43% increase in actual yield per 1% increase in the release yield of adopted varieties (Table 3.10). This value is consistent with the coefficient returned for the dry season in the Philippines.

If varietal release yield is truly comparable over time, this elasticity value suggests that increased varietal release yield increases the gap between attainable yield and actual yield, as only a minority of increases in attainable yield are being captured on farm. Part of this may accord with the reduced prevalence of resistant varieties over time, which means that pest losses would reduce the effects of gains achieved. In terms of abiotic stresses, however, there is a positive correlation between release yield and appraised drought tolerance. Another plausible explanation may relate to changes in the conditions under which varieties are being evaluated over time. If trials are being conducted under management that is improving over time, or the conditions for trials (such as solar radiation and temperature) have become progressively more favorable, changes in release yields may conflate these effects with improvements of genetic potential.

Table 3.10. Rice varietal yield trait effect: A fixed-effects model, Indonesia.

Dep. Var.: Paddy yield	Coefficient	t-statistic
Yield trait	0.4278 ***	6.10
Fertilizer	0.0686 **	2.67
Irrigation	-0.0485 **	-2.15
Dry harvested area	0.0222 ns	0.55
Flood	-0.0037 ***	-3.80
Drought	-0.0030 ***	-3.57
Intercept	0.4135 **	2.10
N	209	
R^2 (within)	0.662	
F(6,22)	42.67 ***	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3.10b. Description of variables used in Table 3.12 model, 23 provinces of Indonesia, dry season, 1996--2010.

	No of provinces	Mean	Std. Dev.	No of provinces	Mean	Std. Dev.	No of provinces	Mean	Std. Dev.	No of provinces	Mean	Std. Dev.
Dependent variable:	***1996***			***2000***			***2001***			***2002***		
Yield, t/ha	20	3.71	0.94	23	3.84	0.91	20	4.00	0.80	22	3.90	0.90
Independent variables:												
Release yield, t/ha	20	4.99	0.14	23	5.08	0.20	20	5.07	0.26	22	5.21	0.27
Fertilizer, kg/ha	20	190.30	114.71	23	238.47	125.31	20	270.73	131.04	22	273.38	125.90
Irrigated area, %	20	69.39	18.57	23	69.64	18.47	20	61.97	26.91	22	61.51	26.43
Dry season area share, %	20	48.46	15.16	23	50.85	13.46	20	53.03	13.88	22	53.87	13.52
Area damaged by flood, %	20	0.38	0.57	23	1.20	2.28	20	1.43	2.15	22	1.42	2.53
Area damaged by drought, %	20	0.42	0.67	23	0.69	1.38	20	0.86	1.32	22	3.10	5.61
Dependent variable:	***2003***			***2004***			***2005***			***2006***		
Yield, t/ha	22	4.04	0.83	23	4.03	0.86	14	4.38	0.74	14	4.36	0.76
Independent variables:												
Release yield, t/ha	22	5.34	0.30	23	5.49	0.37	14	5.62	0.43	14	5.88	0.40
Fertilizer, kg/ha	22	308.12	129.00	23	321.93	135.09	14	336.35	128.14	14	331.53	129.09
Irrigated area, %	22	60.74	27.06	23	58.70	28.07	14	62.33	28.33	14	62.46	28.06
Dry season area share, %	22	55.68	15.12	23	52.25	13.35	14	54.52	15.36	14	53.13	15.55
Area damaged by flood, %	22	3.18	9.21	23	1.99	2.79	14	1.58	1.63	14	3.13	5.16
Area damaged by drought, %	22	2.37	3.24	23	2.47	4.43	14	0.91	1.79	14	3.30	5.57
Dependent variable:	***2007***			***2008***			***2009***			***2010***		
Yield, t/ha	13	4.53	0.73	14	4.68	0.77	12	4.84	0.82	12	4.88	0.78
Independent variables:												
Release yield, t/ha	13	6.08	0.39	14	6.24	0.39	12	6.22	0.46	12	6.17	0.36
Fertilizer, kg/ha	13	317.03	132.18	14	321.87	136.86	12	374.94	130.57	12	418.32	124.84
Irrigated area, %	13	63.82	28.91	14	63.19	27.57	12	65.69	23.40	12	65.80	22.94
Dry season area share, %	13	61.11	14.46	14	54.63	13.85	12	51.94	10.80	12	54.64	9.45
Area damaged by flood, %	13	2.17	1.55	14	2.44	2.41	12	1.25	1.40	12	1.50	1.70
Area damaged by drought, %	13	0.75	1.37	14	1.21	2.10	12	1.64	3.10	12	0.17	0.35

The 23 provinces included in the data set are: Bali, Bengkulu, Jambi, Jawa Barat, Jawa Tehngah, Jawa Timur, Kalimantan Barat, Kalimantan Selatan, Kalimantan Tenggah, Kalimatan Timur, Pemerintah Aceh, Riau, Sulawesi Selatan, Sulawesi Tengah, Sulawesi Tenggara, Sulawesi Utara, Sumatera Barat, Sumatera Selatan, Sumatera Utara, and Yogyakarta.

Sources of data: secondary statistics described in section 2.3.4.3

To test whether this is the case, check yields for IR64 were compiled, and indicate rising yields over time. As a result, it is likely that the varietal yields are being conducted under improving conditions, and that not all release yield growth is attributable to genetic improvement. As a result, the coefficients returned may reflect the true nature of genetic gain.

3.3.2.2 Changes in host plant resistance of adopted varieties

The Feder (1979) damage abatement framework results in significant positive coefficients for Blast and BPH resistance yield contributions, while tungro and BLB have insignificant negative coefficients (Table 3.11). In Indonesia, the interaction effect between BPH resistance and insecticide use is negative, which suggests that higher insecticide use reduces the benefits of BPH resistance. This is an opposite result to that of the wet season in the Philippines. However, it is possible that the sign of the interaction changes as levels of insecticide use rise, and Indonesia has much higher levels of insecticide use than does the Philippines.

Table 3.11. Rice varietal pest resistance trait effects estimate via the damage abatement model, Indonesia.

Dependent variable: Paddy Yield	**Coefficient**	**t-value**
Production function component		
Flooding	-0.00351***	-4.51
Drought	-0.00276***	-6.26
Nitrogen	0.03588	1.38
Irrigation	0.10870**	2.64
Year	0.04717***	5.51
Irrigation*Year	-0.00859***	-3.67
Dry harvested area	-0.00078	-1.01
Damage abatement component		
Constant	0.06737	1.48
Tungro trait	-0.85853	-0.80
Blast trait	0.91921**	2.02
BLB trait	-0.51912	-1.21
BPH trait	1.31968***	2.88
BPH trait*Insecticide	-0.15308	-1.18
Insecticide	-0.00538	-0.05
Observations	209	
R-squared	0.984	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 13.11.a Description of variables used in Table 3.11 model, 23 provinces of Indonesia, dry season, 1996--2010.

	No of provinces	Mean/ Freq	Std. Dev./ %	No of provinces	Mean/ Freq	Std. Dev./ %	No of provinces	Mean/ Freq	Std. Dev./ %	No of provinces	Mean/ Freq	Std. Dev./ %
Dependent variable:	***1996***			***2000***			***2001***			***2002***		
Yield, t/ha	20	3.71	0.94	23	3.84	0.91	20	4.00	0.80	22	3.90	0.90
Independent variables- *Production function component*												
Area damaged by flood, proportion	20	0.38	0.57	23	1.20	2.28	20	1.43	2.15	22	1.42	2.53
Area damaged by drought, proportion	20	0.42	0.67	23	0.69	1.38	20	0.86	1.32	22	3.10	5.61
Fertilizer, kg/ha	20	190.30	114.71	23	238.47	125.31	20	270.73	131.04	22	273.38	125.90
Irrigated area, %	20	69.39	18.57	23	69.64	18.47	20	61.97	26.91	22	61.51	26.43
Dry season area, %	20	48.46	15.16	23	50.85	13.46	20	53.03	13.88	22	53.87	13.52
Independent variables- *Damage abatement component*												
Biotic dummy==1	20	4	20%	23	6	26%	20	4	20%	22	4	18%
Tungro resistance	20	0.25	0.19	23	0.32	0.23	20	0.31	0.27	22	0.31	0.22
Blast resistance	20	0.88	0.11	23	0.95	0.08	20	0.87	0.14	22	0.84	0.13
BLB resistance	20	0.59	0.27	23	0.56	0.25	20	0.59	0.28	22	0.60	0.23
BPH resistance	20	0.78	0.23	23	0.65	0.22	20	0.33	0.19	22	0.41	0.20
Insecticides, kg/ha	20	1.58	1.83	23	1.94	1.53	20	2.22	1.31	22	2.15	1.10
Dependent variable:	***2003***			***2004***			***2005***			***2006***		
Yield, t/ha	22	4.04	0.83	23	4.03	0.86	14	4.38	0.74	14	4.36	0.76
Independent variables- *Production function component*												
Area damaged by flood, proportion	22	3.18	9.21	23	1.99	2.79	14	1.58	1.63	14	3.13	5.16
Area damaged by drought, proportion	22	2.37	3.24	23	2.47	4.43	14	0.91	1.79	14	3.30	5.57
Fertilizer, kg/ha	22	308.12	129.00	23	321.93	135.09	14	336.35	128.14	14	331.53	129.09
Irrigated area, %	22	60.74	27.06	23	58.70	28.07	14	62.33	28.33	14	62.46	28.06
Dry season area, %	22	55.68	15.12	23	52.25	13.35	14	54.52	15.36	14	53.13	15.55
Independent variables- *Damage abatement component*												
Biotic dummy	22	5	23%	23	5	22%	14	4	29%	14	7	50%
Tungro resistance	22	0.28	0.19	23	0.16	0.18	14	0.16	0.18	14	0.08	0.16
Blast resistance	22	0.78	0.14	23	0.59	0.16	14	0.60	0.19	14	0.50	0.20
BLB resistance	22	0.59	0.21	23	0.64	0.18	14	0.76	0.15	14	0.34	0.26
BPH resistance	22	0.42	0.18	23	0.45	0.21	14	0.58	0.24	14	0.66	0.18
Insecticides, kg/ha	22	2.39	0.99	23	2.45	1.06	14	2.27	0.87	14	2.00	0.84
Dependent variable:	***2007***			***2008***			***2009***			***2010***		
Yield, t/ha	13	4.53	0.73	14	4.68	0.77	12	4.84	0.82	12	4.88	0.78
Independent variables- *Production function component*												
Area damaged by flood, proportion	13	2.17	1.55	14	2.44	2.41	12	1.25	1.40	12	1.50	1.70
Area damaged by drought, proportion	13	0.75	1.37	14	1.21	2.10	12	1.64	3.10	12	0.17	0.35
Fertilizer, kg/ha	13	317.03	132.18	14	321.87	136.86	12	374.94	130.57	12	418.32	124.84
Irrigated area, %	13	63.82	28.91	14	63.19	27.57	12	65.69	23.40	12	65.80	22.94
Dry season area, %	13	61.11	14.46	14	54.63	13.85	12	51.94	10.80	12	54.64	9.45
Independent variables- *Damage abatement component*												
Biotic dummy==1	13	6	46%	14	7	50%	12	7	58%	12	8	67%
Tungro resistance	13	0.06	0.11	14	0.03	0.06	12	0.02	0.03	12	0.02	0.03
Blast resistance	13	0.41	0.20	14	0.31	0.17	12	0.30	0.18	12	0.34	0.15
BLB resistance	13	0.24	0.20	14	0.22	0.19	12	0.27	0.19	12	0.25	0.18
BPH resistance	13	0.75	0.15	14	0.80	0.14	12	0.83	0.15	12	0.78	0.16
Insecticides, kg/ha	13	1.72	0.93	14	1.45	1.01	12	1.41	0.59	12	1.60	0.43

The 23 provinces included in the data set are: Bali, Bengkulu, Jambi, Jawa Barat, Jawa Tehngah, Jawa Timur, Kalimantan Barat, Kalimantan Selatan, Kalimantan Tenggah, Kalimatan Timur, Pemerintah Aceh, Riau, Sulawesi Selatan, Sulawesi Tengah, Sulawesi Tenggara, Sulawesi Utara, Sumatera Barat, Sumatera Selatan, Sumatera Utara, and Yogyakarta.

3.3.3 Philippines

3.3.3.1 Changes in release yield of adopted varieties

The Cobb Douglas fixed effect production functions all return significant coefficients on the weighted average varietal release yield of adopted varieties (Table 3.12). These coefficients are elasticities, due to the log transformation of the weighted release yield and actual yields. The magnitude of the coefficients varies from 0.23 to 0.42, indicating a 0.23% to 0.42% increase in actual yield per 1% increase in the release yield of adopted varieties. The lowest values are observed in the wet season in the Philippines, as may be expected due to lower solar radiation in the season, compared with the dry season.

These elasticities of release yield to actual yield may also be lower than initially expected. Unlike in Indonesia, the evolution of check yields does not suggest that trial management is improving over time. However, the lower levels of input usage in the Philippines may make less use of genetic potential.

Table 3.12. Rice varietal yield trait effects by season: A fixed-effects model, Philippines.

Dep. Var.	**Wet Season**		**Dry Season**	
Paddy Yield	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**
Yield trait	0.23160***	2.24	0.42269***	2.49
Fertilizer	0.01264***	2.28	0.00787	1.11
Irrigation	0.00622***	2.64	0.01331***	2.54
Certified seed	0.00069	0.48	0.00284	1.04
Area	0.14152***	2.81	0.23172***	2.12
Drought	-0.00035	-0.57	-0.00124	-1.34
Flooding	-0.00136	-1.72	-0.00689	-1.09
Intercept	0.22806	1.04	-0.33156	-0.55
N	*420*		*271*	
R^2 *(within)*	*0.255*		*0.464*	
F(df)	*7.03****	*df(7,157)*	*7.18****	*df(7,108)*

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3.12b. Summary statistics for the variables used in Table 3.12 model

	1996/97			2001/02			2006/07		
VARIABLE	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
				Wet Season					
Dep. Variable:Yield, t/ha	148	3.19	0.87	145	3.28	0.75	127	3.66	0.98
Independent variables									
Release yield, t/ha	148	4.53	0.57	145	4.75	0.42	127	4.98	0.29
Fertilizer: Nitrogen, kg/ha	148	63.80	32.27	145	80.01	35.63	127	86.55	36.66
Irrigation, % of planted area	148	61.73	46.53	145	54.10	38.76	127	71.49	37.86
Certified seed, % usage	148	13.32	22.22	145	21.60	25.23	127	29.80	26.64
Area planted, ha	148	1.30	0.74	148	1.08	0.47	127	1.04	0.47
Drought incidence, % farmers reporting	148	4.25	11.44	145	10.91	24.12	127	8.57	21.00
Flood incidence, % farmers reporting	148	2.12	8.30	145	0.07	0.86	127	15.01	24.06
				Dry Season					
Dep. Variable:Yield, t/ha	94	3.34	1.12	97	3.59	1.09	80	4.15	1.25
Independent variables									
Release yield, t/ha	94	4.52	0.53	97	4.82	0.51	80	5.04	0.39
Fertilizer: Nitrogen, kg/ha	94	57.97	38.77	97	79.48	38.08	80	83.48	38.30
Irrigation, % of planted area	94	69.80	44.41	97	66.96	37.30	80	84.62	30.83
Certified seed, % usage	94	15.81	24.67	97	21.32	24.05	80	32.20	29.94
Area planted, ha	94	1.30	0.86	97	1.03	0.46	80	1.05	0.52
Drought incidence, % farmers reporting	94	9.79	22.80	97	33.31	34.11	80	30.97	35.16
Flood incidence, % farmers reporting	94	1.81	6.16	97	0.00	0.00	80	0.76	3.56

Source of data: PRRI Rice-based farm household survey, 1996/7, 2001/2, 2006/7 rounds

3.3.3.2 Changes in host plant resistance of adopted varieties

An array of damage model specifications and criteria for observation inclusion were tested for the dry season in the Philippines. However, no specification returned significant coefficients on host plant resistance effects. The damage abatement model specification for the Philippine dry season with most significance and highest explanatory power is reported in Table 3.13. The only damage abatement action with significant effects on yield is found to be herbicide use. Although insignificant, the intercept coefficient of the damage abatement function suggests that

In the wet season, tungro resistance returns a significant positive coefficient, while other host plant resistances for diseases are insignificant. However, the coefficient reflects only very small yield contributions, which accords with low levels of average reported yield loss due to tungro infestation (Savary et al., 2000b). BPH resistance has a significantly negative coefficient in the absence of insecticide use, and a significant positive interaction term with insecticide use. The magnitude of the coefficient in the context of mean application rates suggests that the interaction term offsets the individual BPH term, so that the net effect of BPH resistance is small and unlikely to be significant.

Table 3.13. Rice varietal pest resistance trait effect by season: A damage abatement model, Philippines.

Dep. Var.: Paddy Yield	**Wet Season**		**Dry Season**	
	Coefficient	**t-statistic**	**Coefficient**	**t-statistic**
Production function component				
PF intercept	-.0618371	-1.54	1.36102***	7.29
Cert. seeds	.0017967	1.14	0.00456	1.90
Year	.0065211*	1.89	-0.00158	-0.26
Area	.1978651***	4.79	0.22017*	2.38
Irrigation	.0077307***	3.44	0.01392***	3.42
Drought	.3829034**	2.08	-0.00176*	-2.37
Flood	-.0012446	-1.48	-0.00379	-0.91
Damage abatement function component				
DF intercept	-11.96244**	-2.20	-2.15667	-0.95
Blast trait	.6976054	1.18	-0.15962	-0.43
BLB trait	-0.60159	-0.52	-1.61810	-0.88
Herbicide	-0.29356	-1.50	6.61006*	2.15
Tungro trait	1.546084*	1.86	-0.22452	-0.56
Insecticide	-20.041**	-2.24	2.58539	0.73
BPH*Insecticide	26.91444**	2.22	-1.52832	-0.36
BPH trait	-10.708**	-1.99	0.60519	1.11
N	*420*		*271*	
R^2	*0.727*		*0.826*	
F(df)	*662.25****	*(156,263)*	*51.38****	*(104,166)*

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3.13.a Description of variables used in Table 3.13 model, Philippines, wet and dry season, 1996--2007.

	1996/97			**2001/02**			**2006/07**		
VARIABLE	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
	Wet Season								
Dependent variable:									
Yield, t/ha	148	3.19	0.87	145	3.28	0.75	127	3.66	0.98
Independent variables- *Production function component*									
Certified seeds, % usage	148	13.32	22.22	145	21.60	25.23	127	29.80	26.64
Area planted, ha	148	1.30	0.74	145	1.08	0.47	127	1.04	0.47
Irrigation, % planted area	148	61.73	46.53	145	54.10	38.76	127	71.49	37.86
Drought incidence, % farmers reporting	148	4.25	11.44	145	10.91	24.12	127	8.57	21.00
Flood incidence, % farmers reporting	148	2.12	8.30	145	0.07	0.86	127	15.01	24.06
Independent variables- *Damage abatement component*									
Blast resistance trait, proportion of area	148	0.83	0.29	145	0.79	0.30	127	0.76	0.31
BLB resistance trait, proportion of area	148	1.00	0.00	145	0.98	0.12	127	0.95	0.15
Herbicide, kg a.i./ha	148	0.12	0.15	145	0.38	1.27	127	0.27	0.25
Tungro resistance trait, proportion of area	148	0.67	0.29	145	0.35	0.32	127	0.16	0.23
Insecticide, kg a.i./ha	148	0.20	0.27	145	0.18	0.28	127	0.35	0.73
BPH resistance trait, proportion of area	148	0.79	0.27	145	0.90	0.21	127	0.87	0.19
	Dry Season								
Dependent variable:									
Yield, t/ha	94	3.34	1.12	97	3.59	1.09	80	4.15	1.25
Independent variables- *Production function component*									
Certified seeds, % usage	94	15.81	24.67	97	21.32	24.05	80	32.20	29.94
Area planted, ha	94	1.30	0.86	97	1.03	0.46	80	1.05	0.52
Irrigation, % planted area	94	69.80	44.41	97	66.96	37.30	80	84.62	30.83
Drought incidence, % farmers reporting	94	9.79	22.80	97	33.31	34.11	80	30.97	35.16
Flood incidence, % farmers reporting	94	1.81	6.16	97	0.00	0.00	80	0.76	3.56
Independent variables- *Damage abatement component*									
Blast resistance trait, proportion of area	94	0.84	0.28	97	0.79	0.28	80	0.77	0.31
BLB resistance trait, proportion of area	94	1.00	0.00	97	0.96	0.14	80	0.95	0.18
Herbicide, kg a.i./ha	94	0.10	0.13	97	0.20	0.21	80	0.26	0.22
Tungro resistance trait, proportion of area	94	0.60	0.33	97	0.32	0.33	80	0.09	0.17
Insecticide, kg a.i./ha	94	0.15	0.22	97	0.10	0.18	80	0.25	0.29
BPH resistance trait, proportion of area	94	0.84	0.24	97	0.92	0.16	80	0.80	0.28

Source of data: PRRI Rice-based farm household survey, 1996/7, 2001/2, 2006/7 rounds

3.4 Bio-economic modeling of host plant resistance effects

RICEPEST and EPIRICE generated relative yield effects conditional on resistance to BLB for each year from 2001 to 2010 in Indonesia and the Philippines. The spatial distribution of the averages of these effects over the period are presented in Figures 3.30 and 3.31. These modeled effects range from 2% to 5%, depending on the weather and production conditions in the spatial unit, with similar effects in both countries.

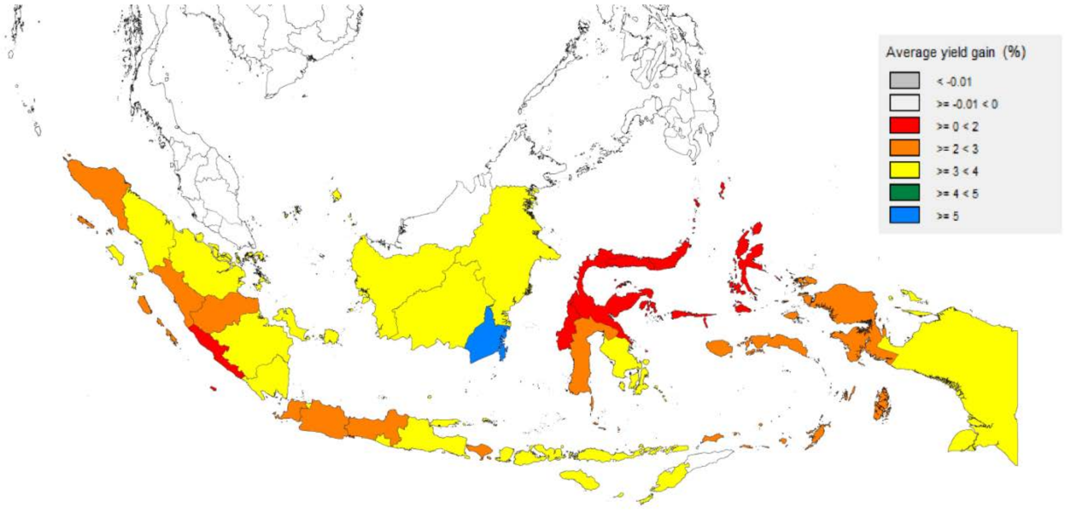

Figure 3.30. Average annual 2001-2010 yield gains conditional on BLB host plant resistance in Indonesia.

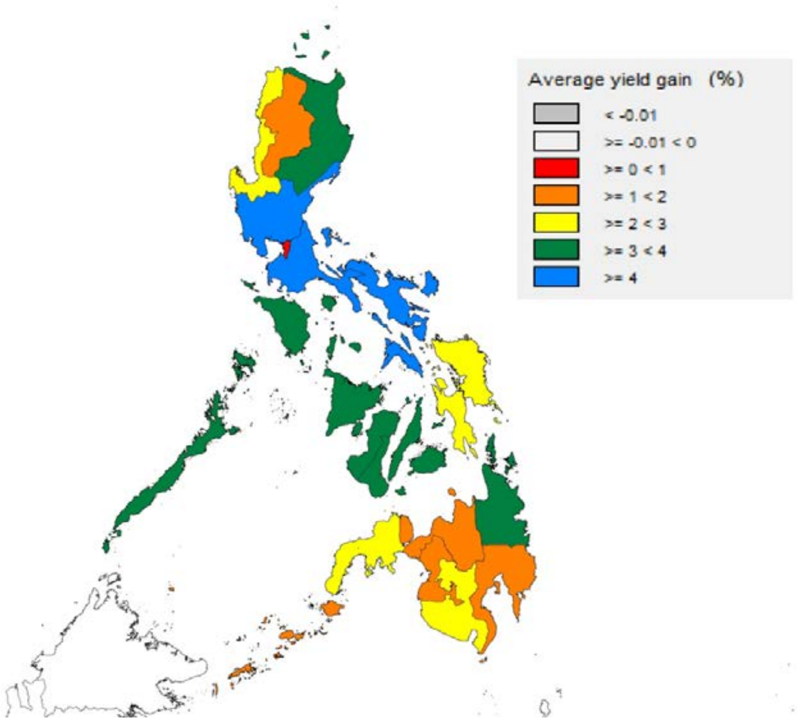

Figure 3.31. Average annual 2001-2010 yield gains conditional on BLB host plant resistance in the Philippines.

3.5 Economic welfare

This section describes results of application of the identified treatment effects of adoption of newer varietal traits in the partial equilibrium welfare modeling framework. All values are presented in 2005 Purchasing Power Parity Dollars.

3.5.1 Bangladesh

3.5.1.1 Production effects of BRRI dhan 28 and BRRI dhan 29

Utilizing data on the adoption of BRRI dhan 28 and 29 as a share of Boro MV area, along with data on the annual Boro MV proportion of provincial production yields gross supply shocks due to these varieties (Table 3.14). By 2010, their contribution to yield is approximately one million tons annually, with 9 million tons contributed over the period.

3.5.1.2 Production effects of IRRI contributions to BRRI dhan 28 and BRRI dhan 29

Multiplying the respective shifts from each variety by the 25% IRRI contribution to BRRI dhan 28 and the 37.5% contribution to BRRI dhan 29 gives attributable yield shocks (Table 3.14). According to these parameters, IRRI contributions to the two varieties result in approximately 350,000 tons of additional annual production by the late 2000s. By 2010, the aggregate attributable contribution is approximately 3 million tons.

3.5.1.3 Welfare impacts of BRRI dhan 28 and BRRI dhan 29

Under a positive shutdown price functional form, approximately PPP$4 billion of benefits are generated over the period by the total yield shocks attributable to the varieties, with annual benefits peaking at about PPP$400 million in the late 2000s. When self-consumption is considered, a majority of the benefits accrue to producers, about a quarter accrue to consumers, and 5% accrue to hired labor. Roughly 2/3 of benefits generated accrue to those under the PPP$2 per day poverty line and about 2/3 of these benefits accrue to producers. A slightly higher share of producer benefits accrues to the poor than consumer benefits, but even more than 60% of the latter accrues to those under the PPP$2/day poverty line. Nearly 50% of benefits accrue to those under the PPP$1.25/day poverty line, and more than 10% of those benefits accrue to poor laborers (Table 3.15). Benefits to poor producers and laborers are concentrated in the Dhaka Division, both an aggregate, as well as on a per capita basis for the poor (in which poor producer and laborer benefits are divided by the total rural poor population, presented in Figure 3.32). However, the area effects of the supply shifts are small and are not often in forested areas, so environmental benefits are minor. The total number of Disability Affected Life Years saved as a result of reduced rice prices is 630,000 over the period (Table 3.16).

3.5.1.4 Welfare impacts of IRRI contributions to BRRI dhan 28 and BRRI dhan 29

IRRI attributable benefits are approximately 1/3 of total benefits from the two varieties (PPP$1.3 billion over the period) and closely mirror total benefits in their distribution among beneficiary groups (Table 3.17). The proportion of benefits to the poor is thus similar to the proportion of total benefits from BRRI dhan 28 and 29, and the effect on hunger is also about 1.3 of the total effect of the varieties.

3.5.1.5 Sensitivity to shutdown price assumption

If a pure constant elasticity functional form is used, producer benefits are negative in the absence of self consumption, and fall to 28% of the producer surplus estimated under the positive shutdown price when self-consumption is included (Table 3.18). As a result, producers only receive 35% of total benefits, and total benefits fall by nearly 40% to PPP$2 billion over the period for the total effect of BRRI dhan 28 and 29 and PPP$0.7 billion for IRRI's contribution. However, the proportion of those benefits accruing to those under the PPP$2 and PPP$1.25 poverty lines is similar to the positive shutdown price results.

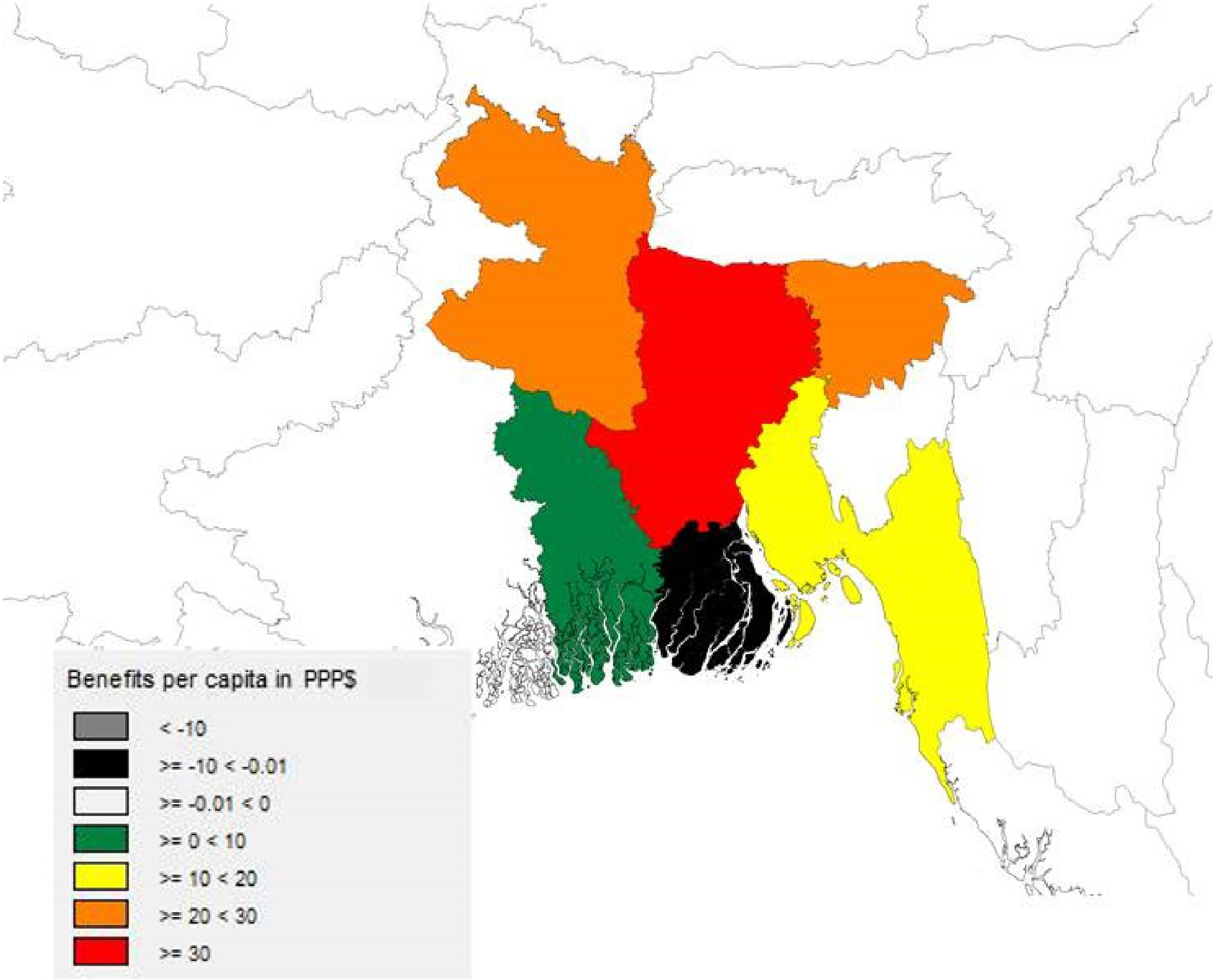

Figure 3.32. Spatial distribution of BRRI dhan 28 and 29 cumulative producer and laborer benefits per person under the PPP$2 per day poverty line in Bangladesh, according to the positive shutdown price functional form for supply.

Table 3.14. Production shock effects of BRRI dhan 28 and 29 in Bangladesh ('000 tons).

	Production ('000 t)		Price effects (%)	
Year	**Total**	**IRRI attributable**	**Total**	**IRRI attributable**
1990	-	-		
1991	-	-		
1992	-	-		
1993	-	-		
1994	0.16	0.06	(0.00)%	(0.00)%
1995	0.32	0.12	(0.00)%	(0.00)%
1996	1.72	0.63	(0.00)%	(0.00)%
1997	14.31	5.15	(0.00)%	(0.02)%
1998	54.25	19.28	(0.00)%	(0.06)%
1999	171.09	59.93	(0.01)%	(0.18)%
2000	300.93	103.71	(0.05)%	(0.28)%
2001	430.32	146.07	(0.16)%	(0.41)%
2002	543.77	182.22	(0.51)%	(0.47)%
2003	656.10	217.47	(0.82)%	(0.55)%
2004	756.24	249.57	(1.23)%	(0.68)%
2005	911.50	298.45	(1.42)%	(0.76)%
2006	938.60	305.63	(1.69)%	(0.80)%
2007	1,156.77	374.19	(2.10)%	(0.76)%
2008	1,080.88	348.71	(2.37)%	(0.74)%
2009	1,070.36	343.83	(2.51)%	(0.76)%
2010	1,112.62	355.98	(2.41)%	(0.69)%
Total	**9,199.95**	**3,010.98**		

Table 3.1. Annual benefits to producers, consumers and hired labor from BRRI dhan 28 and 29 in Bangladesh under positive shutdown price functional form for supply (million PPP$, discounted at 5%).

Year	Producer surplus				Consumer surplus			Hired labor			Environmental benefits	Total benefits		
	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day		All/Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	0.05	0.12	0.07	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.001	0.15	0.09	0.12
1995	0.09	0.23	0.13	0.19	0.03	0.01	0.01	0.02	0.02	0.02	0.002	0.28	0.16	0.22
1996	0.30	1.00	0.55	0.78	0.22	0.09	0.11	0.09	0.08	0.09	0.01	1.33	0.73	0.98
1997	3.32	8.29	4.52	6.41	1.39	0.57	0.65	0.83	0.75	0.79	0.08	10.58	5.84	7.85
1998	15.10	32.82	17.79	25.43	3.86	1.45	1.48	3.64	3.28	3.46	0.24	40.57	22.52	30.37
1999	27.19	73.05	38.87	55.83	25.67	11.53	15.59	6.53	5.88	6.20	0.82	106.08	56.27	77.62
2000	49.46	115.69	60.97	88.44	44.56	20.14	27.84	10.30	9.27	9.78	1.29	171.84	90.37	126.06
2001	59.00	159.64	81.69	121.44	67.96	29.76	41.88	13.13	11.81	12.47	1.83	242.56	123.27	175.79
2002	87.68	200.22	99.42	151.54	76.42	32.57	46.55	17.05	15.35	16.20	2.04	295.74	147.34	214.29
2003	97.89	225.21	108.39	169.32	92.37	38.42	56.19	18.31	16.47	17.39	2.32	338.20	163.29	242.90
2004	104.75	267.13	124.17	198.51	98.96	39.35	57.75	21.03	18.76	19.98	2.64	389.76	182.28	276.24
2005	112.23	269.25	120.43	196.57	119.48	47.01	72.30	21.56	18.96	20.48	2.93	413.22	186.40	289.36
2006	117.11	285.18	123.71	205.92	116.21	43.82	67.93	22.86	19.83	21.72	3.05	427.31	187.37	295.57
2007	174.61	315.84	132.85	225.60	127.05	48.02	78.29	26.03	22.29	24.73	2.75	471.66	203.15	328.62
2008	120.07	235.85	94.01	162.62	124.26	46.02	77.46	19.94	16.69	18.94	2.71	382.75	156.71	259.02
2009	95.28	210.33	80.76	142.76	131.71	47.34	81.72	17.01	13.90	16.16	2.68	361.72	141.99	240.64
2010	125.45	223.27	83.38	150.89	117.59	41.05	72.69	18.55	14.83	17.62	2.32	361.73	139.25	241.20
Total	**1,189.58**	**2,623.12**	**1,171.71**	**1,902.35**	**1,147.75**	**447.13**	**698.45**	**216.89**	**188.17**	**206.05**	**27.72**	**4,015.49**	**1,807.02**	**2,806.85**

Table 3.2. Total annual thousands of DALYs (Disability Adjusted Life Years) saved through reduced hunger in Bangladesh as a result of BRRI dhan 28 & 29, and benefits attributable to IRRI contributions to the two varieties.

Year	Total	Attributable to IRRI
1990	-	-
1991	-	-
1992	-	-
1993	-	-
1994	0.02	0.01
1995	0.04	0.01
1996	0.24	0.09
1997	1.66	0.60
1998	5.45	1.93
1999	16.78	5.87
2000	25.64	8.83
2001	36.32	12.32
2002	41.85	14.02
2003	49.25	16.32
2004	60.50	19.96
2005	67.58	22.12
2006	70.85	23.06
2007	66.97	21.64
2008	64.27	20.72
2009	65.14	20.92
2010	58.29	18.64
Total	**630.84**	**207.07**

Table 3.3. Annual benefits to producers, consumers and hired labor from BRRI dhan 28 and 29 in Bangladesh attributable to IRRI under positive shutdown price functional form for supply(million PPP$, discounted at 5%).

	Producer surplus				Consumer surplus			Hired labor				Total benefits		
Year	**All**	**Adjusted for self-consumption**	**Earning less than PPP$1.25 per day**	**Earning less than PPP$2 per day**	**Adjusted for self-consumption**	**Earning less than PPP$1.25 per day**	**Earning less than PPP$2 per day**	**All**	**Earning less than PPP$1.25 per day**	**Earning less than PPP$2 per day**	**Environmental benefits**	**All/Adjusted for self-consumption**	**Earning less than PPP$1.25 per day**	**Earning less than PPP$2 per day**
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	0.02	0.05	0.03	0.04	0.01	0.002	0.002	0.004	0.004	0.004	0.0004	0.05	0.03	0.04
1995	0.03	0.09	0.05	0.07	0.01	0.004	0.004	0.01	0.01	0.01	0.001	0.11	0.06	0.08
1996	0.11	0.37	0.20	0.28	0.08	0.03	0.04	0.03	0.03	0.03	0.004	0.48	0.26	0.36
1997	1.19	2.98	1.62	2.29	0.50	0.21	0.23	0.30	0.27	0.28	0.03	3.81	2.09	2.81
1998	5.35	11.65	6.27	8.96	1.37	0.51	0.53	1.30	1.17	1.24	0.09	14.40	7.95	10.72
1999	9.49	25.52	13.43	19.27	8.97	4.03	5.45	2.31	2.08	2.20	0.29	37.08	19.54	26.92
2000	16.99	39.72	20.68	29.97	15.30	6.93	9.56	3.60	3.24	3.42	0.44	59.05	30.84	42.94
2001	19.98	53.95	27.28	40.51	22.94	10.08	14.13	4.55	4.09	4.32	0.61	82.04	41.46	58.96
2002	29.30	66.76	32.81	49.93	25.43	10.88	15.49	5.85	5.26	5.56	0.67	98.71	48.95	70.98
2003	32.39	74.24	35.39	55.20	30.37	12.69	18.47	6.24	5.61	5.93	0.75	111.60	53.69	79.60
2004	34.57	87.63	40.42	64.54	32.33	12.94	18.87	7.21	6.43	6.85	0.85	128.02	59.79	90.26
2005	36.82	87.67	38.90	63.40	38.69	15.32	23.41	7.37	6.47	7.00	0.93	134.65	60.68	93.81
2006	38.20	92.28	39.76	66.10	37.39	14.20	21.86	7.77	6.72	7.38	0.96	138.40	60.68	95.34
2007	56.38	101.52	42.40	71.90	40.60	15.43	25.02	8.78	7.49	8.34	0.86	151.75	65.32	105.26
2008	38.80	75.73	29.95	51.73	39.64	14.75	24.71	6.73	5.60	6.39	0.85	122.95	50.31	82.83
2009	30.73	67.28	25.64	45.24	41.84	15.11	25.96	5.74	4.66	5.45	0.84	115.69	45.40	76.65
2010	40.10	71.06	26.35	47.60	37.22	13.05	23.01	6.19	4.91	5.88	0.72	115.19	44.31	76.49
Total	**390.46**	**858.47**	**381.17**	**617.03**	**372.68**	**146.17**	**226.74**	**73.98**	**64.05**	**70.28**	**8.89**	**1,314.02**	**591.38**	**914.05**

Table 3.4. Producer and total benefits in Bangladesh under constant elasticity functional form for supply (million PPP$, discounted at 5%).

Year	Total effect of BRRI dhan 28 and 29							Effects attributable to IRRI contributions to BRRI dhan 28 and 29						
	Producer surplus				Total benefits			Producer surplus				Total benefits		
	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	(0.01)	0.06	0.03	0.05	0.10	0.05	0.07	(0.00)	0.02	0.01	0.02	0.04	0.02	0.02
1995	(0.02)	0.12	0.06	0.09	0.24	0.09	0.12	(0.01)	0.04	0.02	0.03	0.09	0.03	0.05
1996	(0.27)	0.43	0.23	0.33	0.99	0.41	0.52	(0.10)	0.16	0.08	0.12	0.36	0.15	0.19
1997	(1.07)	3.89	2.06	2.91	6.93	3.38	4.35	(0.39)	1.40	0.74	1.04	2.49	1.21	1.56
1998	(0.75)	16.98	9.03	12.88	25.76	13.76	17.82	(0.27)	6.03	3.18	4.54	9.14	4.87	6.30
1999	(20.40)	25.47	12.92	18.36	59.47	30.33	40.16	(7.13)	8.89	4.43	6.29	20.78	10.55	13.93
2000	(30.54)	35.70	17.87	25.62	92.56	47.28	63.24	(10.50)	12.24	5.99	8.57	31.80	16.15	21.54
2001	(50.37)	50.28	24.49	36.02	133.64	66.07	90.37	(17.02)	16.95	8.08	11.85	45.18	22.25	30.31
2002	(44.49)	68.05	32.36	48.90	164.10	80.28	111.65	(14.84)	22.61	10.57	15.93	54.74	26.71	36.97
2003	(54.31)	73.01	33.48	51.82	186.53	88.37	125.40	(17.89)	23.96	10.80	16.67	61.49	29.10	41.07
2004	(63.17)	99.21	43.92	69.73	222.16	102.03	147.46	(20.68)	32.38	14.16	22.44	72.87	33.53	48.16
2005	(80.70)	76.33	31.34	50.50	220.03	97.31	143.29	(26.17)	24.68	9.96	16.00	71.58	31.74	46.41
2006	(72.25)	95.82	39.26	64.75	237.52	102.92	154.40	(23.30)	30.78	12.47	20.51	76.78	33.39	49.75
2007	(47.25)	93.97	36.22	60.72	249.66	106.52	163.74	(15.20)	29.94	11.37	19.01	80.15	34.29	52.37
2008	(77.47)	38.31	11.27	18.54	184.75	73.97	114.94	(24.76)	12.17	3.45	5.61	59.26	23.81	36.72
2009	(91.01)	24.04	5.34	8.50	172.76	66.58	106.38	(28.93)	7.61	1.58	2.45	55.19	21.35	33.86
2010	(58.74)	39.08	11.32	19.68	175.23	67.19	109.99	(18.65)	12.31	3.46	5.96	55.72	21.42	34.85
Total	**(692.80)**	**740.74**	**311.22**	**489.40**	**2,132.43**	**946.52**	**1,393.90**	**(225.83)**	**242.17**	**100.35**	**157.02**	**697.65**	**310.57**	**454.05**

3.5.2 Indonesia

3.5.2.1 Production effects of post 1989 MVs

Traits introduced through post 1989 MVs are estimated to contribute nearly 55 million tons of paddy production between 1991 and 2011, with annual production contributions reaching 7 million tons in the late 2000s. A large majority (92%) of this is contributed by the increased release yield of adopted varieties, from which the production shock rises rapidly in the 2000s, after relatively slow increases during the 1990s. This is largely an artifact of stagnant varietal replacement in the 1990s with dominance by IR64, followed by rapid turnover in the 2000s, particularly driven by the expansion of higher yielding Ciherang. Continued and expanded BPH host plant resistance through post 1989 MVs also makes a substantial contribution of 6.4 million tons over the period, with annual contributions peaking at about 0.9 million tons in the late 2000s. However, this is largely offset by losses in blast resistance coverage in varieties adopted in the 2000s, which lead to an aggregate production loss of 5.3 million tons. The diffusion of BLB resistance through post 1989 MVs contributes about 0.5 million tons annually in the first half of the 2000s, before dropping off as newer adopted varieties no longer have this trait towards the end of the period (Table 3.19).

3.5.2.2 Production effects of IRRI contributions to post 1989 MVs

Just over 1/3 of this production increase is attributable to IRRI contributions to post 1989 varieties, largely through parental contributions to the popular varieties in the 2000s. The breakdown of sources of yield gains is similar to that of the total MV effect, although marginally higher relative contributions occur via BPH resistance and losses via reduction of area under blast resistance. IRRI’s contribution to production gains from BLB resistance is positive, with several hundred thousand tons of annual attributable production in the first half of the 2000s, before turning negative in the end of the analytical period (Table 3.19).

3.5.2.3 Welfare impacts of post 1989 MVs

Under the positive shutdown price functional form for supply, the aggregate economic surplus generated by the diffusion of post 1989 MVs is estimated at PPP$20.1 billion, with annual benefits of PPP$2 billion generated in the late 2000s. A majority (62%) of this welfare effect accrues to consumers through lower rice prices. Just over 1/3 of benefits accrue to producers, while 2% accrues to hired labor (Table 3.20).

Approximately 39% of benefits are assessed to be received by those under the PPP$2/day poverty line, with 56% of those benefits accruing to poor consumers, 39% to poor producers and the remaining 5% to poor laborers. The benefits to those under the PPP$1.25 poverty line aggregate to 18% of benefits over the period, and are still dominated by benefits to consumers, who receive 54% of the welfare effects to those under this poverty line, poor producers who receive 39%, and poor laborers who receive 7%. Although aggregate benefits to poor producers and laborers are concentrated in East and West Java in aggregate, on a per capita basis for the poor benefits are most intense in northern Sumatera, Nusa Tenggara, and Lampung (in which poor producer and laborer benefits are divided by the total rural poor population, presented in Figure 3.33). Environmental benefits total $189 million over the period. In terms of food security, reduced rice prices attributable to post 1989 MVs lead to 881,000 DALYs being saved, principally as a result of the increased release yield of adopted varieties (Table 3.21).

3.5.2.4 Welfare impacts of IRRI contributions to post 1989 MVs

IRRI genetic contributions account for 35% of the economic surplus generated by post 1989 MVs, or nearly $7 billion over the period. The benefit distribution for IRRI genetic contributions is similar among groups to the total effect of the post 1989 MVs, as is the proportion of benefits received by those under the PPP$1.25 and PPP$2.0 poverty lines (Table 3.22). IRRI's genetic contribution leads to 320,000 DALYs being saved (Table 3.21).

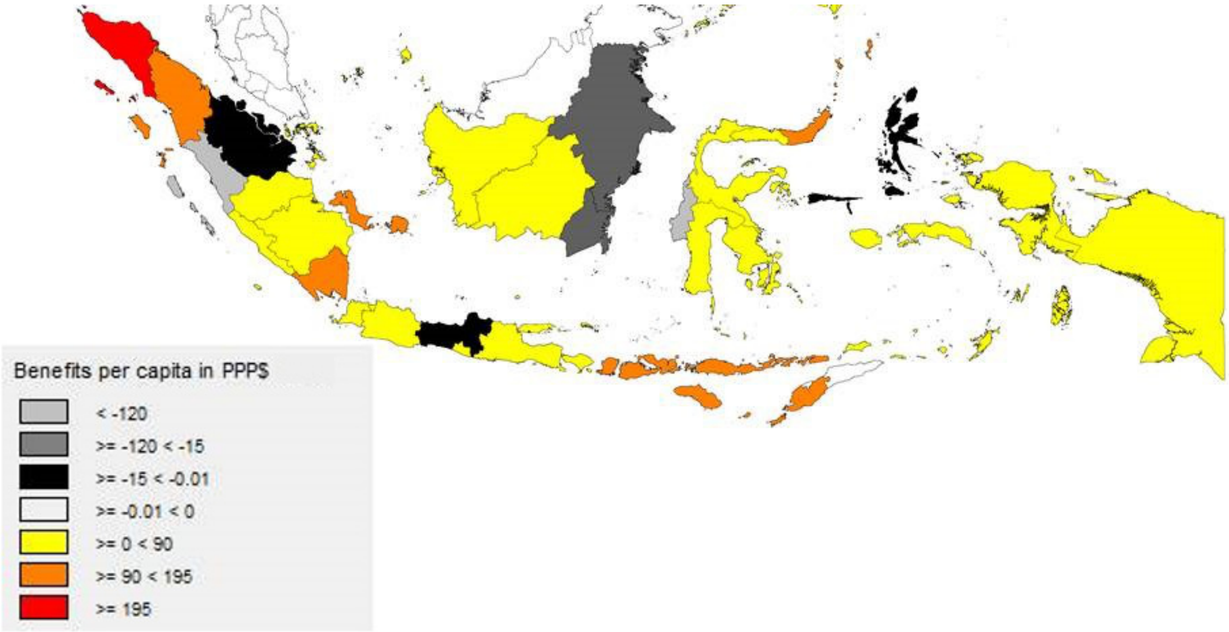

Figure 3.1. Spatial distribution of post 1989 MV cumulative producer and laborer benefits per person under the PPP$2 per day poverty line in Indonesia, according to the positive shutdown price functional form for supply.

3.5.2.5 Trait sources of welfare impacts of post 1989 MVs

The breakdown of benefits by trait is similar to the composition of production shocks, with 91% of benefits generated by increased release yields, 11% generated by BPH resistance, 7% generated by BLB resistance and a negative 9% contribution due to reduced blast resistance (Table 3.23). The share of economic surplus accruing to the poor is similar among traits. For example, 38% of welfare effects from BPH resistance, blast resistance and yield gain accrues to those below the PPP$2.0 poverty line, while BLB resistance is slightly more pro-poor at 46%.

3.5.2.6 Trait sources of welfare impacts of IRRI contributions to post 1989 MVs

The welfare effects of IRRI's contributions follow a similar breakdown to the total effect of post 1989 MVs (Table 3.24). The only divergence is slight, and that is that the proportion of welfare effects via host plant resistances is marginally higher than for all post 1989 MVs.

3.5.2.7 Sensitivity to shutdown price assumption

Under a pure constant elasticity functional form for the supply curve, producer welfare effects are negative, even when benefits through self-consumption are included, with PPP$2.5 billion of welfare loss under the latter as a result of the diffusion of post 1989 MVs. As a result, total benefits from the post 1989 MVs are halved, and the proportion of benefits to the poor falls slightly, with 36% of benefits captured by those under the PPP$2.0 poverty line. The benefits attributable to IRRI are affected in a similar manner to the total benefits of post 1989 MVs (Table 3.25).

Table 3.5. Production shock effects of genetic yield gain and resistance to BLB, blast and BPH in Indonesia ('000 tons) and price consequences.

	Total effect of post 1989 MVs					IRRI contributions to post 1989 MVS					Total Price effects (%)	
Year	**BLB resistance**	**Blast resistance**	**BPH resistance**	**Genetic yield gain**	**Total**	**BLB resistance**	**Blast resistance**	**BPH resistance**	**Genetic yield gain**	**Total**	**Total**	**IRRI attr.**
1990	-	-	-	-	-	-	-	-	-	-		
1991	-	0.83	5.32	18.06	24.21	-	0.83	5.32	-	6.15	(0.06)%	(0.02)%
1992	-	1.20	8.09	32.30	41.59	-	1.20	8.09	-	9.29	(0.10)%	(0.02)%
1993	-	0.82	6.45	34.45	41.72	-	0.82	6.45	-	7.26	(0.09)%	(0.02)%
1994	-	0.83	3.44	30.69	34.95	-	0.83	3.44	-	4.26	(0.07)%	(0.01)%
1995	-	1.21	2.62	121.73	125.56	-	1.00	2.01	-	3.01	(0.27)%	(0.01)%
1996	-	1.27	6.15	400.05	407.47	-	0.32	1.70	-	2.02	(0.88)%	0.00)%
1997	-	1.96	10.48	559.13	571.56	-	0.56	1.53	-	2.09	(0.84)%	0.00)%
1998	-	2.54	20.85	573.21	596.60	-	0.88	6.56	-	7.45	(1.04)%	(0.01)%
1999	-	1.31	23.87	516.01	541.20	-	0.99	9.23	-	10.22	(1.11)%	(0.02)%
2000	-	(1.15)	39.68	480.39	518.92	-	0.70	2.94	-	3.64	(1.04)%	(0.01)%
2001	254.65	(87.90)	71.61	894.87	1,133.24	81.11	(24.07)	13.20	175.83	246.07	(2.05)%	(0.46)%
2002	433.81	(134.90)	179.86	1,656.29	2,135.06	171.28	(41.97)	61.53	505.28	696.12	(4.09)%	(1.33)%
2003	440.14	(211.98)	244.54	2,140.29	2,612.99	183.40	(82.55)	91.45	735.53	927.84	(5.99)%	(2.12)%
2004	686.60	(339.23)	369.03	3,077.77	3,794.17	298.84	(152.17)	154.24	1,186.06	1,486.97	(8.66)%	(3.36)%
2005	676.28	(393.44)	436.81	3,485.80	4,205.45	296.35	(182.43)	186.71	1,352.65	1,653.28	(9.63)%	(3.67)%
2006	854.85	(516.67)	606.68	4,562.48	5,507.35	369.52	(242.01)	262.80	1,754.77	2,145.08	(11.22)%	(4.19)%
2007	31.53	(644.94)	750.67	5,528.81	5,666.07	(22.57)	(306.70)	330.56	2,149.82	2,151.12	(13.17)%	(4.80)%
2008	9.28	(779.63)	942.98	6,572.01	6,744.64	(27.55)	(371.55)	421.76	2,548.95	2,571.60	(15.24)%	(5.53)%
2009	(168.83)	(774.09)	955.61	7,120.08	7,132.77	(143.19)	(375.04)	415.11	2,674.06	2,570.94	(14.11)%	(4.81)%
2010	90.59	(734.35)	887.79	6,524.55	6,768.59	(7.36)	(351.33)	394.46	2,460.29	2,496.07	(11.20)%	(4.01)%
2011	-	(680.03)	813.99	6,203.00	6,336.95	-	(327.12)	353.50	2,299.60	2,325.98	(12.05)%	(4.24)%
Total	**3,308.91**	**(5,286.33)**	**6,386.52**	**50,531.98**	**54,941.08**	**1,199.83**	**(2,448.79)**	**2,732.57**	**17,842.85**	**19,326.46**		

Table 3.6. Total annual benefits to producers, consumers, hired labor and environmental benefits in Indonesia under positive shutdown price functional form for supply (million PPP$, discounted at 5%).

Year	Producer surplus				Consumer surplus			Hired Labor			Environmental benefits	Total benefits		
	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day		All/Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	3.92	8.77	3.23	4.14	11.18	3.82	5.81	0.86	0.63	0.77	0.18	20.99	7.68	10.71
1992	5.28	12.63	4.65	5.86	18.50	6.37	9.79	1.20	0.87	1.06	0.30	32.63	11.88	16.71
1993	6.94	13.65	5.11	6.62	16.99	5.85	8.99	1.27	0.96	1.14	0.27	32.19	11.92	16.74
1994	10.49	15.12	4.87	7.35	11.25	3.59	5.66	1.09	0.82	1.05	0.18	27.64	9.28	14.07
1995	10.33	27.88	10.45	17.41	45.21	13.44	22.09	2.84	2.33	2.68	0.73	76.66	26.22	42.17
1996	28.27	84.35	31.33	53.95	145.86	40.04	68.90	7.61	6.19	7.29	2.29	240.11	77.56	130.14
1997	159.59	214.23	76.74	130.05	135.55	38.34	64.88	15.79	12.93	15.14	2.02	367.59	128.01	210.07
1998	116.32	182.87	68.90	112.75	164.09	48.09	80.85	13.26	11.02	12.82	2.52	362.73	128.01	206.43
1999	45.08	113.44	46.56	71.47	171.59	51.76	86.47	8.87	7.56	8.68	2.60	296.50	105.88	166.62
2000	31.11	88.13	32.34	52.97	146.77	38.58	68.90	7.50	6.27	7.28	2.30	244.70	77.19	129.15
2001	149.61	261.26	65.98	128.03	268.83	60.12	116.20	20.18	13.78	19.33	4.11	554.38	139.88	263.56
2002	238.57	448.43	99.01	222.13	518.31	95.95	209.30	34.62	20.53	32.88	7.85	1,009.22	215.49	464.31
2003	103.55	396.22	80.75	184.92	725.84	122.38	273.21	28.91	14.94	27.50	10.85	1,161.82	218.07	485.63
2004	67.65	450.79	87.22	209.39	1,023.62	155.25	361.11	35.55	18.26	34.72	15.69	1,525.65	260.73	605.22
2005	51.00	466.03	73.06	183.68	1,084.55	145.34	350.54	37.43	16.54	34.10	16.53	1,604.54	234.93	568.32
2006	380.46	841.91	166.86	378.88	1,232.56	197.59	437.93	55.99	29.73	52.97	18.61	2,149.06	394.18	869.78
2007	57.19	558.77	113.39	258.48	1,405.58	223.97	509.37	31.98	16.31	30.58	21.34	2,017.67	353.68	798.44
2008	11.95	543.05	100.99	237.94	1,593.47	230.54	543.17	30.74	14.59	28.23	24.07	2,191.33	346.12	809.34
2009	221.20	676.68	114.36	283.15	1,481.11	196.90	496.42	37.59	16.54	33.46	22.43	2,217.82	327.79	813.04
2010	562.02	915.28	133.74	338.52	1,152.87	139.25	354.94	49.53	19.00	41.91	16.97	2,134.65	291.99	735.37
2011	269.96	639.63	78.87	203.98	1,172.39	124.48	325.31	37.67	12.66	30.31	17.51	1,867.20	216.01	559.60
Total	**2,530.47**	**6,959.16**	**1,398.42**	**3,091.67**	**12,526.08**	**1,941.64**	**4,399.83**	**460.50**	**242.44**	**423.90**	**189.36**	**20,135.10**	**3,582.50**	**7,915.40**

Table 3.7. Total annual thousands of DALYs (Disability Adjusted Life Years) saved through reduced hunger in Indonesia (‘000).

	Total effects of post 1989 MVs					Effects attributable to IRRI contributions to post 1989 MVs				
Year	**BLB resistance**	**Blast resistance**	**BPH resistance**	**Genetic yield gain**	**Total**	**BLB resistance**	**Blast resistance**	**BPH resistance**	**Genetic yield gain**	**Total**
1990	-	-	-	-	-	-	-	-	-	-
1991	-	0.02	0.11	0.39	0.52	-	0.02	0.12	-	0.14
1992	-	0.02	0.16	0.63	0.82	-	0.02	0.16	-	0.19
1993	-	0.01	0.11	0.60	0.73	-	0.01	0.11	-	0.13
1994	-	0.01	0.05	0.43	0.49	-	0.01	0.05	-	0.06
1995	-	0.02	0.04	1.79	1.84	-	0.01	0.03	-	0.04
1996	-	0.02	0.08	5.45	5.55	-	0.00	0.02	-	0.03
1997	-	0.02	0.11	5.62	5.75	-	0.01	0.02	-	0.02
1998	-	0.03	0.27	7.41	7.72	-	0.01	0.09	-	0.10
1999	-	0.02	0.39	8.40	8.82	-	0.02	0.15	-	0.17
2000	-	(0.02)	0.68	8.22	8.88	-	0.01	0.05	-	0.06
2001	4.21	(1.45)	1.18	14.75	18.69	1.42	(0.40)	0.22	2.94	4.19
2002	7.40	(2.30)	3.07	28.24	36.41	3.10	(0.72)	1.05	8.60	12.04
2003	8.77	(4.22)	4.87	42.53	51.94	3.66	(1.69)	1.88	15.06	18.91
2004	13.25	(6.54)	7.11	59.16	72.98	6.09	(3.03)	3.06	23.20	29.33
2005	12.82	(7.46)	8.27	65.88	79.51	5.94	(3.57)	3.65	25.60	31.63
2006	14.04	(8.48)	9.95	74.87	90.38	6.34	(4.10)	4.44	28.80	35.49
2007	0.57	(11.50)	13.35	97.87	100.29	(0.43)	(5.63)	6.06	39.32	39.32
2008	0.16	(13.10)	15.78	109.45	112.29	(0.46)	(6.43)	7.29	43.90	44.30
2009	(2.43)	(11.20)	13.79	102.61	102.77	(2.07)	(5.59)	6.19	39.47	38.00
2010	1.11	(8.98)	10.83	79.91	82.88	(0.09)	(4.43)	4.97	31.07	31.52
2011	-	(9.90)	11.82	90.21	92.12	-	(4.91)	5.30	34.35	34.74
Total	**59.92**	**(84.97)**	**102.01**	**804.41**	**881.37**	**23.52**	**(40.35)**	**44.91**	**292.32**	**320.39**

Table 3.8. Total annual benefits to producers, consumers, hired labor and environmental benefits in Indonesia attributable to IRRI under positive shutdown price functional form for supply (million PPP$, discounted at 5%).

Year	Producer surplus				Consumer surplus			Hired Labor			Environmental benefits	Total benefits		
	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day		All/Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	1.08	2.34	1.01	1.33	2.91	0.99	1.51	0.22	0.18	0.21	0.05	5.53	2.18	3.06
1992	1.31	2.99	1.35	1.78	4.23	1.46	2.24	0.27	0.22	0.26	0.07	7.56	3.03	4.27
1993	1.25	2.42	1.11	1.46	2.96	1.02	1.57	0.24	0.20	0.23	0.05	5.67	2.34	3.26
1994	1.19	1.76	0.63	0.93	1.37	0.44	0.69	0.12	0.10	0.12	0.02	3.27	1.16	1.73
1995	0.51	0.93	0.26	0.44	1.09	0.32	0.53	0.07	0.05	0.07	0.02	2.12	0.64	1.05
1996	0.26	0.54	0.10	0.15	0.72	0.20	0.34	0.06	0.03	0.05	0.01	1.33	0.33	0.55
1997	0.69	0.89	0.26	0.42	0.50	0.14	0.24	0.09	0.06	0.09	0.01	1.49	0.46	0.75
1998	2.12	2.95	1.28	1.99	2.06	0.60	1.01	0.20	0.17	0.19	0.03	5.24	2.05	3.20
1999	1.70	3.00	1.37	2.05	3.26	0.99	1.64	0.18	0.16	0.17	0.05	6.49	2.51	3.86
2000	0.81	1.21	(0.43)	(0.40)	1.04	0.27	0.49	0.06	(0.06)	0.06	0.02	2.32	(0.22)	0.14
2001	40.51	65.32	12.25	25.40	59.74	13.39	25.82	4.23	2.04	4.04	0.90	130.18	27.68	55.26
2002	82.05	150.54	28.06	65.27	169.16	31.45	68.31	11.58	6.03	10.94	2.52	333.80	65.54	144.52
2003	45.26	149.79	26.12	62.76	259.23	43.98	97.58	10.76	4.92	10.12	3.80	423.59	75.01	170.46
2004	37.24	187.35	32.60	80.31	401.03	61.32	141.48	14.95	7.17	14.47	5.99	609.32	101.08	236.25
2005	28.55	188.84	27.30	70.08	418.87	56.66	135.38	16.35	6.82	14.73	6.19	630.25	90.78	220.20
2006	159.84	334.95	63.08	144.59	467.74	75.80	166.19	24.41	12.41	22.96	6.76	833.86	151.29	333.74
2007	51.10	238.13	45.08	103.73	524.13	84.83	189.94	14.84	7.20	14.11	7.56	784.66	137.11	307.79
2008	42.93	240.65	41.81	99.64	593.22	87.35	202.21	15.61	7.18	14.24	8.46	857.95	136.34	316.10
2009	108.58	267.72	41.39	102.97	517.50	69.96	173.45	17.22	7.11	15.02	7.35	809.79	118.47	291.44
2010	229.17	357.88	51.33	130.33	420.05	51.39	129.32	20.28	7.67	17.09	5.83	804.04	110.38	276.75
2011	117.20	250.04	30.51	79.01	421.27	45.38	116.89	16.27	5.49	13.16	5.91	693.49	81.38	209.06
Total	**953.34**	**2,450.25**	**406.47**	**974.25**	**4,272.08**	**627.94**	**1,456.84**	**168.01**	**75.14**	**152.35**	**61.59**	**6,951.94**	**1,109.55**	**2,583.44**

Table 3.9. Total annual benefits to the general population and to those earning less than PPP$1.25 and PPP$2 per day from resistance to BLB, blast, BPH and genetic yield gain in Indonesia under positive shutdown price functional form for supply (million PPP$, discounted at 5%).

Year	BLB resistance			Blast resistance			BPH resistance			Genetic yield gain			Total benefits		
	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	0.68	0.30	0.41	4.73	1.85	2.60	15.58	5.53	7.71	20.99	7.68	10.71
1992	-	-	-	0.87	0.40	0.55	6.54	2.57	3.65	25.22	8.90	12.52	32.63	11.88	16.71
1993	-	-	-	0.60	0.31	0.41	5.06	2.03	2.84	26.53	9.59	13.49	32.19	11.92	16.74
1994	-	-	-	0.72	0.24	0.39	2.55	0.92	1.34	24.37	8.12	12.34	27.64	9.28	14.07
1995	-	-	-	0.91	0.28	0.48	1.65	0.53	0.85	74.11	25.42	40.85	76.66	26.22	42.17
1996	-	-	-	0.74	0.20	0.35	3.98	1.29	2.15	235.39	76.06	127.63	240.11	77.56	130.14
1997	-	-	-	1.28	0.42	0.69	7.51	2.89	4.69	358.81	124.70	204.68	367.59	128.01	210.07
1998	-	-	-	1.68	0.62	0.98	14.42	5.88	9.25	346.63	121.51	196.20	362.73	128.01	206.43
1999	-	-	-	1.02	0.41	0.62	14.82	5.96	9.19	280.67	99.52	156.81	296.50	105.88	166.62
2000	-	-	-	(0.27)	(0.05)	(0.12)	18.72	5.50	9.54	226.25	71.74	119.73	244.70	77.19	129.15
2001	131.32	36.39	68.35	(41.76)	(8.99)	(17.75)	34.22	8.46	16.07	430.60	104.02	196.89	554.38	139.88	263.56
2002	208.41	47.34	101.29	(62.80)	(13.60)	(29.51)	85.12	18.64	40.17	778.49	163.11	352.35	1,009.22	215.49	464.31
2003	198.37	39.64	87.92	(92.32)	(16.81)	(37.74)	107.27	20.51	45.55	948.49	174.72	389.90	1,161.82	218.07	485.63
2004	280.68	52.38	120.17	(133.45)	(22.08)	(51.49)	145.06	24.67	56.80	1,233.36	205.77	479.74	1,525.65	260.73	605.22
2005	259.71	42.56	101.58	(147.43)	(20.96)	(50.68)	162.15	24.03	57.85	1,330.11	189.31	459.57	1,604.54	234.93	568.32
2006	331.56	67.12	145.63	(195.76)	(35.02)	(77.06)	229.98	41.98	91.76	1,783.29	320.09	709.46	2,149.06	394.18	869.78
2007	13.99	6.19	11.82	(221.86)	(39.05)	(86.78)	259.91	45.92	101.92	1,965.64	340.62	771.48	2,017.67	353.68	798.44
2008	3.86	2.70	4.82	(244.64)	(39.61)	(90.60)	296.28	46.91	107.53	2,135.83	336.12	787.59	2,191.33	346.12	809.34
2009	(46.05)	(4.43)	(12.00)	(230.23)	(34.42)	(83.49)	288.05	42.00	102.93	2,206.05	324.64	805.60	2,217.82	327.79	813.04
2010	28.86	5.72	13.88	(221.44)	(30.74)	(76.36)	270.08	36.68	91.69	2,057.15	280.33	706.17	2,134.65	291.99	735.37
2011	-	-	-	(191.76)	(23.06)	(58.62)	230.90	27.18	69.78	1,828.05	211.89	548.43	1,867.20	216.01	559.60
Total	**1,410.71**	**295.62**	**643.45**	**(1,775.23)**	**(281.20)**	**(655.31)**	**2,188.99**	**366.38**	**828.14**	**18,310.63**	**3,201.70**	**7,099.13**	**20,135.10**	**3,582.50**	**7,915.40**

Table 3.10. Total annual benefits to the general population and to those earning less than PPP$1.25 and PPP$2 per day from resistance to BLB, blast, BPH and genetic yield gain in Indonesia attributable to IRRI under positive shutdown price functional form for supply (million PPP$, discounted at 5%).

Year	BLB resistance			Blast resistance			BPH resistance			Genetic yield gain			Total benefits		
	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	0.69	0.30	0.41	4.84	1.88	2.65	-	-	-	5.53	2.18	3.06
1992	-	-	-	0.87	0.41	0.55	6.69	2.62	3.72	-	-	-	7.56	3.03	4.27
1993	-	-	-	0.60	0.31	0.41	5.07	2.03	2.85	-	-	-	5.67	2.34	3.26
1994	-	-	-	0.72	0.24	0.39	2.55	0.93	1.34	-	-	-	3.27	1.16	1.73
1995	-	-	-	0.80	0.24	0.41	1.32	0.40	0.64	-	-	-	2.12	0.64	1.05
1996	-	-	-	0.20	0.05	0.08	1.14	0.28	0.47	-	-	-	1.33	0.33	0.55
1997	-	-	-	0.37	0.11	0.18	1.12	0.35	0.57	-	-	-	1.49	0.46	0.75
1998	-	-	-	0.59	0.21	0.34	4.65	1.84	2.86	-	-	-	5.24	2.05	3.20
1999	-	-	-	0.63	0.23	0.37	5.85	2.28	3.49	-	-	-	6.49	2.51	3.86
2000	-	-	-	0.40	0.12	0.21	1.92	(0.34)	(0.07)	-	-	-	2.32	(0.22)	0.14
2001	47.23	12.77	24.44	(11.74)	(2.24)	(4.54)	7.04	0.67	1.85	87.65	16.49	33.51	130.18	27.68	55.26
2002	89.19	19.04	41.51	(19.72)	(3.96)	(8.68)	29.98	5.68	12.78	234.34	44.78	98.91	333.80	65.54	144.52
2003	84.66	16.13	36.36	(37.20)	(6.60)	(14.92)	42.00	7.26	16.69	334.12	58.22	132.34	423.59	75.01	170.46
2004	129.42	23.29	53.92	(61.80)	(10.13)	(23.68)	62.76	10.10	23.62	478.94	77.82	182.39	609.32	101.08	236.25
2005	120.13	19.06	45.83	(70.03)	(9.87)	(23.90)	71.26	10.12	24.62	508.89	71.46	173.64	630.25	90.78	220.20
2006	150.05	29.78	64.98	(94.13)	(16.65)	(36.73)	102.57	18.16	39.98	675.37	120.00	265.51	833.86	151.29	333.74
2007	(5.72)	0.31	0.04	(108.48)	(18.96)	(42.26)	117.84	20.38	45.48	781.02	135.38	304.53	784.66	137.11	307.79
2008	(7.81)	(0.70)	(2.03)	(119.88)	(19.32)	(44.35)	136.68	21.45	49.38	848.95	134.91	313.10	857.95	136.34	316.10
2009	(40.89)	(5.45)	(13.76)	(114.33)	(16.96)	(41.29)	128.33	18.51	45.42	836.67	122.37	301.06	809.79	118.47	291.44
2010	(0.95)	0.51	1.13	(108.80)	(15.01)	(37.39)	123.16	16.72	41.81	790.63	108.16	271.20	804.04	110.38	276.75
2011	-	-	-	(94.43)	(11.24)	(28.66)	102.70	12.08	30.95	685.22	80.54	206.77	693.49	81.38	209.06
Total	**565.31**	**114.74**	**252.43**	**(834.65)**	**(128.74)**	**(303.06)**	**959.48**	**153.42**	**351.11**	**6,261.81**	**970.13**	**2,282.96**	**6,951.94**	**1,109.55**	**2,583.44**

Table 3.11. Producer and total benefits in Indonesia under constant elasticity functional form for supply (million PPP$, discounted at 5%).

Year	Total effect of post 1989 MVs							Effects attributable to IRRI contributions to post 1989 MVs						
	Producer surplus				Total benefits			Producer surplus				Total benefits		
	All	Adjusted for self-consump-tion	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Adjusted for self-consump-tion	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	0.07	-	-
1991	(6.93)	(2.07)	(0.83)	(1.63)	10.24	3.61	4.95	(1.80)	(0.53)	(0.13)	(0.29)	2.65	1.04	1.44
1992	(12.35)	(5.00)	(2.02)	(3.60)	14.88	5.22	7.25	(2.80)	(1.12)	(0.32)	(0.60)	3.40	1.36	1.90
1993	(9.85)	(3.14)	(1.24)	(2.42)	15.85	5.57	7.71	(1.71)	(0.54)	(0.10)	(0.26)	2.68	1.12	1.54
1994	(3.37)	1.27	0.20	0.12	15.88	4.61	6.83	(0.42)	0.14	0.05	0.05	1.65	0.59	0.85
1995	(27.31)	(9.76)	(2.34)	(3.91)	40.29	13.43	20.85	(0.62)	(0.19)	(0.09)	(0.15)	0.98	0.28	0.46
1996	(90.56)	(34.47)	(7.32)	(13.33)	121.49	38.91	62.86	(0.43)	(0.15)	(0.08)	(0.16)	0.66	0.15	0.24
1997	(0.69)	53.95	22.28	37.06	207.87	73.55	117.08	0.02	0.22	0.06	0.08	0.85	0.26	0.41
1998	(43.59)	22.96	12.34	18.51	202.59	71.44	112.18	(0.44)	0.40	0.28	0.38	2.67	1.05	1.58
1999	(88.19)	(19.83)	(2.11)	(6.95)	164.68	57.21	88.20	(1.53)	(0.23)	0.09	0.03	4.11	1.23	1.84
2000	(82.34)	(25.32)	(3.65)	(10.21)	136.60	41.20	65.96	(0.52)	(0.12)	(0.46)	(0.63)	3.48	(0.25)	(0.09)
2001	(89.41)	22.23	4.81	6.82	321.73	78.70	142.36	(18.91)	5.90	(1.31)	(2.23)	73.63	14.13	27.63
2002	(211.40)	(1.54)	1.27	1.12	566.36	117.75	243.30	(68.92)	(0.43)	(2.63)	(5.15)	186.19	34.85	74.09
2003	(446.96)	(154.29)	(28.26)	(67.63)	616.09	109.06	233.09	(159.04)	(54.51)	(12.55)	(28.10)	221.55	36.35	79.60
2004	(661.21)	(278.07)	(43.69)	(105.06)	798.38	129.82	290.77	(258.60)	(108.49)	(19.06)	(44.66)	314.09	49.42	111.28
2005	(691.18)	(276.15)	(41.85)	(103.86)	865.26	120.03	280.78	(266.96)	(106.67)	(17.49)	(42.61)	335.85	45.99	107.50
2006	(580.34)	(118.90)	(17.43)	(40.01)	1,191.30	209.89	450.90	(221.06)	(45.95)	(8.66)	(19.06)	454.32	79.55	170.08
2007	(906.70)	(405.12)	(71.72)	(166.88)	1,052.48	168.57	373.08	(337.15)	(150.12)	(28.21)	(65.09)	395.92	63.82	138.96
2008	(1,068.82)	(537.72)	(88.58)	(207.96)	1,101.83	156.55	363.44	(396.75)	(199.02)	(34.15)	(79.58)	415.44	60.38	136.88
2009	(866.24)	(410.75)	(60.09)	(151.50)	1,123.71	153.34	378.38	(303.55)	(144.40)	(23.25)	(58.29)	396.01	53.82	130.18
2010	(440.17)	(86.91)	(10.68)	(27.99)	1,115.49	147.57	368.87	(162.43)	(33.71)	(4.71)	(12.05)	406.61	54.35	134.37
2011	(607.43)	(237.75)	(30.03)	(79.59)	972.30	107.11	276.03	(219.65)	(86.82)	(11.16)	(29.52)	350.72	39.71	100.53
Total	**(6,935.06)**	**(2,506.37)**	**(370.95)**	**(928.87)**	**10,655.30**	**1,813.13**	**3,894.87**	**(2,423.26)**	**(926.35)**	**(163.87)**	**(387.90)**	**3,573.46**	**539.21**	**1,221.29**

3.5.3 Philippines

3.5.3.1 Production effects of post 1989 MVs

Gains in release yield from post 1989 varieties only begin to make substantial contributions to production in the 2000s. By 2010, the annual attributable contribution is 300,000 tons, and the aggregate contribution to production is 2.9 million tons over the period. The effect of newer varieties, which are less tungro resistant than their antecedents, is to reduce the net area under tungro resistance. This means that the production effect in terms of tungro resistance is negative, but small, at a loss of about 700 tons per year when the loss is largest in the late 2000s. In the early 2000s, expanded area under effective BLB resistance due to new varieties contributes 10 to 13,000 tons annually before the BLB resistance contribution of new varieties becomes negative, such that losses of a few thousand tons annually occur. The vast majority of the total production increase from all assessed traits (98% over the period) is attributable to the higher release yields of post 1989 varieties (Table 3.26).

3.5.3.2 Production effects of IRRI contributions to post 1989 MVs

Increases in release yield attributable to IRRI contributions to post 1989 varieties represent a large share of the total release yield effect of post 1989 varieties (Table 3.26). In some years, the IRRI attributable release yield effect actual exceeds the total post 1989 MV release yield effect. This is because some of the popular post 1989 MVs produced by the national research institutes of the Philippines have release yields that are lower than the pre 1990 MVs that serve as the basis for the no post 1989 MV counterfactual. However, in the late 2000s, the IRRI attributable share falls to a fraction of the total contribution of post 1989 MVs. Over the period, 80% of the total release yield effect of post 1989 MVs is attributable to IRRI. Given that the tungro resistance of IRRI related varieties is higher than that of other popular post 1989 varieties, the IRRI effect is slightly larger than the effect of all post 1989 MVs, but remains very small in absolute terms. The IRRI attributable BLB contribution is about 40% larger than the total contribution of post 1989 MVS, because IRRI related materials have greater BLB resistance than other MVs that are popular, and which are less resistant than the pre 1990 varieties. However, 96% of the IRRI attributable supply shock still comes from contributions to enhanced release yield.

3.5.3.3 Welfare impacts of post 1989 MVs

In terms of economic welfare, the total effect of post 1989 MVs is to generate PPP$1.2 billion of benefits over the period, with benefits peaking in the late 2000s at over PPP$100 million annually. Consumers receive the largest share of benefits (46%), but this share is very similar to that of producers (44%). Laborers receive nearly 10% of benefits, while environmental benefits are small, probably due to the limited forest cover in regions where there are area responses to equilibrium price effects (Table 3.27).

A substantial share of benefits (44%) accrues to the poor under the PPP$2/day poverty line, while 20% accrues to those under the PPP$1.25 poverty line. Effects on hired labor become a larger share of benefits to the poor as the poverty line becomes lower, as 24% of the benefits to the PPP$1.25 poor accrue via this avenue (compared with 10% of overall benefits and 18% of benefits to PPP$2 poor). Consumer benefits to the poor under the PPP$2 line are similar to benefits to producers under the same poverty line, while benefits to producers under the PPP$1.25 poverty line are 30% greater than to consumers. Benefits to poor producers and laborers are concentrated in southern Mindanao, the Cagayan Valley, Eastern Visayas and Central Luzon in aggregate, while a per capita basis for the poor (in which poor producer and laborer benefits are divided by the total rural poor population, presented in Figure 3.34) benefits are most intense in Southern Mindanao and the Cagayan Valley. In terms of hunger, there is a savings of 41,000 Disability Affected Life Years due to reduced disease risk from less chronic energy deficiency (Table 3.28).

3.5.3.4 Welfare impacts of IRRI contributions to post 1989 MVs

A large share (95%) of benefits is reflected as attributable to IRRI contributions to post 1989 MVs (Table 3.29). The distribution of IRRI attributable benefits among groups and to the poor is similar to that of total post 1989 MV effects, and the IRRI attributable reduction in DALYs is 91% of the total effect of post 1989 MVs (Table 3.28).

This substantial share is derived as an artifact of the dominance of release yield among sources of yield gains, in the context of the fact that some of the adopted non-IRRI varieties from the early 1990s are low yielding and depress the average counterfactual weighted release yield relative to a counterfactual of only pre-1990 MVs. This effect occurs principally in the late 1990s and early 2000s, and these effects are amplified as a result of discounting, compared with the total MV effects which become larger in subsequent years. It is likely that there are other beneficial traits to the lower yielding varieties that are not captured by this analysis, which if included, would lower the IRRI share of total benefits.

3.5.3.5 Trait sources of welfare impacts of post 1989 MVs

In congruence with the magnitude of yield shocks, the vast majority of benefits (98%) is derived from increases in the release yield of adopted varieties. BLB resistance effects of post 1989 varieties contributes PPP$33 million of benefits over the period, while the loss of tungro resistance in new varieties causes PPP$4 million of cumulative welfare loss. This contrasts with PPP$1.14 billion from increased release yield of adopted varieties. There is not a substantial difference in the relevance of welfare effects to the poor from the different traits (Table 3.30).

3.5.3.6 Trait sources of welfare impacts of IRRI contributions to post 1989 MVs

IRRI attributable benefits are dominated by contributions to enhanced release yield (96% of benefits), in a similar manner to the total effects of post 1989 MVs (Table 3.31). However, a somewhat larger share of welfare effects occurs via host plant resistances, as there appears to be greater difference between the resistance of IRRI related varieties and resistance of other popular varieties than between the resistance of 1980s varieties and other popular varieties. As a result, the positive welfare effects of increased BLB resistance and negative welfare effects of reduced area under tungro resistance are 50% higher than the total effects of post 1989 MVs.

3.5.3.7 Sensitivity to shutdown price assumption

Under a pure constant elasticity functional form for the supply curve, producer welfare effects are 18% of the estimates under a positive shutdown price without self-consumption, and are 40% of the positive shutdown estimates even when benefits through self-consumption are included. As a result, total benefits from the post 1989 MVs fall by 27%, while the proportion of benefits to the poor rises slightly, with 46% of benefits captured by those under the PPP$2.0 poverty line. The benefits attributable to IRRI are affected in a similar manner to the total benefits of post 1989 MVs (Table 3.32).

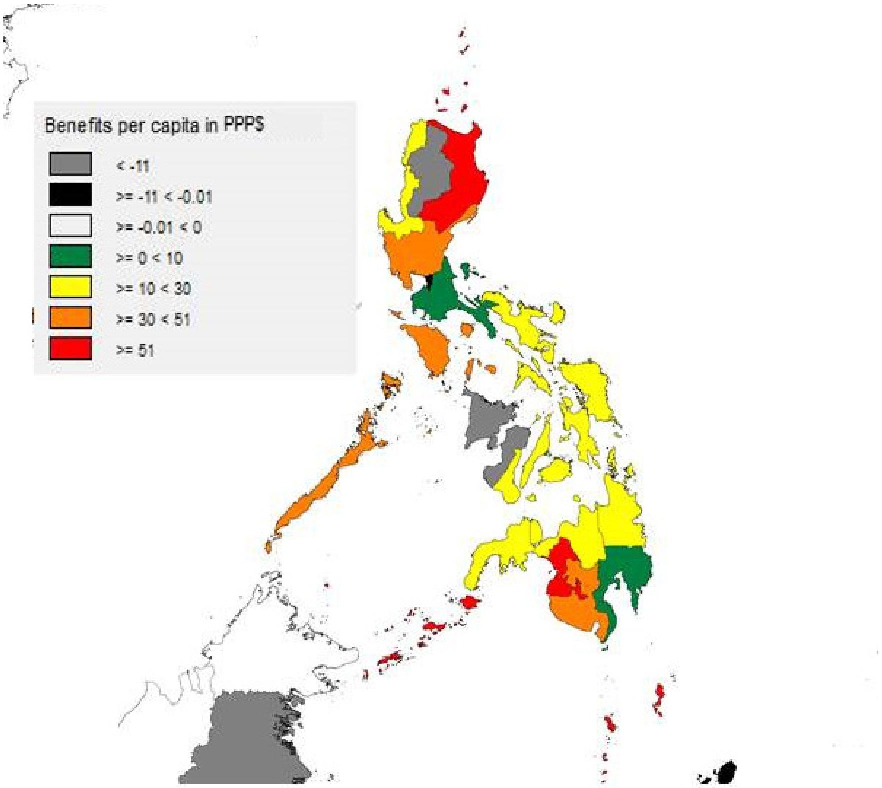

Figure 3.2. Spatial distribution of post 1989 MV cumulative producer and laborer benefits per person under the PPP$2 per day poverty line in the Philippines, according to positive shutdown price functional form for supply.

Table 3.12. Production shock effects of genetic yield gain and resistance to tungro and BLB in the Philippines ('000 tons) and price consequences.

	Total effect of post 1989 MVs				IRRI contributions to post 1989 MVs				Total price effects (%)	
Year	Genetic yield gain	Tungro resistance	BLB resistance	Total	Genetic yield gain	Tungro resistance	BLB resistance	Total	Total	IRRI attr.
1990	-	-	-	-	-	-	-	-		
1991	-	-	-	-	-	-	-	-		
1992	3.55	(0.01)	-	3.54	1.25	(0.01)	-	1.24	0.00)%	(0.01)%
1993	2.49	(0.03)	-	2.45	2.72	(0.02)	-	2.70	(0.03)%	(0.02)%
1994	1.73	(0.07)	-	1.66	5.57	(0.05)	-	5.52	(0.02)%	(0.05)%
1995	2.28	(0.10)	-	2.18	11.91	(0.06)	-	11.84	(0.01)%	(0.07)%
1996	6.30	(0.17)	-	6.14	28.20	(0.18)	-	28.01	(0.01)%	(0.18)%
1997	11.88	(0.20)	-	11.68	51.07	(0.26)	-	50.81	(0.04)%	(0.26)%
1998	18.43	(0.19)	-	18.24	59.00	(0.25)	-	58.75	(0.06)%	(0.36)%
1999	43.67	(0.31)	-	43.35	104.68	(0.45)	-	104.24	(0.11)%	(0.62)%
2000	73.98	(0.45)	-	73.52	136.93	(0.72)	-	136.21	(0.26)%	(0.66)%
2001	112.52	(0.52)	13.48	125.49	165.86	(0.84)	12.06	177.07	(0.34)%	(0.88)%
2002	154.72	(0.60)	11.49	165.61	188.81	(0.93)	10.37	198.25	(0.60)%	(0.87)%
2003	159.92	(0.66)	10.50	169.76	191.77	(1.09)	12.53	203.21	(0.73)%	(0.98)%
2004	178.37	(0.78)	9.58	187.16	210.70	(1.27)	12.14	221.57	(0.79)%	(0.96)%
2005	175.37	(0.84)	13.85	188.38	220.07	(1.38)	15.46	234.15	(0.77)%	(0.95)%
2006	165.34	(0.99)	13.20	177.55	230.61	(1.50)	17.12	246.23	(0.76)%	(0.96)%
2007	195.61	(0.67)	13.10	208.05	183.52	(0.90)	17.72	200.34	(0.69)%	(0.69)%
2008	239.35	(0.75)	6.16	244.75	148.56	(0.98)	11.54	159.13	(0.69)%	(0.52)%
2009	274.20	(0.72)	(4.24)	269.24	126.97	(1.00)	1.03	127.00	(0.77)%	(0.46)%
2010	334.31	(0.75)	(8.50)	325.07	111.37	(1.02)	0.37	110.73	(0.94)%	(0.48)%
2011	447.15	(0.76)	-	446.39	109.12	(1.09)	-	108.03	(1.36)%	(0.41)%
2012	291.03	-	-	291.03	40.04	0.06	-	40.11	(1.65)%	(0.15)%
Total	**2,892.21**	**(9.59)**	**78.61**	**2,961.23**	**2,328.72**	**(13.94)**	**110.33**	**2,425.11**		

Table 3.13. Total annual benefits to producers, consumers, hired labor and environmental benefits in the Philippines under positive shutdown price functional form for supply (million PPP$, discounted at 5%)

Year	Producer surplus				Consumer surplus			Hired Labor			Environmental benefits	Total benefits		
	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day		All/adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	0.00	-	-	-
1992	0.19	0.78	0.09	0.16	1.45	0.30	0.68	0.38	0.15	0.26	0.04	2.64	0.54	1.11
1993	0.23	0.56	0.18	0.34	0.91	0.19	0.43	0.29	0.22	0.28	0.02	1.79	0.59	1.05
1994	0.06	0.25	0.11	0.21	0.60	0.12	0.29	0.16	0.13	0.16	0.02	1.02	0.37	0.66
1995	0.44	0.63	0.19	0.37	0.59	0.11	0.26	0.21	0.14	0.20	0.01	1.44	0.44	0.84
1996	0.93	1.48	0.38	0.74	1.81	0.31	0.77	0.49	0.30	0.40	0.04	3.83	0.99	1.91
1997	2.60	3.44	0.73	1.47	2.72	0.42	1.08	0.99	0.51	0.79	0.06	7.22	1.66	3.33
1998	4.56	6.54	1.45	2.89	4.01	0.60	1.52	2.19	1.19	1.78	0.09	12.84	3.24	6.20
1999	5.56	9.12	2.14	4.26	11.56	1.85	4.66	3.05	1.73	2.50	0.26	23.98	5.72	11.42
2000	13.83	18.43	4.29	8.48	15.69	2.55	6.40	5.18	2.99	4.33	0.34	39.64	9.84	19.21
2001	20.18	27.77	6.50	12.85	27.07	4.40	11.01	7.43	4.30	6.38	0.57	62.83	15.19	30.24
2002	28.03	37.28	8.20	16.24	33.41	5.40	13.52	9.50	5.11	7.74	0.66	80.85	18.70	37.51
2003	23.92	33.70	7.24	14.35	34.78	5.57	13.93	8.88	4.62	7.20	0.67	78.03	17.44	35.48
2004	27.53	36.81	8.00	15.84	36.90	6.03	15.08	8.82	4.55	6.98	0.65	83.18	18.57	37.89
2005	27.36	36.40	7.94	15.73	36.57	6.05	15.13	8.22	4.25	6.51	0.60	81.79	18.24	37.37
2006	24.75	32.60	7.76	15.36	33.38	5.59	13.98	7.12	3.94	5.83	0.53	73.62	17.29	35.18
2007	31.74	39.53	8.28	17.02	34.92	5.50	14.30	7.60	3.72	6.05	0.52	82.57	17.51	37.37
2008	36.46	44.57	8.74	18.71	38.89	5.74	15.54	8.24	3.78	6.48	0.58	92.27	18.26	40.74
2009	34.36	43.98	7.76	17.41	42.84	5.86	16.64	8.91	3.62	6.69	0.69	96.42	17.25	40.74
2010	29.09	43.18	7.57	17.15	60.86	8.09	23.18	9.31	3.75	7.06	0.93	114.28	19.41	47.39
2011	41.63	57.47	9.96	22.78	74.29	9.65	27.94	11.05	4.47	8.49	1.09	143.89	24.07	59.21
2012	26.29	35.92	6.18	14.25	44.80	5.68	16.58	6.74	2.68	5.26	0.67	88.14	14.53	36.10
Total	**379.74**	**510.43**	**103.70**	**216.60**	**538.06**	**80.00**	**212.96**	**114.76**	**56.15**	**91.39**	**9.03**	**1,172.28**	**239.86**	**520.95**

Table 3.14. Total annual thousands of DALYs (Disability Adjusted Life Years) saved through reduced hunger in the Philippines ('000).

	Total contribution of post 1989 MVs				IRRI contribution to post 1989 MVs			
Year	**Genetic yield gain**	**Tungro resistance**	**BLB resistance**	**Total**	**Genetic yield gain**	**Tungro resistance**	**BLB resistance**	**Total**
1990	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-
1992	0.13	(0.000)	-	0.13	0.05	(0.0003)	-	0.05
1993	0.08	(0.001)	-	0.08	0.09	(0.001)	-	0.09
1994	0.05	(0.002)	-	0.05	0.18	(0.001)	-	0.17
1995	0.05	(0.002)	-	0.05	0.27	(0.001)	-	0.27
1996	0.14	(0.004)	-	0.14	0.66	(0.004)	-	0.66
1997	0.22	(0.004)	-	0.22	0.97	(0.005)	-	0.97
1998	0.40	(0.004)	-	0.40	1.35	(0.006)	-	1.34
1999	0.96	(0.01)	-	0.95	2.30	(0.010)	-	2.29
2000	1.27	(0.01)	-	1.27	2.46	(0.012)	-	2.44
2001	1.98	(0.01)	0.24	2.21	3.04	(0.015)	0.21	3.24
2002	2.50	(0.01)	0.19	2.67	3.05	(0.015)	0.17	3.20
2003	2.71	(0.01)	0.18	2.88	3.39	(0.018)	0.21	3.58
2004	2.68	(0.01)	0.14	2.81	3.29	(0.019)	0.20	3.47
2005	2.54	(0.01)	0.20	2.73	3.19	(0.020)	0.24	3.41
2006	2.26	(0.01)	0.18	2.43	3.16	(0.021)	0.25	3.39
2007	2.26	(0.01)	0.15	2.41	2.21	(0.010)	0.22	2.42
2008	2.58	(0.01)	0.06	2.64	1.67	(0.011)	0.12	1.78
2009	3.24	(0.01)	(0.05)	3.18	1.54	(0.012)	0.01	1.54
2010	4.59	(0.01)	(0.12)	4.46	1.59	(0.014)	0.004	1.58
2011	5.58	(0.01)	-	5.57	1.41	(0.014)	-	1.39
2012	3.59	-	-	3.59	0.51	0.001	-	0.51
Total	**39.83**	**(0.14)**	**1.17**	**40.85**	**36.36**	**(0.21)**	**1.64**	**37.80**

Table 3.15. Total annual benefits to producers, consumers, hired labor and environmental benefits in the Philippines attributable to IRRI under positive shutdown price functional form for supply (million PPP$, discounted at 5%).

Year	Producer surplus				Consumer surplus			Hired Labor			Environmental benefits	Total benefits		
	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day		All/adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	0.00	-	-	-
1992	0.08	0.30	0.07	0.13	0.53	0.11	0.25	0.15	0.09	0.14	0.01	0.99	0.28	0.52
1993	0.29	0.66	0.27	0.48	1.05	0.21	0.50	0.34	0.28	0.33	0.03	2.07	0.76	1.31
1994	0.29	0.94	0.43	0.81	2.10	0.42	1.00	0.48	0.42	0.48	0.05	3.57	1.27	2.28
1995	2.50	3.57	0.89	1.71	3.32	0.62	1.50	1.07	0.63	0.89	0.08	8.04	2.15	4.10
1996	4.32	6.92	1.37	2.68	8.63	1.48	3.66	2.09	1.03	1.55	0.21	17.85	3.88	7.89
1997	11.34	15.09	2.95	5.94	12.08	1.88	4.79	4.18	2.05	3.17	0.28	31.64	6.87	13.90
1998	15.10	21.79	4.37	8.75	13.49	2.03	5.12	6.53	3.21	4.99	0.31	42.12	9.61	18.86
1999	13.51	22.11	4.52	8.99	27.90	4.46	11.25	7.04	3.54	5.44	0.64	57.69	12.52	25.68
2000	26.90	35.80	7.37	14.61	30.36	4.94	12.39	9.20	4.69	7.23	0.65	76.02	17.01	34.23
2001	29.73	40.88	8.42	16.67	39.76	6.46	16.17	10.29	5.31	8.31	0.83	91.77	20.19	41.15
2002	33.83	44.93	9.29	18.37	40.07	6.47	16.22	11.26	5.75	9.10	0.79	97.04	21.51	43.69
2003	30.33	42.51	8.61	17.03	43.30	6.93	17.34	10.09	5.05	8.31	0.84	96.74	20.59	42.68
2004	34.60	46.08	9.37	18.53	45.62	7.45	18.64	10.06	5.01	8.16	0.80	102.56	21.83	45.34
2005	34.32	45.64	8.88	17.62	45.79	7.57	18.95	10.26	4.91	8.13	0.75	102.45	21.36	44.69
2006	34.33	45.29	8.47	16.80	46.66	7.81	19.55	9.79	4.49	7.56	0.74	102.48	20.76	43.91
2007	32.42	40.25	7.48	15.37	35.09	5.53	14.37	7.35	3.34	6.18	0.52	83.21	16.34	35.92
2008	24.93	30.38	5.35	11.44	26.14	3.86	10.45	5.43	2.36	4.55	0.39	62.34	11.57	26.44
2009	17.05	21.69	3.33	7.46	20.70	2.83	8.04	4.09	1.55	3.23	0.33	46.81	7.72	18.73
2010	10.66	15.62	2.28	5.16	21.44	2.85	8.17	3.10	1.14	2.46	0.33	40.49	6.27	15.78
2011	10.96	14.89	2.45	5.57	18.41	2.39	6.92	2.57	1.07	2.15	0.27	36.13	5.91	14.64
2012	3.80	5.15	1.04	2.36	6.29	0.80	2.33	0.92	0.43	0.83	0.09	12.45	2.27	5.52
Total	**371.30**	**500.49**	**97.20**	**196.49**	**488.74**	**77.12**	**197.60**	**116.28**	**56.35**	**93.18**	**8.95**	**1,114.45**	**230.67**	**487.27**

Table 3.16. Total annual benefits to the general population and to those earning less than PPP$1.25 and PPP$2 per day from genetic yield gain and resistance to tungro and BLB in the Philippines under positive shutdown price functional form for supply (million PPP$, discounted at 5%).

Year	Genetic yield gain			Tungro resistance			BLB resistance			Total benefits		
	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-
1992	2.65	0.54	1.12	(0.01)	(0.001)	(0.003)	-	-	-	2.64	0.54	1.11
1993	1.81	0.60	1.06	(0.03)	(0.01)	(0.01)	-	-	-	1.79	0.59	1.05
1994	1.07	0.38	0.68	(0.05)	(0.01)	(0.03)	-	-	-	1.02	0.37	0.66
1995	1.51	0.46	0.87	(0.07)	(0.02)	(0.04)	-	-	-	1.44	0.44	0.84
1996	3.94	1.02	1.96	(0.11)	(0.03)	(0.05)	-	-	-	3.83	0.99	1.91
1997	7.35	1.69	3.40	(0.13)	(0.03)	(0.06)	-	-	-	7.22	1.66	3.33
1998	12.98	3.28	6.26	(0.14)	(0.03)	(0.07)	-	-	-	12.84	3.24	6.20
1999	24.17	5.76	11.51	(0.18)	(0.04)	(0.08)	-	-	-	23.98	5.72	11.42
2000	39.90	9.90	19.33	(0.25)	(0.06)	(0.12)	-	-	-	39.64	9.84	19.21
2001	56.42	13.78	27.26	(0.27)	(0.06)	(0.13)	6.68	1.48	3.12	62.83	15.19	30.24
2002	75.71	17.61	35.17	(0.30)	(0.07)	(0.14)	5.44	1.16	2.48	80.85	18.70	37.51
2003	73.88	16.55	33.42	(0.32)	(0.07)	(0.15)	4.47	0.96	2.20	78.03	17.44	35.48
2004	79.60	17.82	36.22	(0.36)	(0.08)	(0.17)	3.94	0.83	1.84	83.18	18.57	37.89
2005	76.51	17.19	35.03	(0.38)	(0.09)	(0.18)	5.67	1.13	2.52	81.79	18.24	37.37
2006	69.01	16.54	33.38	(0.42)	(0.10)	(0.20)	5.03	0.85	1.99	73.62	17.29	35.18
2007	78.14	16.88	35.65	(0.27)	(0.07)	(0.14)	4.70	0.69	1.85	82.57	17.51	37.37
2008	90.63	18.14	40.22	(0.29)	(0.07)	(0.14)	1.94	0.18	0.67	92.27	18.26	40.74
2009	98.51	17.98	42.18	(0.26)	(0.06)	(0.13)	(1.83)	(0.67)	(1.31)	96.42	17.25	40.74
2010	117.81	20.32	49.30	(0.27)	(0.05)	(0.13)	(3.25)	(0.86)	(1.79)	114.28	19.41	47.39
2011	144.15	24.12	59.32	(0.25)	(0.05)	(0.11)	-	-	-	143.89	24.07	59.21
2012	88.14	14.53	36.10	-	-	-	-	-	-	88.14	14.53	36.10
Total	**1,143.86**	**235.08**	**509.45**	**(4.36)**	**(0.98)**	**(2.07)**	**32.78**	**5.76**	**13.57**	**1,172.28**	**239.86**	**520.95**

Table 3.17. Total annual benefits to the general population and to those earning less than PPP$1.25 and PPP$2 per day from genetic yield gain and resistance to tungro and BLB in the Philippines attributable to IRRI under positive shutdown price functional form for supply (million PPP$, discounted at 5%).

Year	Genetic yield gain			Tungro resistance			BLB resistance			Total benefits		
	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-
1992	1.00	0.28	0.52	(0.01)	(0.001)	(0.002)	-	-	-	0.99	0.28	0.52
1993	2.09	0.76	1.32	(0.02)	(0.004)	(0.01)	-	-	-	2.07	0.76	1.31
1994	3.60	1.28	2.30	(0.03)	(0.008)	(0.02)	-	-	-	3.57	1.27	2.28
1995	8.09	2.16	4.12	(0.04)	(0.011)	(0.02)	-	-	-	8.04	2.15	4.10
1996	17.96	3.91	7.94	(0.12)	(0.026)	(0.05)	-	-	-	17.85	3.88	7.89
1997	31.80	6.91	13.97	(0.16)	(0.033)	(0.07)	-	-	-	31.64	6.87	13.90
1998	42.30	9.65	18.94	(0.18)	(0.039)	(0.08)	-	-	-	42.12	9.61	18.86
1999	57.93	12.57	25.78	(0.25)	(0.050)	(0.10)	-	-	-	57.69	12.52	25.68
2000	76.41	17.10	34.40	(0.39)	(0.086)	(0.18)	-	-	-	76.02	17.01	34.23
2001	86.21	18.95	38.54	(0.43)	(0.091)	(0.19)	5.98	1.33	2.80	91.77	20.19	41.15
2002	92.60	20.56	41.64	(0.46)	(0.098)	(0.20)	4.91	1.05	2.25	97.04	21.51	43.69
2003	91.75	19.60	40.39	(0.51)	(0.111)	(0.23)	5.49	1.10	2.52	96.74	20.59	42.68
2004	97.56	20.90	43.23	(0.57)	(0.126)	(0.26)	5.57	1.06	2.37	102.56	21.83	45.34
2005	96.08	20.19	42.05	(0.61)	(0.136)	(0.28)	6.97	1.30	2.92	102.45	21.36	44.69
2006	95.81	19.73	41.46	(0.63)	(0.144)	(0.30)	7.30	1.18	2.75	102.48	20.76	43.91
2007	76.36	15.39	33.45	(0.36)	(0.093)	(0.19)	7.22	1.04	2.66	83.21	16.34	35.92
2008	58.65	11.18	25.28	(0.37)	(0.089)	(0.19)	4.06	0.48	1.36	62.34	11.57	26.44
2009	47.02	8.21	19.58	(0.36)	(0.079)	(0.18)	0.15	(0.42)	(0.67)	46.81	7.72	18.73
2010	40.93	6.82	16.76	(0.36)	(0.074)	(0.17)	(0.08)	(0.48)	(0.80)	40.49	6.27	15.78
2011	36.48	5.98	14.81	(0.36)	(0.070)	(0.17)	-	-	-	36.13	5.91	14.64
2012	12.43	2.27	5.51	0.02	0.002	0.01	-	-	-	12.45	2.27	5.52
Total	**1,073.07**	**224.39**	**472.00**	**(6.19)**	**(1.37)**	**(2.87)**	**47.56**	**7.65**	**18.14**	**1,114.45**	**230.67**	**487.27**

Table 3.18. Producer and total benefits in the Philippines under constant elasticity functional form for supply (million PPP$, discounted at 5%).

Year	Total effect of post 1989 MVs							Effects attributable to IRRI contributions to post 1989 MVs						
	Producer surplus				Total benefits			Producer surplus				Total benefits		
	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Adjusted for self-consumption	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day	All	Earning less than PPP$1.25 per day	Earning less than PPP$2 per day
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	(0.52)	0.06	(0.06)	(0.11)	1.90	0.39	0.84	(0.19)	0.02	0.01	0.01	0.76	0.21	0.40
1993	(0.23)	0.09	0.05	0.10	1.31	0.46	0.81	(0.26)	0.11	0.10	0.18	1.58	0.59	1.01
1994	(0.23)	(0.04)	0.03	0.05	0.76	0.28	0.50	(0.78)	(0.12)	0.11	0.21	2.66	0.95	1.69
1995	0.05	0.24	0.09	0.17	1.10	0.34	0.64	0.30	1.36	0.35	0.68	6.04	1.61	3.07
1996	(0.13)	0.42	0.13	0.25	2.82	0.74	1.42	(0.63)	1.97	0.33	0.64	13.00	2.84	5.85
1997	0.64	1.48	0.33	0.66	5.46	1.26	2.53	2.78	6.53	1.26	2.53	23.42	5.18	10.49
1998	1.63	3.62	0.82	1.64	10.16	2.62	4.94	5.42	12.10	2.42	4.85	32.77	7.67	14.96
1999	(0.96)	2.60	0.73	1.44	17.76	4.31	8.60	(2.25)	6.34	1.29	2.55	42.11	9.29	19.24
2000	3.24	7.84	1.95	3.84	29.36	7.49	14.57	6.32	15.22	3.11	6.14	55.56	12.74	25.76
2001	2.83	10.42	2.69	5.30	45.59	11.38	22.69	4.19	15.33	3.16	6.22	66.22	14.92	30.71
2002	6.29	15.54	3.56	7.05	59.10	14.07	28.32	7.64	18.74	3.90	7.69	70.86	16.12	33.01
2003	2.70	12.48	2.81	5.56	56.74	13.00	26.68	3.51	15.68	3.19	6.29	69.81	15.17	31.94
2004	5.07	14.35	3.20	6.32	60.59	13.77	28.38	6.40	17.88	3.58	7.07	74.29	16.04	33.87
2005	5.69	14.73	3.25	6.44	60.04	13.55	28.09	7.17	18.50	3.37	6.69	75.07	15.85	33.76
2006	5.07	12.91	3.30	6.53	53.98	12.83	26.34	7.05	18.01	3.02	6.01	74.86	15.32	33.12
2007	9.84	17.62	3.74	7.69	60.82	12.97	28.04	10.00	17.83	3.18	6.53	60.60	12.05	27.08
2008	11.93	20.03	3.99	8.54	68.08	13.51	30.57	8.11	13.56	2.32	4.95	45.45	8.54	19.95
2009	8.81	18.43	3.24	7.25	71.25	12.72	30.59	4.35	8.99	1.26	2.82	34.05	5.65	14.09
2010	(0.15)	13.95	2.52	5.71	84.78	14.36	35.95	0.01	4.97	0.60	1.36	29.61	4.60	11.99
2011	3.31	19.15	3.46	7.93	104.49	17.58	44.36	0.94	4.86	0.81	1.84	25.83	4.27	10.91
2012	2.04	11.67	2.13	4.91	63.21	10.49	26.76	0.30	1.65	0.41	0.93	8.86	1.64	4.08
Total	**66.91**	**197.59**	**41.96**	**87.27**	**859.31**	**178.12**	**391.62**	**70.36**	**199.55**	**37.78**	**76.19**	**813.41**	**171.26**	**366.97**

4. Discussion

4.1 Limitations

While this study offers important advances over previous attempts to assess the impacts of rice genetic improvement, it is still subject to a number of limitations. Perhaps most importantly, the traits assessed do not include all the potential enhancements offered by newer classes of modern varieties, such as enhanced quality or improved abiotic tolerances. This probably renders the results conservative if progress has been made regarding these attributes.

It is possible to take a hedonic approach to the valuation of quality attributes introduced through new varieties. However, in practice, isolation of quality effects is rendered difficult, due to the fact that: 1) many non-genetic factors, such as postharvest processing and marketing affect sales price; 2) rice varieties are not marketed individually, such that they have individually associated price, but are instead sold in mixtures; and 3) that proper economic surplus analysis of quality shifts involves differentiated supply curves based on quality, with shifts to each curve as a result of technological change. Data on other independent variables affecting price were generally unavailable for this study, and cannot be assumed to be time invariant. In the absence of this, it is difficult to accurately model shifts in quality differentiated supply curves.

Abiotic tolerances were not directly included as a result of data and adoption limitations that prohibited rigorous analysis of substantial impacts. The most popular higher yielding varieties in Indonesia and the Philippines, such as Ciherang and PSBRc 82, were consistently rated by experts as having tolerance to drought. At the same time, adoption of these varieties drives increases in the release yield of adopted varieties, so that area under drought tolerance becomes multi-collinear with the average release yield of adopted varieties. This prevents effective econometric distinction between the traits. On the other hand, flood tolerance adoption is very limited, and little area is affected by salinity in Indonesia or the Philippines.

The contributions of hybrid rice were not assessed in this study, as the pool of observations for the econometric analyses did not include substantial hybrid adoption. In Indonesia, hybrid adoption is still very limited, while in the Philippines and Bangladesh, hybrid adoption has expanded in the period since the most recent observations used in the econometric analyses (2007 and 2008, respectively). Thus, it was not possible to obtain significant regression coefficients for the yield effects of hybrids, although resistance area effects of hybrid adoption are included for the Philippines using coefficients derived from inbreds. As hybrids may have an important yield advantage, this may render results conservative.

The host plant resistances assessed include the resistances to major pests and diseases for which breeding efforts have been explicitly focused. However, there are additional more minor levels of resistance that genetic improvement may affect, such as to stemborers, brown spot and sheath blight. These were not included, due to the minor levels of resistance expected, as well as the gaps in resistance information available. However, it is possible that resistances to these pests and diseases may be changing through new varieties, with attendant yield effects.

It is possible that the diffusion of host plant resistances to insects or diseases transmitted by insects may confer additional benefits to those documented by reducing the returns to insecticides for farmers and thereby inducing reductions in insecticide use. However, the limited precision of the insecticide use data for Indonesia, where coefficients to BPH resistance are significant, do not permit conclusive analysis of this effect. Here, the expected pattern of impact would suggest that exclusion of the effect leads benefits to be underestimated.

The estimation of the effects of BLB resistance is reliant on a statistical epidemic model and a biophysical crop growth model in the context of weather data in the main production season. This has the obvious limitation that resistance effects in the secondary season are omitted, biasing results downward. This biophysical modeling approach also has some potential constraints to external validity, in that limited data exist to underpin the relationship between resistance and disease severity under farm conditions used in the model. The parameterization of RICEPEST to reflect the physiological effects of biotic damage is also based on a limited number of varieties and may not fully reflect the phenotypic diversity of actually adopted varieties, while EPIRICE is run under a single “production situation”, which may not fully reflect spatial differences in input use and irrigation.

In the econometric analysis, while the approach attempts to minimize the possibility of omitted variable bias through the use of fixed effects approaches that eliminate the effects of time-invariant variables, the potential for such bias cannot be fully eliminated. If there are time variant unobserved covariates that systematically determine outcomes of interest, results may still be biased. As most behavioral determinants of adoption should be time invariant, and adoption is conditioned by many time invariant farm characteristics, such as soil type and hydrology, this is a generally reasonable assumption.

Omitted variable bias is most likely to threaten the econometrics on host plant resistances, if farmers actively select varieties based on resistance. However, studies of farmer varietal preferences (e.g. Wang et al., 2012, Hossain et al., 2012, Pandey et al., 2012), suggest that host plant resistance is not a priority consideration by farmers when choosing varieties to adopt. For the most part, weak separability of inputs is assumed. To validate this assumption, a range of interaction terms among inputs was tested, and significant interaction terms were retained.

The data on varietal characteristics that underpin the econometric analysis and estimation of supply shocks face limitations as well. Adoption characterization is based on reporting by farmers and may be incorrect, while sampling protocols used for adoption characterization may not be fully nationally representative. In the case of Indonesia, adoption reporting is not through a farm survey, but from field officials who may not fully accurately represent field conditions.

Release yields may reflect differences in trial site composition, weather and/or trial management, so that they are not directly comparable. This study tries to account for this by comparing the trajectory of release yields over time with the trajectory of check yields, which hold variety constant. Characterization of biotic resistance depends on the strain used in testing procedures, which may differ from field conditions, while damage identified may have only indirect effects on yield. Information on host plant resistance effectiveness in the years subsequent to varietal release are often non-existent, so that expert appraisal needed to be used in lieu of systematic screening results. This appraisal may depend upon personal perceptions and the spatial distribution of field contact by experts. To the degree possible, this risk was mitigated by involving groups of experts from multiple disciplines and regions in the appraisal process.

The use of mean observation values for municipalities for the Philippines and provinces in Indonesia may have the effect of suppressing within location variability and inflating the explanatory power of regressions, as may be observed in high fit values for Indonesia. It may also increase potential for measurement error if there is sampling inconsistency. At the same time, the use of national or subnational means is a characteristic of nearly all prior econometric literature on impacts of rice varietal improvement (e.g. Herdt and Capule, 1983, David and Otsuka, 1994, Evenson, 1997, Evenson, 2003, etc.). Given that those analyses typically do not control for time invariant factors driving selection bias through fixed effects, this study, although imperfect, still represents an improvement.

The analysis is also premised on the assumption that pricing policies by governments would have been unaffected by less production in the counterfactual scenario of no new genetic improvement. Were governments instead to increase subsidies to offset these effects, generally the losses in welfare would be larger than quantified here, as a result of increased deadweight losses due to market distortions, but the costs would accrue to different groups in different proportions than indicated in this study.

A relatively complex partial equilibrium model is used to quantify welfare impacts. Embedded within the model are supply and demand elasticities for the rice market, as well as for the labor market. Elasticities for the former were synthesized from available literature on the study countries, but the literature is limited and dated, while elasticities for the latter were based on economic theory and a very limited set of observations from other countries. There is some sensitivity of overall results to elasiticities, as more inelastic demand and inelastic supply for rice lead to smaller producer benefits. At the same time, the elasticity values applied are consistent with a range of literature and other models, such as IMPACT (Rosegrant et al., 2012) . The introduction of a positive shutdown price, as well as consideration of self-consumption by producers, however, lessens this sensitivity considerably.

In the absence of detailed data for each spatial unit and year, a number of the parameters underpinning the model needed to be approximated through interpolative and approximation techniques. For example, subnational poverty rates were adjusted over time based on national poverty trends, and the proportion of DALYs attributable to caloric deficiency were approximated based on DALY estimates for associated syndromes and estimates of the prevalence of caloric deficiency. Other assumptions underpin the model, which may be gross simplifications of actual interactions. This particularly true for the environmental components, where land use change only incorporates shifts according to supply elasticity responses to equilibrium price shifts.

The model also does not take into account simultaneous effects of supply and demand interactions on the world market for rice, which may affect world rice prices, and feed back into domestic prices. All countries in the study import small shares of rice consumed domestically, and thus simultaneous contractions in import demand may affect world market prices to amplify the domestic price declines reflected in the results. The original intention of the study was to use a global rice trade model to reflect this interaction effect. However, the structure of the prevailing forms of such model is to resolve a single global rice price, rather than incorporate domestic price effects from shifts in domestic supply and demand in the context of simultaneous shifts on the global market. Given the small share of imports to domestic consumption in the study countries (<5%), the fact that importation is actively government managed, and that price transmission from the global market is minimal, resolving all price effects through the global rice price was not determined to be appropriate for accurate welfare analysis.

Benefits to the poor are incomplete, as they omit multiplier effects and consequences of improved labor productivity as a result of better nutrition. These benefits are also conditioned on the poor having equal rates of adoption of improved varietal traits within a given location to the generational population, with adoption varying across locations to capture variable adoption rates between poorer and richer areas. While this may at first appear to overestimate benefits to the poor, it is actually a plausible assumption, given that many studies (e.g. Herdt and Capule, 1983, Hossain et al., 2007), have documented equal or higher adoption of newer rice varieties in smaller and/or poorer farms in particular locations. Due to data limitations, the approach also applies treatment effects of trait adoption per hectare that are nationally uniform in conjunction with spatially disaggregated adoption estimates. If the true treatment effects are correlated with poverty, the approach may be biased.

Food security impacts focus on reduced caloric insufficiency from lower prices as the driver of health improvements. These benefits are conditioned on the assumption that the caloric deficient have a higher own price elasticity of demand than the general population, which is consistent with declining income elasticities of rice demand as incomes rise. Broader aspects of food security, such as access and availability or interactions with other nutrient deficiencies are beyond the scope of the methods applied.

4.2 Overall findings

The results obtained by this study generally illustrate substantial continued impact from modern rice varieties in the post Green Revolution era for the general public, the poor and the food insecure in three populous major rice producing countries. These findings are consistent with much of the prior literature on rice genetic improvement impacts, which find both large economic benefits, and which qualitatively affirm the poverty relevance of those benefits. Overall, the findings produced here affirm that rice genetic improvement in the post IR period since 1989 continues to have similar impacts to those of the IR varieties developed in the 1970s and 1980s. Moreover, it illustrates that even in the context of structural transformation and exogenous reductions in poverty, that impacts continue to be pro-poor, such that nearly half of benefits accrue to those under the PPP$2/day poverty line.

4.3 Sources of productivity growth

Patterns of release yield and significant coefficients for release yield on farm indicate that progress in increasing genetic attainable yield is substantial in Indonesia and the Philippines, with much faster rates of growth in the former than in the latter. Bangladesh, on the other hand, has had largely stagnant release yields, and only experienced substantial progress during the Boro season in the early 1990s. This trend suggests that the research system in Bangladesh may need to be strengthened for improvement in genetic potential to be realized.

At the same time, there are observed patterns in the genetic improvement process that appear to contravene prior literature. The general pattern presented by the work of many scientists at IRRI and elsewhere is that genetic potential plateaued in the early modern varieties of rice, whereas subsequent gains in released varieties were made through enhanced host plant resistance and abiotic tolerance (Khush et al., 2001, Fisher and Edmeades, 2010). What is observed here, however, is that genetic potential, as represented by release yields, has continued to grow over the period, and that the growth was greater in the 2000s than in the 1990s. Concurrently, however, the average proportion of released varieties with resistance to major diseases has declined.

These patterns in scientific productivity are mirrored on farm, as the average release yield of adopted varieties has rapidly risen, while the proportion of area under disease resistant varieties has declined. Interestingly, however, the econometric results offer little clear evidence of deleterious yield effects as a consequence of reduced resistance area. The econometric damage abatement models find no significant coefficients for any resistance other than tungro in the Philippines, and the yield effects of tungro resistance are estimated as minor. In Indonesia, tungro and BLB resistances are not found to be significant, while blast and BPH resistances are determined to be significant. The loss from a dramatic decline in blast resistance adoption is estimated at about 1% of yield in recent years. The sole case where the econometric findings and adoption patterns suggest that new varieties are helping to increase yield substantially through enhanced resistance is BPH resistance in Indonesia. However, these gains are not much larger than the losses due to reduced blast resistance, according to the regressions.

These econometric findings of limited yield effects from host plant resistance are consistent with the limited previous econometric literature on resistance effects in rice. The work of Widawsky et al. (1995) on the diffusion of host plant resistances in Chinese rice varieties finds only significant coefficients on insect resistance, rather than disease resistance, which has coefficients close to zero. Similarly, Evenson (1997) finds that disease resistance in Indonesia does not reduce crop losses by more than 1%. In this context, it is perhaps not surprising that significant coefficients are only returned for those resistances where the area under resistance exhibits large fluctuations over the period. Moreover, in the

Philippines, with lower levels of chemical input use, BPH pressure is much lower, so the effects to be observed from resistance against the pest are likely to be smaller.

Although BLB resistance does not come out as significant in the econometric models (the sign is consistently negative, but insignificant), biophysical modeling suggests some yield impacts. However, these are not large in magnitude, which may explain why the econometric approach is insignificant. In the case of BLB, the adoption of varieties released through the 1990s appears to have enhanced resistance coverage, while adoption of the most recent varieties appears to have reduced it. As a result, the contribution to yield shifts from positive to negative over the period in the two countries.

The effect of release yield is consistently found to be positive and significant in the regressions, while the release yields of adopted varieties in the Philippines and Indonesia are observed to rise over the period, leading to significant suggested yield and production impacts. Similarly, in Bangladesh, BRRI dhan 28 and 29 have higher release yields than the varieties replaced, and have significant coefficients on yield, which reflect a similar ratio of actual yield to release yield effect to the other two countries. However, the release yield to actual yield elasticities estimated are lower than might be expected. It could be plausibly assumed that adoption of a new variety over the longer term may leave “yield gaps” between attainable and actual yield unaffected. Under such a scenario, the proportional shift in attainable and actual yield due to adoption of a variety that increases the former should be equal, so that the release yield to actual yield elasticity is 1. However, the elasticities found by the econometric fixed effects models range from 0.2 to 0.4, which suggests that either yield gaps are growing when higher release yield varieties are being adopted, or that increases in release yield are not solely attributable to genetic gain. To address the latter possibility, the yields of check varieties, where available for many years, were compiled to see whether release yields are changing when the variety is held constant. In Indonesia, rising check varietal yields over time suggest that production conditions for releases are improving over time, such that not all increases are attributable to enhanced genetic potential. This is an easy potential explanation to the low elasticity for Indonesia, but it does not explain the Philippines, where check yields are flat.

The results for the Philippines imply that the adoption of varieties with increased attainable yield may actually be increasing yield gaps. A plausible potential explanation for this may be that newer higher yielding varieties need adjusted management for attainable yield to be expressed, such as increased fertilizer rates, and that the regression derived elasticity holds input usage constant. However, if interaction terms are included for inputs and release yield in the production function regressions, the coefficients returned are either negative or insignificant. Thus, there is no obvious change in input use rates that appears to act in synergy with release yield for new genetic potential to be expressed. It should also be noted that there are important changes occurring in input use over the period, with intensified application of fertilizer and other inputs, so farmers are adjusting practices being applied.

A potential explanation may relate to the pattern that many new higher yielding varieties appear to have reduced resistance to many pests and diseases, compared with earlier releases. This could mean that adoption of such varieties improves attainable yield, but that a reduced proportion of the improved attainable yield is realized on farm, due to increased biotic yield reductions. If this is the case, it may suggest that the resistance and release yield effects are not independent, and that the resistance effects are embedded in the release yield to actual yield elasticities. Such an explanation, however, is only plausible if the net resistance yield effects are negative for newer varieties with higher release yields. While this may be true for a few of the final years of observations, it appears not to be the case for most years. Alternatively, it could be that there is increasing divergence between release conditions and actual on farm conditions, which means that improvement in release yield is under conditions that are increasingly unrepresentative of farmers' fields.

Regardless of the explanation, a release yield to actual yield elasticity below 1 also implies that "index of varietal improvement" approaches substantially overestimate the benefits of genetic improvement. Such approaches implicitly assume an elasticity of 1 when they calculate concomitant relative increases in actual yield to increases in the release yield of adopted varieties. Thus, the yield shocks using the econometric coefficients estimated in this study are 60% to 80% lower than the yield shocks using previous IVI methods, such as by Brennan and Malabayabas (2011). Given that the IVI implicit elasticity is applied without empirical substantiation, the balance of evidence suggests that results derived from IVI methods are inflated, and many documented returns to crop breeding may be exaggerated.

More generally, the results suggest that the relative contributions from varietal improvement to productivity growth are very different among the study countries. In Indonesia, varietal improvement appears to be the source of more than half the yield growth experienced over the period. However, in Bangladesh, it is the source of less than 5% of the yield growth experienced, and in the Philippines it is the source of just over 10% of yield growth. To a certain extent this might be expected, given the large contribution of shifts in cropping seasons in Bangladesh and irrigation expansion, along with slow varietal replacement, while the Philippines has rapid growth in fertilizer use. On the other hand, in Indonesia, input use was already high by the early 1990s, and there has been minimal irrigation expansion, so that varieties may have a larger relative contribution.

4.4 Economic welfare

The welfare effects estimated are largely congruent with the production shocks identified, as the traits with the highest yield shocks generate the greatest economic welfare, and that the welfare effect per ton of additional production is similar across countries and traits. The greatest welfare effects of new varieties are found to be generated in Indonesia, followed by the Philippines and Bangladesh across both functional forms used for welfare estimation.

4.4.1 Functional forms

At the same time, the results indicate substantial sensitivity to relatively minor assumptions regarding the nature of the supply function, particularly in terms of producer surplus. Total benefits under a positive shutdown price assumption are approximately twice those estimated under a supply function with a zero shutdown price. This difference in total benefits is exclusively derived from difference in producer welfare estimated, as the positive shutdown price results in additional area gained above the supply curve towards its intersection with the price axis, as the supply curve shifts downward after a supply shock.

In the absence of a positive shutdown price, under the inelastic demand typical of rice markets, producers lose welfare from rightward or downward shifts of the supply curve, as the price falls faster than the rightward shift of the intersection with the demand curve, so that the area above the supply curve and below the price contracts.

Even with the inclusion of benefits from self-consumed production, a pure constant elasticity functional form suggests that producers lose from productivity enhancing technologies in Indonesia, and that the benefits to producers are a minor share of total benefits in Bangladesh and the Philippines. This contrasts with the positive shutdown price form, where the proportion of benefits to producers is nearly as high as to consumers in Indonesia and the Philippines and is twice as high as for consumers in Bangladesh. Consumer benefits are unaffected by the choice of functional form, and benefits to laborers are only slightly affected (due to small differences in area responses). Overall, the shares of benefits to those under the two poverty lines are only slightly reduced under a constant elasticity form, compared with a positive shutdown price form, due to the fact that the poverty relevance of producer benefits only exceeds that of consumer benefits by a small amount.

It is difficult to conclusively determine which functional form is a more accurate approximation of the true nature of the supply curve, because the behavior of the supply function is only observed in the vicinity of the market equilibrium, while the divergence between the functional forms is greatest as the quantity supplied approaches zero. Rice is a unique crop for which there is a cultural affinity for production in much of Asia, and a substantial share is produced for self-consumption, where direct exposure to prices is limited. During periods of historically low real rice prices, dramatic drops in production have not been observed. At the same time, economic theory suggests that production will not be sustained if, at all levels of production, price is less than minimum average variable cost. Such an effect is also not necessarily confined to market oriented producers, as subsistence producers can be expected to respond if the opportunity cost of purchasing rice falls below the opportunity cost of production. For these reasons, the positive shutdown price functional form appears to embed a more realistic set of behavioral assumptions, and generates the most plausible set of results.

4.4.2 Benefit distribution among countries

While the magnitude of total benefits across countries is largely a function of the magnitude of supply shocks, there is also important differentiation in terms of the modeled distribution of benefits per country. In Bangladesh, as a result of relatively inelastic supply, a damping effect of imports on price responses and large shares of self consumed production, producers are found to receive a large proportion of benefits from new varieties. In Indonesia, which has the lowest proportion of rice imported, and is thus closest to a closed economy, the lowest share of benefits is found to go to producers, under conditions of relatively inelastic demand. Benefits to laborers tend to co-vary with producer benefits, as greater price responses to supply shocks are modeled to result in greater area reductions and concomitant reductions in hired labor demand for all operations, which offset increases in labor demand for harvesting when yield increases. However, modeled environmental benefits, which arise from reductions in equilibrium area under cultivation, vary inversely with benefits to producers and laborers.

Although the results indicate that the proportion of benefits to those under the poverty line is highest in Bangladesh, due to the high poverty rates in the country and preponderance of producer benefits, the magnitude of benefits to the poor is highest in Indonesia, as a result of much greater total benefits. The Philippines has a somewhat higher proportion of benefits to the poor than Indonesia, but lowest level of total benefits among the countries, due to its smaller size and lower level of yield effects, compared with Indonesia. If benefits are considered per paddy hectare cultivated, benefits in the Philippines are slightly higher than in Bangladesh. Among these countries, there appears to be a tradeoff between efficiency and equity, with the lowest share of benefits to the poor in Indonesia, where yields and per hectare benefits are greatest. However, there is no apparent tradeoff between poverty alleviation and efficiency in national benefit distribution, as the greatest absolute change in both overall economic welfare and welfare of the poor occurs in Indonesia.

In terms food security effects, there is a stronger departure from patterns of overall economic benefits in the results. In Bangladesh, larger health benefits relative to supply shocks are found as a result of higher prevalence rates of caloric insufficiency, coupled with much higher levels of disease risk and disease burden attributable to each percent caloric insufficiency in the population. This means that Bangladesh has nearly as many Disability Affected Life Years saved as Indonesia, according to these results, despite its smaller population, supply shocks and price effects. The Philippines is found to have comparatively low health impacts. This is largely a product of the lower rates of Protein Energy Malnutrition and underweight risk factor DALYs in the Philippines per population, compared with Bangladesh, coupled with the fact that price effects are dampened in the Philippines as an importing country.

The above results are predicated on the use of geographically disaggregated welfare effects driven by differential trait adoption rates in subnational units with different levels of poverty. However, the treatment effects of each hectare of replacement of MV traits with improved traits are uniform within a country and season. It remains as an area of future long term research to generate and apply a much richer data set to try to distinguish treatment effects of adoption of individual traits by location and poverty level through application of detailed large panel sample surveys than have been conducted to date.

4.4.3 Trait contributions

Given that overall welfare effects are concomitant to yield shocks, increases in release yield dominate the quantified economic impacts of new varieties. By comparison, the effects of host plant resistances are found to be small in terms of welfare. This is especially so in terms of net effects, as the loss of areas under resistance for blast in Indonesia largely offsets the gains from BLB and BPH resistance. Meanwhile the net effect of BLB resistance through new varieties in the Philippines is small, as a result of small differences in resistance adoption areas attributable to the new varieties.

At the same time, the results suggest that there may be more scope for contributions to yield and production from host plant resistances than is presently the case, particularly in Indonesia. This is because host plant resistance coverage has fallen over time for BLB, while the difference between actual and counterfactual resistance coverage assessed here is only a small fraction of the area where resistance is currently lacking. Moreover the downward trend in resistance coverage for blast and BLB suggests that the scope for increased resistance effects through new resistant varieties may grow further over time.

Surprisingly, the results indicate little differentiation in terms of the poverty relevance of the traits assessed, as the proportion of benefits to the poor does not vary substantially. This may be because all the beneficial traits introduced through the new varieties are of principal relevance to favorable environments, and that they are embodied the same delivery mechanism of new specific varieties, with shared spatial adoption patterns.

4.4.4 IRRI contributions

It should be noted that the IRRI contributions reflected in this study may appear to be lower than previous work, as the credit rules applies are slightly different. Whereas other studies, such as Brennan and Malabayabas (2011) attribute credit only based on share of pedigree, this study also takes into account the institutional source of crosses, and uses this for 50% of credit weighting. Thus, while a national cross using IRRI parents would be credited only to IRRI in previous studies, it would be credited 50% to the national institute and 50% to IRRI under the present attribution rules. As a result, the IRRI contribution to nationally bred varieties is generally halved in this study, compared with previous work. This does not reflect an actual decline in IRRI's contribution relative to prior studies, but rather is an enhanced recognition of the contribution from national partners.

There remains scope to improve attribution of benefits by institution., as the above attribution rules are arbitrary, rather than rooted in evidence of counterfactual conditions. A rigorous institutional counterfactual would represent the characteristics of the variety in the absence of an institutional contribution by ascertaining the differential between the next best substitute with the same level of farmer acceptability and the variety with the collaborative contribution. This remains an area for further work.

Production shocks and benefits attributable to IRRI are estimated as increasing over the period, which may appear to be a surprising result, given the rising capacity of many National Agricultural Research Systems. However, here this pattern is largely an artifact of rising levels of production shocks and benefits from new varieties over the period, rather than rising IRRI contribution shares. This rise is partially an artifact of the fact that the study focuses on 1990 and later MVs, which will force benefits towards the end of the period, due to long lag times from varietal release to peak adoption.

However, it should also be noted that many of the IRRI contributions are from research that pre-dates the analytical period, as the materials used in many of the popular nationally bred varieties in the study were developed in the 1970s and 1980s. This is probably to be expected, given that the timeframe from a cross to varietal release is approximately a decade, so that the most recent materials that could have been used in even a year 2000 release would likely have been from the 1980s. When this is coupled with lag times of 7-15 years from release to peak adoption, there is limited scope for IRRI material from after the 1980s to have been used in the national releases observed here Thus, even with a focus on varieties released in the period since 1989, most of the IRRI contributions are from research decades earlier, as a result of the substantial lag times involve in the breeding process.

5. Conclusions

The present analysis offers new evidence that newer generations of MVs released since 1989 have continued to make substantial contributions to productivity and welfare in three major rice dependent developing countries in Asia. Under the positive shutdown price model, the study finds PPP$25 billion of benefits generated in the three focal countries, of which approximately 45% is captured by those under the PPP$2.0 per day poverty line. It does through a new combination of methods involving econometric techniques that better account for unobserved covariates to adoption than in previous studies, innovative bio-economic modeling approaches, and development of a more detailed partial equilibrium modeling framework than has been applied previously to assess the distribution of economic impacts.

The study suggests that attainable yield, as reflected by yield during release trials, is the dominant varietal source of productivity growth, economic welfare, and benefits to the poor. It also illustrates that IRRI genetic contributions to those effects and impacts continue to be substantial during the analytical period. In spite of the fact that Indonesia has experienced the lowest level of overall proportionate yield growth during the analytical period, it is the country that emerges as most benefitting from genetic improvement, and is the country where the greatest benefits to the poor are quantified as well.

Even if approximate, this is the first study that attempts to explicitly quantify the proportion of economic benefits from genetic improvement captured by poor populations, and it is the first attempt to include economic surplus implications for hired labor. It also is the first attempt to quantify the health implications of food security effects from genetic improvement, and is an early attempt to include values for greenhouse gas and water savings. The approach necessarily has some limitations, but it can offer a useful example of how impacts more directly related to development goals of poverty alleviation, health, food security and environmental protection can be incorporated in more detail than has been the case in the literature to date.

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