HYBRID RICE AS A PRO-POOR TECHNOLOGY? EVIDENCE FROM BANGLADESH

by WILLIAM A. MCFALL

(Under the Direction of Nicholas Magnan)

ABSTRACT

Hybrids are often thought to be generally beneficial due to the benefits offered from higher yield performance. However, in the case of hybrid rice, these yield gains are offset by poor grain quality that reduces the price farmers receive in the market. Despite the price discount and poor grain quality, hybrid rice offers “cheap calories” that may be desirable for households that consume a large portion of their production. Using data from a recent nationally representative household survey of Bangladesh, I examine the potential of hybrid rice as a pro-poor technology for rice-producing households. I develop two double hurdle models to explore the decision-making process of rice-producing households as they allocate their land and consumption bundle between hybrid and non-hybrid varieties. I find evidence that households with larger land holdings are more likely to adopt hybrid rice. Additional, I find evidence that wealth alone does not affect hybrid rice adoption. However, contingent on adoption, I find that poor households allocate a higher percentage of their land to hybrids. Moreover, I find that own-produced hybrid rice consumption constitutes a higher percentage of total rice consumption for poor households than for rich households. These results suggest that widespread adoption of hybrid rice may be beneficial in promoting food security in South Asia.

Key Words: hybrid rice, technological adoption, market access

HYBRID RICE AS A PRO-POOR TECHNOLOGY? EVIDENCE FROM BANGLADESH

by

WILLIAM A. MCFALL

B.S., The University of Illinois, 2009

A Thesis Submitted to the Graduate Faculty of the University of Georgia

in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2013

© 2013

William A. McFall

All Rights Reserved

HYBRID RICE AS A PRO-POOR TECHNOLOGY? EVIDENCE FROM BANGLADESH

by

WILLIAM A. MCFALL

Major Professor: Nicholas Magnan

Committee: Berna Karali
Greg Colson

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
August 2013

TABLE OF CONTENTS

Introduction

Culturally and economically, rice is one of the world's most important cereals, sustaining over half the world's population. Although produced in 113 countries across the globe, the majority of rice production is concentrated in developing countries; more than half of the world's 840 million chronically hungry people live in areas dependent on rice production (Redoña, 2004, United Nations, 2005). Nowhere is rice more important than in Asia, which accounts for 90 percent of the world's production and consumption (Papademetriou, et al., 2000). The twin pressures of rapid population growth and urbanization have left many Asian countries searching for ways of increasing rice production on ever smaller land areas allocated to rice cultivation. Yet during the last two decades, many countries—particularly in South Asia— have seen a slowdown in the growth rate of rice yields, leading many governments to explore the possibility of yield increases through widespread hybrid rice adoption (Papademetriou, et al., 2000). A wide range of studies note the yield advantage that hybrids offer when compared to modern high-yielding inbred varieties, although issues of grain quality and price—a topic explored in more detail later in this study— complicate the assessment of these advantages (Spielman, et al., 2012).

The leading "success story" for hybrid rice adoption is China, which has seen rapid and widespread adoption since its initial commercialization in 1976. The large-scale cultivation of hybrid rice in China is estimated to have helped feed an additional 60 million people per year while opening 5 million hectares of land for alternative uses (Li,

et al., 2010). China's success largely reflects long-term investment in research and development of hybrid varieties that began in 1964 (Li, et al., 2010, Spielman, et al., 2012). Beyond China, development of the technology has been much slower due to limited investment in research, development, and marketing (Spielman, et al., 2012). As a result, hybrids that have been commercialized in Asian countries outside of China have been poorly adapted to local agro-ecological conditions, exhibited significant yield variability, and been poorly adapted to local cooking quality, grain quality, and taste preferences. Moreover, those opposed to hybrid rice adoption have raised concerns about the detrimental environmental and economic effects associated with the technology. They cite concerns of increased use of pesticides, herbicides, and scarce ground water, as well as potentially damaging welfare impacts on farmers required to purchase high-priced hybrid seed from monopolistic multinational firms (GRAIN, 2009).

The issues of grain quality, cooking quality, and taste have been of particular importance in Bangladesh where the initial generations of hybrids imported from China were viewed as inferior for consumption purposes, resulting in a significant discount on the price received by farmers selling hybrid rice surpluses. In Bangladesh, consumers generally prefer somewhat longer grain slender rice with a higher amylose content (i.e., less stickiness) than was found in these early hybrid imports (Muazzam Husain, et al., 2001, Rashid, 2011, Spielman, et al., 2012).[1] For many farmers cultivating hybrid rice in Bangladesh, the implicit decision they face is whether to use hybrids for home

[1] Consumers in Bangladesh seem to prefer rice with an amylose content of 25 percent or greater as anything below that threshold gives a "sticky" texture.

consumption despite their inferior taste qualities, or to sell it in a market that imposes a price penalty of 7 percent over more popular inbred varieties.[2] Recently, local breeding efforts have produced hybrid varieties more suitable to local consumption preferences however as of now they have limited commercial availability, thus the market issue remains.

In effect, farmers can sell their low-quality hybrid rice in the market with a price penalty, while consumers cannot actually purchase hybrid rice itself. The hybrid rice "mysteriously" disappears into the supply chain once traders or millers mix it with higher-quality inbred varieties.[3] A similar market asymmetry can be seen in Arslan and Taylor (2009) with the market for traditional maize varieties in Mexico. For subsistence farmers in indigenous communities in Mexico—who value cultural preservation and tastes associated with traditional varieties—the market for traditional maize varieties is assymetric, allowing for the sale of traditional maize varieties but not the purchase of specific traditional maize varieties. In addition to issues with asymmetry, the market for hybrid rice in Bangladesh is affected by recent changes in consumer preferences for higher-quality rice, despite persistently high food insecurity levels. Recent evidence from Minten et al. (2013) shows that higher-quality rice varieties—specifically, medium and long grain rice—account for a significantly larger percentage of Bangladesh's rice

[2] Calculation of sale price using the Bangladesh Integrated Household Survey (BIHS) dataset indicate a price of 15.85 Taka per kilogram for *boro* hybrid rice and a price of 17.00 Taka per kilogram for *boro* non-hybrid open-pollinated rice. Author's calculation from Ahmed, 2013.

[3] Evidence of market asymmetry supported through personal communication with Akther Ahmed.

market over the last 30 years, during which time the price premium for these varieties have actually doubled.

Bangladesh thus presents us with an interesting economic paradox. Economic theory suggests that calorie-insufficient households would maximize their utility by consuming the cheapest calories available, thus allowing the household to reach a level of calorie intake sufficient to maintain life. However, recent research suggests that calorie-insufficient households sometimes choose to consume higher quality foods even when the additional cost prevents a household from reaching minimum calorie requirements (Deaton and Drèze, 2009, Jensen and Miller, 2008, Minten, et al., 2013).[4] When markets function perfectly, it is appropriate to model household consumption decisions separately from production decisions. Because of market failures, however, it is more likely that poor agricultural households actually face a joint production and consumption decision (de Janvry, et al., 1991, Henning and Henningsen, 2007, Taylor and Adelman, 2003).

In the case of Bangladesh, where a large proportion of the population is calorie-insufficient, the paradox is reflected in an understanding of how farm households make production decisions given the physical and economic characteristics of the new technology. Households face the contemporaneous existence of a yield-increasing production technology and a price penalty on the sale of surpluses resulting from adoption of that technology, all against the background of household demand for lower-

[4] Suggestions for the changing behavior include declines in calorie requirements due to recent changes in transportation systems, labor requirements, and rice milling practices.

cost calories from food staples and strong preferences for certain staple consumption qualities. In other words, the relationships between hybrid rice adoption and income, wealth, and vulnerability are both complicated and multifaceted.

This study specifically looks at the hybrid rice adoption decision by analyzing the role of hybrid rice in Bangladesh as a "cheap" calorie source for poor agricultural households. I model the production and consumption decisions of hybrid rice producers using double hurdle models to better understand who is producing and consuming hybrid rice and to what extent. I begin by providing some background information on cereal grain hybridization and hybrid rice in Asia. I then introduce the study area, Bangladesh, and present the data used for the study. Next, I outline the methodology used and present relevant findings. Finally, I present concluding remarks, potential implications of the study, and areas for further research.

Background

Hybrid Rice in Asia

Hybridization is the process of crossing differing inbred parent lines to create offspring having yields, uniformity, or vigor that are superior to the parent, a phenomena called heterosis (International Rice Research Institute, 2003, Spielman, et al., 2012). The offspring of these crosses exhibit these traits for only one generation, after which the gains from heterosis decline dramatically. As a result, farmers generally cannot save hybrid seed for replanting in the subsequent year if they want to capture the gains from hybridization. Instead, they must purchase new hybrid seed each year, which may be more costly than saving seed from landrace or modern high-yielding varieties that are open- or self-pollinating and do not lose vigor in subsequent generations. Farmers' inability to save hybrid seed, although potentially creating dependence on commercial seed companies, creates economic incentives for seed companies to improve their product through investments in research and development. This could potentially help promote significant advancements in seed technology as seen in maize, cotton, and other hybrid crops (Spielman, et al., 2012).

The hybridization of rice, though more difficult to achieve than with maize or sorghum, has benefited from China's continuous investment in research and development since the 1970s. The adoption of hybrid rice on more than half of China's land area under rice cultivation has allowed China to increase its yields from 3.5 ton/ha in 1975 to almost 7 ton/ha in 2010 (Li, et al., 2010). However, only China has benefited

from outcomes at this massive scale: hybrid rice accounts for less than 10 percent of area under cultivation in Bangladesh, India, Indonesia, and the Philippines and just 10 percent in Vietnam (Spielman, et al., 2012).

Hybrid rice research and development in Bangladesh began in 1993 at the Bangladesh Rice Research Institute (BRRI), although concerted efforts were not undertaken until 1996 with additional technical support from the International Rice Research Institute (IRRI) and financial support from the Bangladesh Agricultural Research Council (BARC) (Julfiquar, 2002, Rashid, 2011). In 1998/99, widespread floods caused shortfalls in the domestic seed supply, leading the National Seed Board (NSB) to allow imports of two hybrid varieties: *Alok*, a variety from China and *Sonar Bangla*, a variety from India.[5]

In 2001, the government of Bangladesh released its first publicly developed hybrid: *BRRI Hybrid Dhan-1* (Julfiquar, 2002). From 1998-2010, a total of 85 hybrid varieties were released in Bangladesh, 83 of which were intended for transplanting in the *boro* season and two for the *aman* season (Rashid, 2011). Private firms and non-governmental organizations accounted for 80 of the 85 releases, with only 5 coming from the public sector. Moreover, only eight of these hybrids were developed within Bangladesh: four from BRRI, two from BARC, and two from private firms.

[5] The NSB is a statutory body comprised of 21 members from governmental institutions and private seed companies. The board advises the government of Bangladesh on the creation of rules and regulations related to the seed industry. All new rice varieties must undergo registration, testing, and certification before gaining approval from the NSB.

Despite the many releases, currently the most commonly cultivated varieties are privately developed varieties including *Hira, Lal Teer*, and *ACI-5.*[6] Hybrid rice cultivation generally occurs within the *boro* season in northern districts, particularly within Rajshahi and Rangpur districts (Spielman, et al., 2012). These areas are generally drier than other rice producing regions of the country and are heavily irrigated.

Bangladesh, Poverty, and Rice

The potential benefits of hybrid rice are not, however, lost on Bangladesh's policymakers: there is a strong interest in promoting greater adoption of hybrid rice throughout the country as a means of improving national food security (Julfiquar, 2002). Bangladesh is one of the most densely populated countries on the planet with an estimated 139.25 million people in an area of only 147,570 square kilometers (Bangladesh Bureau of Statistics, 2011). Although densely populated, the country is largely rural with 81 percent of the population living in rural areas and 47 percent of the population working in the agricultural sector (Bangladesh Bureau of Statistics, 2011, Bangladesh Bureau of Statistics, 2011).

Sitting at the base of the Himalayan Mountains, Bangladesh is one of the world's wettest countries with average annual rainfall levels of 2.3 meters. Rivers flowing from the Himalayas to the Bay of Bengal provide a rich composition of nutrients beneficial to agricultural production, but also render the country prone to flooding as 80 percent of

[6] Author's calculation from Ahmed, 2013.

the country lies within a floodplain (Brammer, 1990). Frequent floods and cyclones destroy assets and productive resources, leaving many individuals chronically impoverished. Bangladesh is one of the poorest in Asia with an estimated 32 percent of the population living below the national upper poverty line[7] (Bangladesh Bureau of Statistics, 2011). Poverty levels have led to widespread malnutrition in the country with an estimated 48 percent of children under five underweight.

The major crops produced in Bangladesh are rice, jute, wheat, and potato although in 2010/11, 77 percent of the area under cultivation was used for rice cultivation (Bangladesh Bureau of Statistics, 2011). In Bangladesh, rice cultivation is conducted during three seasons: *aus*, *aman*, and *boro*. *Aus* is generally directly planted in March-April and harvested in July-August; *aman* is generally transplanted in June-July and harvested in November-December; and *boro* is generally transplanted in December-January and harvested in May-June. This study focuses largely on the *boro* season as the vast majority of hybrid rice production occurs in this season. Annual harvested area and yield for rice during the period 2007/08 to 2010/11 seasons are shown below in Table 1.

[7] The Bangladesh Bureau of Statistics estimates the national upper poverty line by adding the food and nonfood poverty lines. The food poverty line is calculated using the total cost of an eleven item food basket. The nonfood poverty line is an estimation of the cost of nonfood items consumed by households living close to the poverty line. In addition, the poverty line is adjusted for cost of living differences between divisions and between urban and rural areas. In 2010, the upper poverty line ranged from 1311 Taka in rural Sylhet division to 2038 Taka in urban Dhaka division.

Table 1. Annual Harvest Area and Yield by Season and Variety, 2008/09 - 2010/11

		2008/09		2009/10		2010/11	
Season	**Variety**	**Area[1]**	**Yield[2]**	**Area**	**Yield**	**Area**	**Yield**
Aman	Broadcast[3]	996	463	1175	482	1053	483
	Local	3444	603	3495	640	3251	658
	High-Yielding Variety (HYV)	9145	992	9323	1009	9647	1051
	Total	13585	855	13993	872	13951	917
Boro	Local	302	721	265	809	195	829
	High-Yielding Variety (HYV)	9342	1484	9671	1512	9968	1538
	Hybrid	2011	1853	1695	1901	1625	1924
	Total	11654	1528	11631	1553	11788	1579
Aus	Local	929	481	832	473	780	504
	High-Yielding Variety (HYV)	1704	850	1600	823	1970	883
	Total	2633	720	2432	703	2750	776

Source: (Bangladesh Bureau of Statistics, 2011)

[1] Area in thousands of acres harvested.

[2] Yield in kilograms per acre.

[3] Broadcast includes areas directly sown as opposed to the more common practice of transplanting seedlings. Broadcast production generally uses traditional landrace varieties.

Beyond its importance to producers, rice is the most important foodstuff in Bangladesh, providing 71 percent of daily caloric intake and 66 percent of daily protein intake for rural consumers (Ahmed, et al., 2013, Salam, et al., 2009). In addition, rice expenditures make up a significant portion of total food expenditures, comprising 35 percent for rural households (Ahmed, et al., 2013).

Before delving into an empirical analysis of the data, I first present a conceptual framework to serve as a guide. Under perfect market conditions, farmers might choose one of several strategies around the production and consumption of their major food staple. First, they may choose to consume everything they produce and nothing else, operating in autarky. Second, they may consume some proportion of their production and sell the remaining surplus in the market. Third, they may produce a food staple of

superior quality, sell it in the market, and purchase a larger quantity of a more inferior food staple (or a more inferior type of the same food staple) to consume. Fourth, they may produce a crop that they do not consume—a cash crop, for example—for sale in the market, and purchase some quantity of the food staple to consume. In a competitive market, commodity prices determine the quantities sold and purchased.

In the case of hybrid rice in Bangladesh, the market is imperfect in a peculiar manner. Specifically, the market is characterized by an asymmetry in which producers are able to sell hybrid rice but consumers are unable to buy hybrid rice. Moreover, hybrid rice has the attribute of being higher yielding but lower quality than its immediate substitutes. Given the constraints imposed by the asymmetry and the commodity's yield and quality attributes, I might expect poorer households to allocate a larger percentage of their land to hybrid rice so they can produce relatively cheap calories that cannot be purchased in the market. I might also expect poorer households to consume a larger percentage of hybrid rice as compared to wealthier households.

In addition, I recognize that a number of other constraints might prevent poorer farmers from adopting hybrid rice at all. Given the constraints to adoption for poor farmers and the incentives to produce and consume a greater amount of "cheap calories" using hybrid rice, I model the adoption process in two steps using double hurdle models for the production and consumption decision process facing rice producers.

Data

The data for this study comes from the Bangladesh Integrated Household Survey Questionnaire (BIHS) 2011-2012 (Ahmed, 2013). The BIHS is a household-level survey that was administered to 5,503 households between October 2011 and March 2012, of which 2,571 households were rice-producing households.[8] The nationally and divisionally representative survey was designed and supervised by the International Food Policy Research Institute (IFPRI) and administered by Data Analysis and Technical Assistance Limited (DATA). The survey covers a wide range of household-level economic and social variables as well as plot-level agricultural production variables.

For analytical purposes, I divide rice-producing households into hybrid and non-hybrid (both traditional landraces and modern high-yielding) households and calculate basic statistics of central tendency for a range of household characteristics. Households are classified as hybrid households if hybrid rice is cultivated on at least one of their plots, regardless of extent of adoption.[9] Households that do not produce hybrid rice on any of their plots are classified as non-hybrid households. Descriptive statistics for hybrid and non-hybrid households are shown below in Table 2.

[8] Rice producers from Barisal division have been removed as no hybrid households were found in this division. Therefore I have an effective sample size of 2402 rice-producing households.

[9] Note that according to the classification criteria for hybrid households that I have selected, hybrid households can and generally do produce non-hybrid varieties as well.

Table 2. Descriptive Statistics for Hybrid and Non-Hybrid Households

Variable	Hybrid Households[1] N = 206 Mean Value	Non-Hybrid Households N = 2196 Mean Value	P-value of Difference
Geographic Variables:			
Dhaka (=1)	0.214	0.369	0.00***
Rajshahi (=1)	0.189	0.138	0.07
Chittagong (=1)	0.121	0.113	0.74
Khulna (=1)	0.150	0.134	0.52
Rangpur (=1)	0.209	0.118	0.00***
Syhet (=1)	0.117	0.128	0.62
Primary Respondent Characteristics			
Age (years)	45	46	0.23
Literate (=1)[2]	0.534	0.455	0.03**
Primary education completed (=1)	0.481	0.379	0.01***
Consumption Variables:			
Ratio of hybrid rice consumption to total own-produced rice consumption[3]	0.647	-	-
Household consumption of own rice (kg)	915	657	0.00***
Number of household members	4.6	4.5	0.48
Production Variables:			
Ratio of hybrid rice cultivated area to total rice cultivated area	0.573	-	-
Rice cultivation area (acres)	183	132	0.00***
Agricultural extension services (=1)[4]	0.126	0.073	0.03**

Note: *, **, *** indicate that mean values are statistically different at the 10%, 5%, and 1% levels. A paired t-test is used for continuous variables and a Pearson's chi-squared test for binary variables.

[1] A household is classified as a hybrid household if hybrid rice was cultivated on one or more plots within the previous year, regardless of extent of adoption.

[2] A household is considered literate if the primary respondent self-reported the ability to both read and write. Individuals that can only write or only read are considered illiterate.

[3] Production ratios are not shown for non-hybrid households because non-hybrid households, according to the definition of this study, do not produce hybrid rice. Consumption ratios are not shown for non-hybrid households because non-hybrid households can't consume hybrid rice because of the market asymmetry limiting purchase of hybrid rice.

[4] A household is considered to have been exposed to agricultural extension services if an agricultural extension agent had visited the household within the previous year.

The descriptive statistics show that hybrid households consume a larger amount of rice and cultivate a larger amount of land than non-hybrid households. As expected, hybrid households are better educated than non-hybrid households and have been exposed to agricultural extension services to a greater degree.

Wealth Index

In order to understand the relationship between wealth and hybrid adoption I first determine appropriate indicators of wealth. In Bangladesh, income based wealth measures are difficult to ascertain because of informal labor markets and wide fluctuations in annual income, leading me to use asset and expenditure based measures. Single-variable wealth indicators are shown below in Table 3. In addition to single-variable wealth indicators I calculate land and non-land based wealth indices, which generally offer a more complete picture of wealth over single-variable measures. To calculate wealth indices I use principal factor analysis. Factors satisfying the selection criteria are split into land and non-land based wealth indices based on the factor loadings of individual wealth indicators.[10] The land based wealth index is largely comprised of variables for the area of landholdings and the value of landholdings while the non-land based wealth index is largely comprised of variables for expenditures on religious ceremonies, recreation, jewelry, and cosmetics.

[10] Only factors with eigenvalues greater than one are considered for analysis.

Table 3. Descriptive Wealth Statistics for Hybrid and Non-Hybrid Households

Variable	Hybrid Households N = 206 Mean Value	Non-Hybrid Households N = 2196 Mean Value	P-value of Difference
Single-Variable Wealth Indicators:			
Religious expenditure (Taka[1])	11,993	7,121	0.11
Recreation expenditure (Taka)	471	679	0.10*
Jewelry expenditure (Taka)	27,406	16,226	0.00***
Cosmetic expenditure (Taka)	219	203	0.22
Savings (Taka)	18,027	17,633	0.90
Electricity (=1)	0.505	0.483	0.55
Cellular phone ownership (=1)	0.820	0.759	0.03**
Television ownership (= 1)	0.350	0.272	0.03**
Landholdings (acres)	110	81	0.01***
Landholdings estimated market value (Taka)[2]	1,287,665	1,112,003	0.19
Undamaged house (=1)[3]	0.417	0.337	0.03**
Unshared house (=1)[4]	0.510	0.548	0.30
Wealth Indices:			
Non-land based index	0.115	0.0383	0.02**
Land based index	0.358	0.163	0.25

Note: *, **, *** indicate that mean values are statistically different at the 10%, 5%, and 1% levels. A paired t-test is used for continuous variables and a Pearson's chi-squared test for binary variables.

[1] The exchange rate offered by the Central Bank of Bangladesh on March 29th, 2012 was 81.75 Taka/USD

[2] A household's estimated landholdings value is based on respondent's subjective estimation of sale price if sold in domestic market.

[3] A household is considered to have an undamaged house based on survey enumerator observation of housing condition. Enumerator responses of 'no sign of damage' or 'slightly damaged' were classified as the affirmative responses.

[4] A household is considered to have an unshared house if all individuals living in the home were members of the primary household unit.

As shown in Table 3, certain single-variable wealth indicators—television ownership, cellular ownership, landholdings, jewelry expenditure, and undamaged house—indicate that hybrid households are generally wealthier than non-hybrid households although additional wealth variables are not statistically significant. The variable for recreation

expenditure presents an opposing view, suggesting non-hybrid households are wealthier. As noted earlier, wealth indices can be helpful in eliminating bias from selection of single-variable wealth indicators and are generally less sensitive to outliers than single-variable wealth indicators. The non-land based wealth index indicates that hybrid households are in fact wealthier. Splitting the wealth indices into quartiles of the distribution, I am able to look at adoption rates within hybrid and non-hybrid households. Table 4 shows that hybrid adoption rates are highest among the wealthiest quartile and lowest among the poorest quartile.

Table 4. Hybrid Adoption Rates by Wealth Quartile

	Hybrid Households		Non-Hybrid Households	
Wealth Quartile[1]	**Mean Value**	**Adoption Rate of Wealth Quartile (%)**	**Mean Value**	**Adoption Rate of Wealth Quartile (%)**
0% - 25%	*43*	*7.17*	*557*	*92.83*
25% - 50%	46	7.65	555	92.35
50% - 75%	48	8.00	552	92.00
75% - 100%	69	11.48	532	88.52
Total	206	8.01	2365	91.99

[1] Wealth quartiles calculated using land-based wealth index.

Hurdle Model Estimation

To further investigate the role of hybrid rice as a pro-poor technology I use two double hurdle models run separately for the production decision process and the consumption decision process. A double hurdle model is a two-tiered model which estimates a probit model in the first hurdle and a truncated normal linear model in the second hurdle (Cragg, 1971).[11] The model helps account for the high frequency of non-hybrid households in the data and allows for the explanatory variables to differ by hurdle. Double hurdle models have been used in numerous studies to address issues associated with limited initial adoption of a technology and with limited selection into governmental support programs (Garcia and Labeaga, 1996, Jones, 1992, Ricker-Gilbert, et al., 2011). Ricker-Gilbert et al. 2011 use a double hurdle model to analyze the effect of subsidies on consumer demand for fertilizers in Malawi. The model accounts for non-separability of the consumption and production decision and for the large number of households that do not purchase fertilizer. In this study, the double hurdle models are estimated twice using a land based and non-land based wealth index. The land based wealth index accounts for the dual role that land plays as a factor of production and as a household asset. Because greater landholdings allow for experimentation and diversification, land may be particularly correlated with adoption of a new technology (Feder, 1980). The non-land based wealth index is an indicator of overall wealth.

[11] Alternate acceptable terminology for “hurdle” include “tier” and “stage.”

I first estimate a double hurdle model focused on the production decision, which I call the production model. This production model is specified with a first hurdle that estimates a household's decision whether or not to adopt the technology and a second hurdle that, contingent on adoption, estimates the extent of adoption (Ricker-Gilbert, et al., 2011). I then estimate the second double hurdle model; the consumption model. This model focuses on the consumption decision process. The consumption model is specified with a first hurdle that estimates a household's decision whether or not to consume own-produced hybrid rice and a second hurdle that, contingent on consumption, estimates the extent of own-produced consumption. The following sections provide a more in-depth explanation of the models used.

Hybrid Production

Based on the conceptual framework, I expect that in the first hurdle of the production model I will find that wealthier households will be more likely to adopt hybrid rice as they generally have greater access to complementary production inputs, credit, and extension. Numerous studies indicate that households with larger landholdings are more likely to adopt hybrid technologies because they can spread the risk of adoption across a larger diversified production area and they generally have better access to credit (Griliches, 1957, Matuschke, et al., 2006). Households with larger land holdings are also more likely to be better educated and to have had contact with agricultural extension agents. However in the second hurdle I expect to find that conditional on

adoption, poorer households dedicate a higher percentage of their land to hybrid rice as they attempt to maximize the number of "cheap calories" available to them. To reiterate, households that desire the "cheap calories" offered by hybrid rice must produce their own because of the market asymmetry noted above. Empirically, the dependent variable in the first hurdle is a dichotomous variable indicating household adoption. The adoption variable takes a value of one if a household allocates hybrid rice to one or more plots and takes a value of zero otherwise. Division dummy variables are included to account for geographical fixed effects with Dhaka division as the omitted dummy. Dhaka division is omitted because of noted differences between Dhaka and the other divisions due to extensive urbanization in the division.

In the second hurdle, the dependent variable is a continuous variable of the ratio of the area under hybrid rice cultivation over the total area under rice cultivation. In other words, this variable represents the percentage of the total area under rice cultivation that is used for hybrid rice production, thus a higher percentage would indicate that the household adopts the technology to a greater degree. In the second hurdle, independent variables for age, education, and extension exposure are removed, as it is hypothesized that beyond the initial adoption, the extent of adoption is determined largely by wealth. Because of the important role that wealth plays in the analysis, I estimate the production model separately for the land and non-land based wealth indices to ensure robustness and to better understand the role of land in hybrid

adoption. The results of the double hurdle models for household production are shown below in Table 5.

Table 5. Double-Hurdle Model of Factors Influencing Adoption and Extent of Adoption of Hybrid Rice: Production Model Using Land and Non-Land Based Wealth Indices

	Land Based Wealth		Non-Land Based Wealth	
	Hurdle 1 Probability of Adopting Hybrid Rice	**Hurdle 2** Ratio of Hybrid Rice Cultivated Area to Total Rice Cultivated Area	**Hurdle 1** Probability of Adopting Hybrid Rice	**Hurdle 2** Ratio of Hybrid Rice Cultivated Area to Total Rice Cultivated Area
	Probit Estimator[1]	Truncated Normal Estimator	Probit Estimator	Truncated Normal Estimator
	N=2402	N=206	N=2402	N=206
Independent Variables:	**Coefficient (t-value)**	**Coefficient (t-value)**	**Coefficient (t-value)**	**Coefficient (t-value)**
Wealth index	0.0545*	-0.0624***	0.0145	-0.0961***
	(0.0325)	(0.0232)	(0.0286)	(0.0291)
Age of primary respondent (years)	-0.00255	-	-0.00187	-
	(0.00293)	-	(0.00290)	-
Primary school completion (=1)[2]	0.152*	-	0.176**	-
	(0.0779)	-	(0.0762)	-
Agricultural extension (=1)[3]	0.0921	-	0.107	-
	(0.241)	-	(0.242)	-
Seed extension (=1)[4]	0.308	-	0.324	-
	(0.273)	-	(0.273)	-
Chittagong division (=1)	0.326**	-0.0159	0.314**	0.0338
	(0.130)	(0.0779)	(0.130)	(0.0786)
Khulna division (=1)	0.304**	-0.0900	0.313***	-0.0787
	(0.121)	(0.0741)	(0.121)	(0.0730)
Rajshahi division (=1)	0.412***	-0.374***	0.417***	-0.376***
	(0.117)	(0.0788)	(0.116)	(0.0773)
Rangpur division (=1)	0.582***	-0.223***	0.576***	-0.192***
	(0.116)	(0.0701)	(0.116)	(0.0692)
Sylhet division(=1)	0.226*	0.124	0.224*	0.167**
	(0.128)	(0.0777)	(0.128)	(0.0783)
Intercept[5]	-1.626***	0.679***	-1.657***	0.650***
	(0.159)	(0.0471)	(0.158)	(0.0465)

Note: *, **, *** indicates that coefficients are statistically significant at the 10%, 5%, and 1% levels.

[1] The mean value of probability of adopting hybrid rice is .049.

[2] Indicates that the primary respondent completed primary school (*Ebtedayee).*

[3] Indicates an affirmative response to the question "Did any agricultural extension agent visit your farm during the last 12 months?"

[4] Indicates an affirmative response to the question "Did you receive advice on seed use?"

[5] Intercept includes Dhaka division which was removed to prevent perfect multicollinearity. The seventh division, Barisal, is not shown due to lack of adoption observations in the area.

The results of the first hurdle of the double hurdle model for production, estimated with the land based wealth index, indicate that households with larger land holdings are more likely to adopt hybrid rice. Completion of primary school is positively correlated with adoption of hybrid rice, which could indicate that more highly educated households have a better understanding of the additional costs and benefits of adopting the technology. Agricultural extension exposure is not statistically significant which opposes established knowledge however exposure to extension services is likely correlated to education and wealth, effectively limiting the significance of the effect of agricultural extension on hybrid adoption. The results of the first hurdle estimated with the non-land based wealth index indicate that wealthier households, as defined by the non-land wealth index, are not necessarily more likely to adopt hybrid rice. This suggests that the positive relationship seen in the previous estimation is reflecting the relationship between land holdings and hybrid adoption as opposed to overall wealth and hybrid adoption.

The results of the second hurdle estimated with both the land based and non-land based wealth index indicate that, contingent on adoption, poorer households utilize a higher percentage of their land for hybrid rice production. These findings suggest that hybrid rice offers additional utility to resource-poor households willing to sacrifice taste preferences for the relatively cheap calories offered by hybrid rice. However, further information on the consumption decision process is necessary to fully investigate the role of the technology as a non-marketed consumptive good.

Hybrid Consumption

The second model that I use for this study is the consumption model. It is important to note that consumption in this analysis refers only to the consumption of rice grown by the household; own-produced rice. Additional purchase of rice is not included in this model due to limitations on data related to rice quality and characteristics for purchased rice. The rationale for using a hurdle model for consumption is similar to the rationale for using one for production. I expect that the first hurdle of the consumption model will be very similar to the first hurdle of the production model in that a producer's decision to consume their own hybrid rice requires that they first grow hybrid rice. But the decision of how much of the own-produced hybrid rice to consume could be different, both from the decision to consume any hybrid rice and different from the decision of how much of their land to produce hybrid on, given that they adopt hybrid at all.

In the second hurdle I expect that poorer households will consume a higher percentage of hybrid rice; indicating a desire for the "cheap calories" offered by hybrid rice and not available in markets due to the market asymmetry. Variables for age, education, and extension are not included as it is assumed that consumption of rice is affected by these variables only through their relationship with wealth. Stated more clearly, according to our theoretical framework, a more highly educated individual may have different consumption patterns than a less highly educated individual but only through the mechanism that more highly educated individuals are generally wealthier. As in the production model, I estimate the model using both the land and non-land

based wealth indices to insure robustness and to better understand the role of land in hybrid adoption. The results of the double hurdle models for household consumption are shown below in Table 6.

Table 6. Double-Hurdle Model of Factors Influencing Consumption and Extent of Consumption of Hybrid Rice: Consumption Model Using Land and Non-Land Based Wealth Indices

	Land Based Wealth		**Non-Land Based Wealth**	
	Hurdle 1 Probability of Consuming Hybrid Rice	**Hurdle 2** Ratio of Hybrid Rice Consumption to Total Rice Consumption	**Hurdle 1** Probability of Consuming Hybrid Rice	**Hurdle 2** Ratio of Hybrid Rice Consumption to Total Rice Consumption
	Probit Estimator[1]	Truncated Normal Estimator	Probit Estimator	Truncated Normal Estimator
	N=2383	N=176	N=2383	N=176
Independent Variables:	**Coefficient (t-value)**	**Coefficient (t-value)**	**Coefficient (t-value)**	**Coefficient (t-value)**
Wealth index	0.0568*	-0.0592***	0.00566	-0.0994***
	(0.0329)	(0.0198)	(0.0335)	(0.0274)
Chittagong	0.339***	-0.0617	0.330**	-0.0141
	(0.129)	(0.0696)	(0.129)	(0.0707)
Khulna	0.260**	0.0592	0.267**	0.0840
	(0.125)	(0.0681)	(0.125)	(0.0675)
Rajshahi	0.271**	-0.192***	0.275**	-0.187***
	(0.123)	(0.0683)	(0.123)	(0.0673)
Rangpur	0.504***	-0.0257	0.495***	-0.00453
	(0.119)	(0.0622)	(0.119)	(0.0614)
Sylhet	0.157	0.0362	0.157	0.0789
	(0.133)	(0.0743)	(0.134)	(0.0748)
Intercept[2]	-1.676***	0.811***	-1.663***	0.779***
	(0.0738)	(0.0426)	(0.0733)	(0.0423)

Note: *, **, *** indicate that means are statistically different at the 10%, 5%, and 1% levels.

[1] The mean value of probability of consuming hybrid rice is .056.

[2] Intercept includes Dhaka division which was removed to prevent perfect multicollinearity. The seventh division, Barisal, is not shown due to lack of adoption observations in the region.

The results of the first hurdle estimated with the land based wealth index, indicate that wealthier households are more likely to consume hybrid rice. This is not surprising as households that choose to adopt hybrid rice are also likely to consume that rice. In addition, divisional dummies are statistically significant. The results of the first hurdle estimated with the non-land based wealth index, indicate that wealthier households are not necessarily more likely to consume hybrid rice. As stated earlier, estimates from the first hurdle of the production and consumption models should be similar; therefore it is not surprising that I find a lack of significance for the wealth variable in the first hurdle for both models estimated with the non-land based wealth index.

The results of the second hurdle estimated with both the land based and non-land based wealth index indicate that as wealth increases, the percentage of total household rice consumption that comes from hybrid rice decreases. Stated more clearly, hybrid rice comprises a large percentage of total own-produced rice consumption for poor household than for rich households. Overall the findings from the second hurdle of the consumption model, in combination with the findings of the second hurdle of the production model, strongly support the hypothesis that poor households prefer the relatively cheap calories provided by hybrid rice despite the lack of market demand for the crop. These findings are especially strong when reiterating that households operated in the context of a market asymmetry that does not allow for purchase of these “cheap calories” in the market.

Conclusions

In South Asia, hybrid rice adoption has been slow with less than 10 percent of rice area allocated to hybrid rice. In addition, lack of domestic research and development has left the region dependent on imported hybrid seed poorly suited to South Asian tastes. Low consumer demand and limited production has created an asymmetric market for hybrid rice in which producers can sell hybrid rice but cannot easily buy it.

In this study I find evidence that despite price penalties for hybrid rice and taste preferences for local open-pollinated varieties, producers in the region may choose to adopt hybrid rice as a means of obtaining "cheap calories" offered by the technology. In effect, hybrid rice can serve as a pro-poor technology by supplying households with cheap calories not available in the market. Using two double hurdle models, I model the decision making process of rice-producing households as they allocate their land and consumption between hybrid and non-hybrid open-pollinated varieties. I find evidence that households with larger landholdings are more likely to adopt hybrid rice. I also find evidence that wealth alone does not affect hybrid adoption. However, contingent on adoption, I find that poor households allocate a higher percentage of their land to the technology. Moreover, I find that hybrid rice consumption constitutes a higher percentage of own-produced rice consumption for poor households than for rich households. These findings support the hypothesis that rice producers in the region adopt hybrid rice as a means of obtaining "cheap calories" offered by the technology.

In addition to more direct findings of the study, this paper highlights the importance of understanding the role of consumer demand in hybrid adoption. Studies of technological adoption often focus solely on the advantages of a technology to the producer while mentioning only briefly the effect that the technology may have on consumer demand. In addition, this study provides justification for increased institutional support for research and development of hybrid varieties well adapted to domestic challenges.

References

Ahmed, A.U. (2013) "Bangladesh Integrated Household Survey (BIHS) 2011-2012." In I.F.P.R.I. (IFPRI) ed. Bangladesh, International Food Policy Research Institute (IFPRI).

Ahmed, A.U., K. Ahmad, V. Chou, R. Hernandez, P. Menon, F. Naeem, F. Naher, W. Quabili, E. Sraboni, and B. Yu. 2013. "The Status of Food Security in the Feed the Future Zone and Other Regions of Bangladesh: Results from the 2011–2012 Bangladesh Integrated Household Survey." *Project report submitted to the US Agency for International Development. International Food Policy Research Institute, Dhaka*.

Arslan, A., and J. Taylor. 2009. "Farmers' Subjective Valuation of Subsistence Crops: The Case of Traditional Maize in Mexico." *America Journal of Agricultural Economics*. 4:956-972.

Bangladesh Bureau of Statistics. 2011. *Bangladesh Population & Housing Census.* Dhaka, Bangladesh: Bangladesh Bureau of Statistics.

---. 2011. *Report of the Household Income & Expenditure Survey 2010.* Dhaka, Bangladesh: Bangladesh Bureau of Statistics.

---. 2011. *Yearbook of Agricultural Statistics of Bangladesh.* Dhaka, Bangladesh: Bangladesh Bureau of Statistics.

Brammer, H. 1990. "Floods in Bangladesh: Geographical Background to the 1987 and 1988 Floods." *The Geographical Journal*:12.

Cragg, J.G. 1971. "Some statistical models for limited dependent variables with application to the demand for durable goods." *Econometrica: Journal of the Econometric Society*:829-844.

de Janvry, A., M. Fafchamps, and E. Sadoulet. 1991. "Peasant Household Behaviour with Missing Markets: Some Paradoxes Explained." *The Economic Journal*: 1400.

Deaton, A., and J. Drèze. 2009. "Food and Nutrition in India: Facts and Interpretations." *Economic and Political Weekly*:42.

Feder, G. 1980. "Farm Size, Risk Aversion and the Adoption of New Technology under Uncertainty."*Oxford Economic Papers, New Series*. 32(2): 263-283.

Garcia, J. and J.M. Labeaga.1996. Alternative Approaches to Modeling Zero Expenditure: An Application to Spanish Demand for Tobacco. *Oxford Bulletin of Economics and Statistics.* 58(3):489-504.

GRAIN (2009) "Bangladesh: Spread of Hybrid Rice Degrading Land, Increasing Pesticide Use Say Experts." In *Hybrid Rice Files (2002-2010).* GRAIN.

Griliches. 1957. "Hybrid corn: An exploration in the economics of technological change." *Econometrica, Journal of the Econometric Society*, 501-522.

Henning, C.H.C.A., and A. Henningsen. 2007. "Modeling Farm Households' Price Responses in the Presence of Transaction Costs and Heterogeneity in Labor Markets." *American Journal of Agricultural Economics* 89:665-681.

International Rice Research Institute. 2003. *Hybrid rice for food security, poverty alleviation, and environmental protection*. Metro Manila, Philippines: IRRI.

Jensen, R.T., and N.H. Miller. 2008. "Giffen Behavior and Subsistence Consumption." *The American Economic Review*:1553.

Jones, A.M. 1992. A Note on Computation of the Double-Hurdle Model with Dependence with an Application to Tobacco Expenditure. *Bulletin of Economic Research* 44(1):67-74.

Julfiquar, A.W. (2002) "Hybrid Rice Research and Development in Bangladesh: Hybrid Rice for Food Security, Poverty Alleviation and Environmental Protection." In *4th International Symposium on Hybrid Rice.* Hanoi, Vietnam, pp. 235-245.

Li, J., Y. Xin, and L. Yuan (2010) "Hybrid rice technology development: ensuring China's food security." In D.J. Spielman, and R. Pandya-Lorch eds. *Proven successes in agricultural development: a technical compendium to Millions Fed.* Washington; USA, International Food Policy Research Institute.

Matuschke, I., Mishra R. R., and M. Qaim. 2007. "Adoption and impact of hybrid wheat in India." *World Development* 35(8):1422-1435

Minten, B., K.A.S. Murshid, and T. Reardon. 2013. "Food Quality Changes and Implications: Evidence from the Rice Value Chain of Bangladesh." *World Development* 42:100-113.

Muazzam Husain, A.M., M. Hossain, and A. Janaiah. 2001. *Hybrid rice adoption in Bangladesh : a socioeconomic assessment of farmers' experiences*. Dhaka: Research and Evaluation Division, BRAC.

Papademetriou, M.K., F.J. Dent, and E.M. Herath. 2000. *Bridging the Rice Yield Gap in the Asia-Pacific Region*: FAO Regional Office for Asia and the Pacific.

Rashid, H.-A. "Farmers' Participatory Yield Maximization Trial of Potential Rice Hybrids: Boro 2010-2011." Agricultural Advisory Society (AAS), July 2011.

Redoña, E.D. (2004) "Rice Biotechnology for Developing Countries in Asia." In A. Eaglesham,A. Wildeman, and R.W.F. Hardy eds. *Agricultural biotechnology: finding common international goals. NABC's sixteenth annual meeting, Guelph, 13-15 June 2004.* Ithaca; USA, National Agricultural Biotechnology Council.

Ricker-Gilbert, J., T.S. Jayne, and E. Chirwa. 2011. "Subsidies and Crowding Out: A Double-Hurdle Model of Fertilizer Demand in Malawi." *American Journal of Agricultural Economics* 93:26.

Salam, M.A., M.S. Alam, and M.S. Islam. 2009. "Changing land use pattern and hybrid rice production: a way to improve food security in Bangladesh." *Bangladesh Journal of Political Economy* 25:191-204.

Spielman, D.J., D. Kolady, P. Ward, R. Harun ar, and K. Gulati (2012) "Public expenditures, private incentives, and technology adoption: the economics of hybrid rice in South Asia." In *IFPRI - Discussion Papers.* Washington; USA, International Food Policy Research Institute.

Taylor, J.E., and I. Adelman. 2003. "Agricultural Household Models: Genesis, Evolution, and Extensions." *Review of Economics of the Household* 1:33-58.

United Nations, ed. 2005. *Rice is life : International Year of Rice 2004*: Rome, Italy : International Rice Commission : FAO, 2005.