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Economic Impact and Returns on Investment of Rice Research and Extension in Bangladesh: An Economic Surplus Approach

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Abstract: This study quantifies the impact and returns on investment from rice breeding research and extension in Bangladesh from 1971 to 2022 with an economic surplus model and project evaluation techniques. This study aimed to assess the financial impact and effectiveness of public investments in rice breeding research and extension, providing insights for future policy and funding decisions. The novelty of this study lies in its comprehensive evaluation over 51 years, applying both closed and open economic perspectives to capture a broader range of benefits and potential savings. Results indicate that rice breeding research generated social benefits for Taka of 3751.78 billion in a closed economy and 3601.01 billion in an open economy, saving $104.96 billion in foreign exchange. The investment yielded an estimated net present value (NPV) of Taka 3,538.76 million, an internal rate of return (IRR) of 68%, and a benefit-cost ratio (BCR) of 20. These findings underscore the need for increased public support for agricultural research in Bangladesh. However, benefits are primarily accrued to consumers, with producers facing losses due to the assumptions of a small open economy and lower demand elasticity relative to supply. The study recommends increased investments in public rice research institutes for R&D and extension programs to improve food sufficiency.

Keywords: rice research and extension, economic surplus model, improved rice varieties, Monte Carlo simulation, Bangladesh.

孟加拉水稻研究和推廣的經濟影響和投資回報：經濟盈餘方法

摘要：本研究採用經濟盈餘模型和專案評估技術，量化了 1971 年至 2022 年孟加拉水稻育種研究和推廣的投資影響和回報。本研究旨在評估公共投資對水稻育種研究和推廣的財務影響和有效性，為未來的政策和資金決策提供見解。這項研究的新穎之處在於它對 51 年來的全面評估，運用封閉和開放的經濟視角來捕捉更廣泛的利益和潛在的節省。結果表明，水稻育種研究在封閉經濟中為塔卡創造社會效益 37517.8 億美元，在開放經濟中為塔卡創造社會效益 36010.1 億美元，節省外匯 1049.6 億美元。該投資預計淨現值為 35.3876 億塔卡，

內部收益率為 68%，效益成本比為 20。然而，受益主要是消費者，而由於開放經濟規模較小和相對於供應的需求彈性較低的假設，生產商面臨損失。該研究建議增加對公共稻米研究機構的研發和推廣計畫的投資，以提高糧食自給率。
关键词：水稻研究與推廣，經濟盈餘模型，改良水稻品種，蒙特卡羅模擬，孟加拉。

1. Introduction

Rice (*Oryza sativa L.*) is crucial for food security in Asia, particularly in countries like Bangladesh, where it is a staple food [1, 2]. Rice is an essential source of micronutrients, and it supplies 70%–75% of the daily caloric intake and 56%–60% of protein [3, 4]. Rice is also the country's agricultural backbone [5], accounting for almost 60% of the agricultural gross domestic product (AgGDP) and 11.21% of the national gross domestic product (GDP) [6, 7]. It makes Bangladesh's food security, like that of other countries, reliant on rice security [8, 9]. The country's rice cultivation comprises three overlapping seasons: Boro, Aman, and Aus. Boro is the dry season irrigated rice; Aman is the monsoon rained rice, also the common rice for consumption; and Aus is the pre-monsoon upland rice-growing season under rained conditions [10]. Rice is the most extensively grown crop in the country, planted in approximately 75% of the total agricultural land area harvested [11].

Bangladesh's rice R&D (R&D) efforts have been central to increasing rice production and achieving food security [12]. The Green Revolution in the 1960s and 1970s introduced high-yielding rice varieties (HYV) and modern agricultural techniques, marking the start of systematic rice R&D in the country [13]. Key institutions like the Bangladesh Rice Research Institute (BRRI), established in 1970, and the Bangladesh Institute of Nuclear Agriculture (BINA) have played significant roles in developing high-yielding, disease-resistant, and climate-resilient rice varieties. These institutions collaborate with international bodies, such as the International Rice Research Institute (IRRI), to enhance rice varieties suitable for local conditions [14]. BRRI, BINA, and agricultural universities like Bangladesh Agricultural University (BAU) and Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), significantly contribute to rice research through academic programs, field trials, and collaborative projects. The Department of Agricultural Extension (DAE) and the Bangladesh Agricultural Research Council (BARC) support these research activities. Since 1971, 139 modern high-yielding rice varieties have been developed, with the BRRI accounting for about 78%, BINA for 17%, and public agricultural universities for 5% [5].

The introduction of IRRI-bred varieties, such as IR8 and IR20 before Bangladesh's independence was pivotal. Collaborative research between the BRRI and IRRI since 1973 has led to the development of new rice varieties, focusing on disease resistance and yield improvement. Notable varieties like BRRI dhan29, released in 1994, have significantly boosted yields. BRRI dhan28 and BRRI dhan29 have dominated Boro season production, while BR11 and BRRI dhan49 are prevalent in the Aman season [12, 15]. As a result, average rice yields in Bangladesh have increased from 1.75 t/ha in the 1970s to 4.57 t/ha in the past decade, transforming Bangladesh from a food-deficient country to one that is self-sufficient in food despite its growing population. However, recent years have seen a slowdown in yield growth rates, highlighting the need for continued investments in R&D in rice [12].

Public spending on agricultural R&D in developing countries, including Bangladesh, remains relatively low. In 2017 and 2016, Bangladesh invested only 0.4% of its agricultural GDP in research. Despite this, investments in R&D in rice have been crucial to driving production growth. The introduction of improved rice varieties during the Green Revolution generated substantial economic gains, estimated at USD 10.8 billion annually by the late 1990s in South and Southeast Asia [12]. However, concerns have emerged regarding the slowing pace of varietal replacement and the smaller increase in yield potential since the 1970s [12, 16]. If not addressed, this trend could threaten future food security. Increased investments in rice breeding research are vital for food security and environmental sustainability. Understanding the impact of past investments is crucial for guiding future efforts.

The research subject of rice breeding was chosen due to its economic significance, as rice is a staple food in Bangladesh, substantial historical public investment, its impact on rural livelihoods, and policy relevance. The findings support increased funding and resource allocation for agricultural research, highlighting the high benefit-to-cost ratio (BCR) and internal rate of return (IRR) of rice research. Additionally, this study underscores the significant social benefits and foreign exchange savings that can inform economic planning and development strategies. Disseminating these findings can enhance public support for agricultural initiatives, advocating continuous investments in public rice research institutes for R&D and extension programs to achieve food self-sufficiency.

This study aims to quantify the economic impact and returns on investment from rice varietal improvement research and extension in Bangladesh using the economic surplus approach from 1971 to 2022. This study contributes to filling this gap and strengthening the evidence basis for research investments in modern rice cultivars.

2. Literature Review

2.1. Theoretical Basis

There are two main evaluation techniques, the econometric approach (EA) and the economic surplus approach (ESA), that are used to quantify the impacts and returns from agricultural research [26]. The econometric approach evaluates the change in productivity due to research investment using methods like the production function approach (PFA), cost function, or total factor productivity (TFP) approach. PFA calculates returns on investments by estimating a production function that includes technical knowledge, conventional inputs (land, labor), and non-conventional inputs (education, infrastructure). The TFP measures productivity growth and the effects of technical advancements using the TFP index. However, challenges include time lag, difficulty in selecting a suitable functional form, and treating research as an exogenous variable [17].

The most commonly used model for analyzing the welfare consequences of agricultural research in a partial equilibrium setting uses the economic surplus approach [18]. Early instances of using the economic surplus concept to evaluate agricultural research ex post are from [19] and [20], while more modern versions are from [21] and [22]. The economic surplus approach (ESA) examines how supply and demand interact to determine market exchange value. When used to evaluate research, ESA demonstrates how research influence supply, demand, and ensuing market consequences [23]. This is the accumulation of benefits received by both producers and consumers. This model is based on the Marshallian theory of economic surplus, which postulates that changes in supply and demand curves over time cause economic excess [21, 22].

According to [22], the relative elasticities of supply and demand, types of supply shifts brought about by research, and—less importantly—functional forms of supply and demand all influence how farmers and consumers gain from agricultural research. The absolute value of price elasticity of demand plays a critical role in determining whether producers enjoy a positive surplus during technological transition [21, 24]. Furthermore, the degree of economic openness or closedness—including the presence or absence of international commerce—has a substantial impact on how surpluses are distributed between producers and consumers [25].

In a free market, domestic prices are lower than those outside. Therefore, local prices often need to be readjusted to match those of other countries, which prevents domestic prices from falling and reduces consumer surplus while raising producer surplus. The model assumes that a free market. In other words, there are no policy inequalities like subsidies, trade, production quotas, or tariffs. The degree and distribution of benefits from technological change are affected by policy distortions in many markets, especially those of agricultural products [22, 26].

The Economic Surplus Approach (ESA) is the most widely accepted method for evaluating the effects of investments in agricultural research [26]. The model calculates the change in consumer and producer surpluses resulting from technological changes due to research, leading to an outward shift in the industry supply function. This approach is favorable for its ability to estimate average rates of return and its lower data requirements than econometric techniques [22]. The ESA can only evaluate the distributional benefits of varietal improvement research and development. It requires less high-quality time-series data than other econometric techniques, making it more suitable for developing nations [18, 21].

Although a set of empirical studies have mentioned the advantages of ESA [12, 25, 27-30], this model has some limitations. For example, this model cannot measure the social, nutritional, and environmental consequences of technology [31]. Although this method has received numerous criticisms, it continues to be the most popular method for conducting economic evaluations of research and technology [12, 21, 25, 29, 30, 32].

2.2. Empirical Review

Rice R&D has consistently demonstrated high returns compared to other agricultural commodities [12, 18, 33]. Various studies have estimated significant social benefits from rice research and extension efforts globally. For instance, [34] found that rice research in China yielded a net present value (NPV) of USD 5.2 billion between 1991 and 2000. In India, similar efforts generated USD 3.6 billion in social benefits, whereas in the Philippines, [35] estimated an NPV of USD 4.3 billion from 1985 to 2009. Raitzer et al. [36] concluded that publicly funded rice research produced more social benefits than other types of research funding.

In Bangladesh, several studies have assessed the economic returns of rice R&D. Notable works include [37-40, 29], and, more recently, [12]. These studies highlight the significant economic impacts of rice research and extension in the country. However, few scholars have focused on the distributional impacts between producers and consumers. most of these studies evaluated rice varieties that were developed before the 2000s, except for [12].

According to [22], the distribution of benefits from agricultural research depends on the elasticities of supply and demand, nature of supply shifts caused by research, and functional forms of supply and demand. The price elasticity of demand is crucial for determining whether producers gain a surplus during technological transitions [21, 32, 29, and 25]. The distribution of surplus between producers and consumers is significantly influenced by whether the economy is open or closed and the presence of international trade [25], [30].

Akino and Hayami [21], Flores et al. [25], Herruzo [32], and Deb and Mustafi [29] have shown that rice research and extension are most beneficial in closed economies, where consumers are the sole beneficiaries, and producers are disadvantaged. In an open economy, producers also benefit, while consumers continue to enjoy economic welfare and save foreign exchange. However, no studies to date have aggregated returns, considering all public research and extension costs comprehensively. Therefore, this research generates updated and aggregate rates of returns by considering all public costs of rice research and extension from 1971 to 2022. Additionally, it will measure total social welfare and its distribution between producers and consumers, thus contributing new knowledge to the existing literature on rice research.

Although a set of empirical studies have mentioned the advantages of ESA [12, 22, 25, 29, 30, and 35], this model has some limitations. For example, this model cannot measure the social, nutritional, and environmental consequences of such technology [18]. Although this method has received numerous criticisms, it continues to be the most popular method for conducting economic evaluations of research and technology [12, 28, 31, 41]. Therefore, a significant body of literature has assessed the economic benefits of rice R&D around the globe. However, most impact studies were conducted on rice varieties before the 2000s, except for [12]. Thus, the results of the research will generate updated and aggregate rates of return considering all public costs of rice research and extension between 1971 and 2022. In addition, this study will measure total social welfare and its distribution between producers and consumers and will contribute new knowledge to the existing literature on rice research.

3. Materials and Methods

3.1. Data

3.1.1. Adoption Data of High-Yielding Modern Rice

The adoption data of modern rice varieties were collected from the annual household survey of the Bangladesh Rice Research Institute (BRRI), the Bangladesh Institute of Nuclear Agriculture (BINA), and the district survey of the Department of Agriculture Extension (DAE).

3.1.2. Rice Production, Price, and Yield Data

The study collected data on rice production, prices, and yields from published and unpublished studies and informal interviews with scientists. The consumer price index (CPI), rice price, acreage, output, and yield of modern and local rice varieties were taken from the Bangladesh Bureau of Statistics (BBS) Statistical Yearbooks (1971–2022). Prices for the middle-income respondents were adjusted to the 2018-19 constant prices using the Bangladesh CPI.

3.1.3. Demand and supply elasticity

Demand and supply elasticities were chosen after reviewing relevant studies conducted in Bangladesh between 1971 and 2022. The average value of demand elasticity was estimated at 0.37 from [42-47]. On the other hand, the average supply elasticity of rice was estimated at 0.27 from [12, 41, 45, 47, 48]. This study estimated the demand elasticity of rice in an open economy at -1.00 based on studies such as [47, 49, 50].

3.1.4. Rice Research and Extension Expenditures

The entire cost of developing improved rice varieties and bringing them to farmers' fields has been incurred by various institutions, including the Bangladesh Agricultural Research Council (BARC), the Department of Agriculture Extension (DAE), the Bangladesh Institute of Nuclear Agriculture (BINA), the Bangladesh Rice Research Institute (BRRI), the International Rice Research Institute (IRRI), and other agricultural universities. Infrastructure, benefits and salaries, vehicles, maintenance and repairs, research and development, training, higher education, and other expenses were included in these institutional costs. In the absence of detailed information about the costs of rice research by other institutions like the International Rice Research Institute (IRRI), BINA, the Bangladesh Agricultural Research Council (BARC), and other agricultural universities, we assumed the BRRI cost to be a benchmark for technology generation. BARC is mainly provided at administrative costs.

We evaluated the extension expenses incurred by DAE by conducting in-depth interviews with scientists working on rice research and development in Bangladesh from both the DEA and the BRRI. These scientists estimated that the extension costs were nearly equal to the R&D expenditures. In conclusion, we incorporate national agricultural research expenditure data from ASTI [51]. A similar method was used by [12, 52, and 30] in Bangladesh. For the analysis, current total expenditures were converted to 2018–19 constant prices (inflated prices) using the national Consumer Price Index. Therefore, the total deflated spending on rice research and extension was estimated at Taka 247.110 billion, where about 50% of the costs incurred for extension services and rice research and development (R&D) account for the rest of the total expenditure. It is noted that the Bangladesh Rice Research Institute (BRRI) has the highest share (22% of expenditure), followed by BINA (13%), IRRI (9%), and the administrative cost of BARC (5%).

3.2. Economic Surplus Model

Akino and Hayami [21] established a model that evaluates consumer and producer surplus by assuming a pivotal shift in the supply curve and regarded supply function movements as horizontal shifts. The economic surplus concept was used to assess economic well-being and the effects of policies and other interventions on economic well-being [22]. The concept is commonly used to measure the benefits of adopting improved varieties. Gains from consumers and producers constitute the economic surplus. Fig. 1 depicts consumer surplus as Area P_aP_nB under initial conditions (i.e., pre-research supply curve S_n and demand curve D) that is the surplus or benefit that a well-functioning market provides to consumers. A consumer surplus is the area beneath the demand curve minus consumption cost. Consumption cost is defined as the region below the pricing line, P_n.

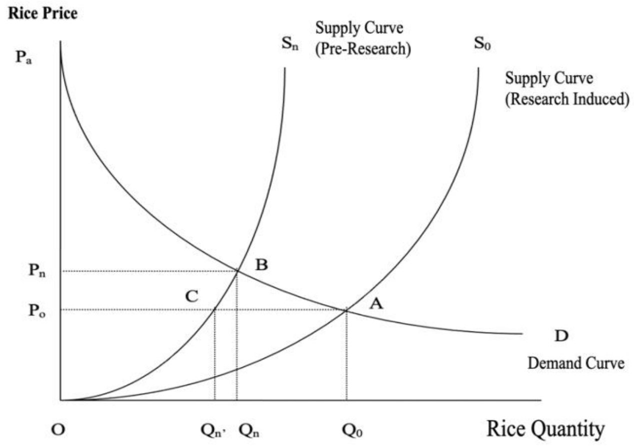

Fig. 1 Model estimating the social benefits of rice research and extension (closed economy) [21]

The producer surplus depicted by the area P_nBO in Fig. 1 represents the excess after farmers have paid all of their production costs, whereas the area OBQ_n is the remaining area after farmers have paid all of their production costs [22]. Farmers who adopt an intervention, such as an improved variety, typically indicate one of two things: (i) they can produce more of the commodity with the same number of resources (i.e., land area and other inputs); or (ii) they can produce the same number of commodity outputs with fewer resources. In either case, a shift to the right of the supply curve is indicated, as shown in Fig. 1 (the shift from S_n to S_o). The shift in the supply curve caused by adopting an intervention also shifts the commodity's initial equilibrium price and quantity. The discrepancy in the economic surplus between the pre-research and post-research periods is used to estimate the new price quantity equilibrium economic surplus (economic benefits).

The change in consumer surplus due to a shift in the supply curve from S_n to S_o is depicted in Fig. 1 as Area ABC + Area P_nBCP_0. Changes in the supply curve reduce the price of commodities that are now available. Fig. 1 also shows a change in producer surplus as Area OAC Area P_nBCP_o when the supply curve moves from S_n to S_o. The reduced production cost of the same unit product that farmers enjoy because of the intervention is known as an Area OAC. This shows the monetary value of the benefits to farmers because of implementing the intervention. Adoption of the intervention, on the other hand, increased the quantity produced, dropping the commodity's price (P_n to P_o) and decreasing farmers' revenue. Farmers recover some of their losses by selling larger amounts of the commodity (Q_n to Q_o). Nevertheless, the reduced price indicates that farmers have lost the same amount as in Area P_nBCP_o. If the area of OAC is greater than Area P_nBCP_o, farmers collectively benefit from the adoption of an intervention, and Area P_nBCP_o may increase under certain circumstances. The size of the two areas is measured by the elasticities of the supply and demand curves, and the type of supply curve shift.

The sum of the change in consumer surplus, in addition to the change in producer surplus, i.e., (Area ABC + Area BP_nP_0C) + (Area OAC-Area BP_nP_0C) = Area ABC + Area OAC is the total social gains to society as a result of the new interventions [22]. Thus, the equation can be written as follows:

$$
\begin{aligned}
&\text{Change in Consumer Surplus } (\Delta CS) && = \text{Area } P_nBCP_o + \text{Area ABC} \\
&\text{Change in Producer Surplus } (\Delta PS) && = \text{Area OAC Area } P_nBCP_o. \\
&\text{Change in Total Social Surplus } (\Delta TS) && = \text{Area } P_nBCP_o + \text{Area ABC} + \text{Area OAC Area } P_nBCP_o \\
& && = \text{Area ABC} + \text{Area OAC} = \text{Area OAB}
\end{aligned}
$$

The estimated price elasticity of demand is employed in the preceding equations for a closed economy model. A sufficiently large number of studies, such as [25, 29, 30, 32], have been utilized in a small open-economy model with an entirely elastic demand. The number of exports and imports in a small open economy market is lower than the total global commodity trade. As a result, the commodity's global price has little or no effect (the small country assumption). In this case, the product price does not change as the supply curve shifts. In the context of this study, the rice market in Bangladesh is modelled as a small open-economy market.

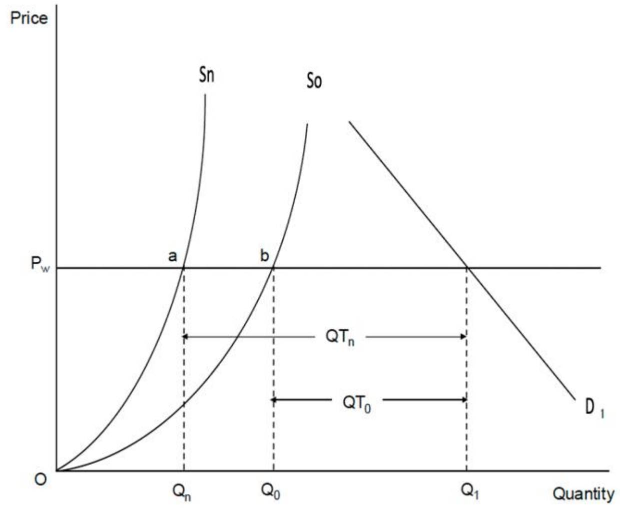

Fig. 2 Model of estimating foreign exchange savings (small open-economy) [21, 25, 29]

Fig. 2 depicts the change in the economic surplus for a small open-economy market that is mostly dependent on local production but still allows imports to fill the deficit. The rice market in Bangladesh is an example of such a market. The initial equilibrium is characterized by the global price, P_W and the quantity demanded by Bangladeshi consumers, Q_1. When confronted with the pre-research supply curve, S_n, producers supply Q_n rice at a price of P_W. The imports of rice are equal to a QT_n. Rice producers raised their output to an amount Q_o and increased Q_nQ_0 when confronted with the research-induced supply curve (the supply curve that exists because farmers have adopted new high-yielding varieties). Imports of rice decreased by the same amount as production, Q_nQ_0, bringing them to QT_0. Because P_w does not change (small economy assumption), so does the consumer surplus. Neither the situation is better or worse off. As a result, the change in the economic surplus brought on by the adoption of new rice varieties is the only change in the producer surplus, as shown in Fig. 2, by area OAB (which corresponds to area OAC in Fig.1). P_w Q_nQ_0 is the amount of money saved by selecting better rice varieties.

3.3. Estimation of Social Benefits and Their Distribution

The approximation formulas for determining changes in producer and consumer economic surplus developed by [21] are described below. For a closed economy study (Fig. 1), the following equation is used to determine the change in the economic surplus:

$$\text{Area ABC} \approx 0.5\, P_oQ_o\{k(1+\gamma)\}^2/(\gamma+\eta) \quad (1)$$

$$\text{Area OAC} \approx k\, P_oQ_o. \quad (2)$$

$$\text{Area } BP_nP_oC \approx \{P_oQ_ok(1+\gamma)/(\gamma+\eta)\} \times [1-\{(0.5\, k(1+\gamma)\,\eta\}/(\gamma+\eta) - 0.5(1+\gamma)] \quad (3)$$

where:

P_o - price of paddy rice in BDT/ton (existing market price)

Q_o - quantity of paddy rice production in tons (existing production)

P_n - price that exists in the absence of research

Q_n - quantity of the production that would exist in the absence of research

k - horizontal supply shifter

γ - price elasticity of rice supply

η - absolute price elasticity of rice demand

3.4. Estimation Yield Advantage

The yield advantage is one of the most important determinants of economic surplus growth. The higher the growth in surplus, the higher the yield of modern rice varieties is. The major HYV of rice in terms of its adoption rate in various seasons was considered in this study, and the variety was examined over time. In this study, the average yield of local varieties was assumed at the beginning of 1971, and then the average yield of modern rice varieties in farmers' fields was replaced as a check variety in the following years. The following formula was used to calculate the yield advantage (increase) of new varieties over an older or more traditional variety:

Yield advantage = 1 – average yield of traditional varieties/average yield of new varieties (4)

The data on local and HYV rice yields at the farmers' level were collected from various issues of the Statistical Year Books of Bangladesh published by the Bangladesh Bureau of Statistics (BBS).

3.5. Estimation of Supply Shifter (k)

The total yield advantage of the improved rice variety over the local variety, measured by the area sown to the improved variety, is known as the supply shifter k. The horizontal shift from the equilibrium price P_n given S_n to the equilibrium price P_o given S_0, which corresponds to a distance equal to Q_nQ_o in Fig. 2, is known as k in [21] approximation formula. Several studies, such as [12] and [30], used this method. The following formula is used to calculate the supply shifter k:

$$k_t = \sum_{i=1}^{n} \left(1 - \frac{Y_t}{Y_{it}}\right) A_{it} \quad (5)$$

where:

Y_{it} - yield of the improved rice variety in year t

Y_t - the base yield (or average yield of old rice varieties) previously grown that will continue to be produced in the absence of new varieties

A_{it} - proportion of the total area sown to rice varieties in year t

n - number of improved rice varieties

3.6. Estimation of Return Rates

This study, which required data on annual social returns and their corresponding annual social costs, employed the following efficiency measurement criteria to evaluate the efficiency of investment in rice research and extension: Ex-ante analysis often employs a discounting approach. Because this study is an ex-post analysis, we employed the consumer price index (CPI) instead of the discounting factor to render money commensurable across time. In addition, using CPI is ideal because it is based on actual data.

3.7. Net Present Value (NPV)

Net present value (NPV) is the sum of all funds recovered from the research investment. The following formula was used to calculate the NPV of the benefits:

$$NPV_n = \sum_{t=0}^{n} \frac{B_t \bullet CPI_n}{CPI_t} - \sum_{t=0}^{n} \frac{C_t \bullet CPI_n}{CPI_t} \tag{6}$$

where:
CPI - consumer price index
B_t - the gross benefit in year t
C_t - the cost in year t
t - time duration, from 0 to n years. Here, 0 is the initial investment cost.

3.8. Benefit-Cost Ratio (BCR)

Likewise, the formula of the converted or inflated benefit-cost ratio (BCR) is as follows:

$$BCR_n = \sum_{t=0}^{n} \frac{B_t \bullet CPI_n}{CPI_t} \div \sum_{t=0}^{n} \frac{C_t \bullet CPI_n}{CPI_t} \tag{7}$$

where:
CPI - consumer price index
B_t - the gross benefit in year t
C_t - the cost in year t
t - time duration, from 0 to n years. Here, 0 is the initial investment cost.

3.9. Internal Rate of Return (IRR)

The internal rate of return (IRR) is the discount rate that equates the NPV of an investment opportunity to zero [53]. The IRR was calculated in the same manner as the net present value (NPV), except that the NPV was zero. The IRR is always expressed as a percentage. The following formulas and calculations were used to obtain the figure:

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 \tag{8}$$

where:
C_t - net cash inflow during period t
C_0 - total initial investment cost
IRR - internal rate of return
t - number of periods

4. Results and Discussion

4.1. Estimation of Social Benefits and Their Distribution

This study revealed that rice research and extension investments yielded substantial social benefits in both closed and open economies. Table 1 presents the social gains from rice research and extension under a closed economy in Bangladesh from 1971 to 2022.

Table 1 Social benefits from rice research and extension 1971-2022 (The authors)

Closed economy case			
Year	**Consumer surplus (CS)**	**Producer surplus (PS)**	**Total surplus (TS)**
1970-71	0	0	0
1972-73	0	0	0
1974-75	0	0	0
1976-77	38.90	-12.00	26.90
1978-79	44.75	-13.49	31.26
1980-81	76.02	-25.85	50.17
1982-83	94.18	-30.68	63.50
1984-85	123.85	-39.36	84.49
1986-87	132.26	-39.86	92.40
1988-89	149.38	-44.95	104.43
1990-91	191.29	-54.35	136.94
1992-93	155.75	-40.49	115.26
1994-95	156.63	-45.28	111.35
1996-97	129.93	-39.08	90.85
1998-99	150.29	-47.99	102.30
2000-01	97.51	-30.59	66.92
2002-03	105.54	-33.35	72.19
2004-05	168.01	-51.90	116.11
2006-07	139.5	-44.07	95.43
2008-09	149.34	-50.48	98.86
2010-11	203.01	-68.44	134.57
2012-13	115.21	-39.62	75.59
2014-15	128.08	-44.61	83.47
2016-17	71.71	-25.88	45.83
2018-19	47.01	-16.66	30.35
2020-21	46.12	-16.90	29.22
2021-22	45.33	-15.50	30.23
Mean	105.11	(32.97)	72.15
Total	5465.89	-1714.51	3751.78

Notes: Producer surplus, consumer surplus, and social surplus data are presented in billion Taka of 2018-2019 constant price. For estimation purposes, we assume demand and supply elasticity values of 0.37 and 0.33, respectively.

Table 1 shows that society benefited substantially from investment in rice research and extension in

Bangladesh. The total social surplus was estimated at Taka 3751.78 billion, while the total changes in consumers' and producers' surpluses were estimated at Taka 5465.89 and Tk 1714.51 billion, respectively, from rice research and extension from 1971 to 2022. The results show that consumers were the sole beneficiaries of the research and that producers were made worse off (Table 1 and Fig. 3). This result is due to the low price elasticity of demand. The rightward shift in the supply function against an inelastic demand led to reduced revenue for rice growers. However, social gains amounted to Taka 3751.78 billion from rice research and extension from 1971 to 2022.

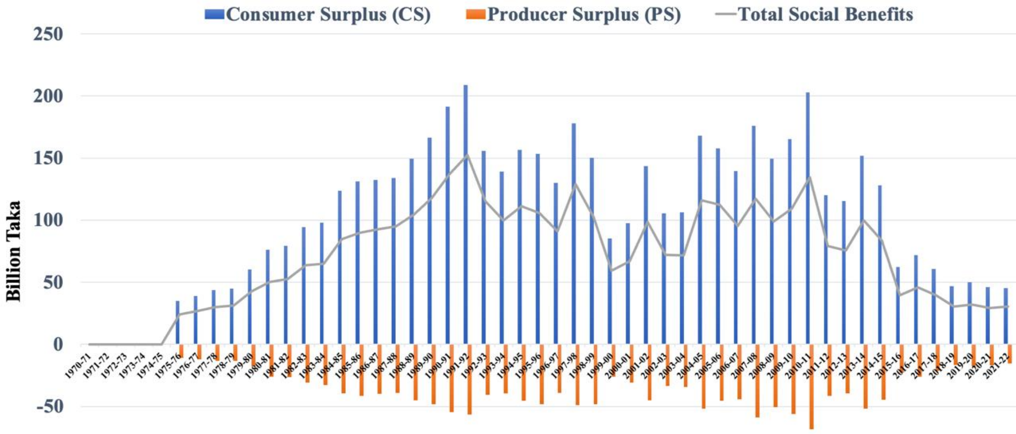

Fig. 3 Social benefits and their distribution in a closed economy (The authors)

Table 2 and Fig. 4 demonstrate that in an open-economy scenario, both consumers and producers benefit significantly, enhancing economic welfare and saving foreign exchange. The consumers' surplus totals Taka 3216.38 billion, which is substantially higher than the producers' surplus of Taka 385.37 billion, largely because of the high price elasticity of demand. Overall, the country achieved a total social surplus of the Taka 3601 billion. Additionally, the increased production of improved rice varieties resulted in a foreign exchange saving of US$104.96 billion from 1971 to 2022. These findings are consistent with previous studies using similar models conducted in Bangladesh [24, 30, 38, 52], the Philippines [25], Spain [32], and Japan [21].

Table 2 Social benefits from rice research and extension (1971-2022) (The authors)

Open Economy Case				
Year	**Consumer surplus (CS)**	**Producer surplus (PS)**	**Total surplus (TS)**	**Total foreign earning savings (US$)**
1970-71	0	0	0	0.25
1972-73	0	0	0	1.20
1974-75	0	0	0	4.46
1976-77	24.00	2.15	26.15	1.94
1978-79	27.59	2.69	30.28	1.66
1980-81	45.44	3.46	48.90	3.83
1982-83	56.39	5.21	61.60	2.43
1984-85	73.47	8.04	81.51	2.16
1986-87	78.29	10.27	88.56	2.08
1988-89	87.88	12.00	99.88	3.14
1990-91	112.14	17.92	130.06	3.27
1992-93	90.81	17.68	108.49	2.46
1994-95	92.24	13.83	106.07	2.59
1996-97	76.01	10.64	86.65	2.92
1998-99	87.05	10.80	97.85	2.12
2000-01	55.80	7.88	63.68	0.97
2002-03	60.12	8.53	68.65	1.08
2004-05	97.45	13.25	110.70	1.91
2006-07	80.78	10.34	91.12	1.56
2008-09	86.54	8.69	95.23	2.17
2010-11	118.74	11.27	130.01	1.87
2012-13	67.44	5.81	73.25	1.39
2014-15	75.80	5.50	81.30	0.98
2016-17	43.29	1.85	45.14	0.47
2018-19	29.00	1.01	30.01	0.32
2020-21	28.11	0.82	28.93	0.40
2021-22	29.20	1.10	29.56	0.32
Mean	61.85	7.41	69.25	2.02
Total	3216.38	385.37	3601.01	104.96

Note: For estimation purposes, we assumed demand and supply elasticity values of -1.00 and 0.33, respectively, and imported rice prices are from FOASTAT and 1USD=85 Taka (in 2018-19).

However, in reality, the same level of consumer welfare in the Philippines could not have been achieved without a shift in the domestic rice supply as a result of rice research. This is because foreign exchange constraints may have prevented significant additional rice imports. Thus, the open-economy and closed-economy scenarios in this analysis represent polar extremes.

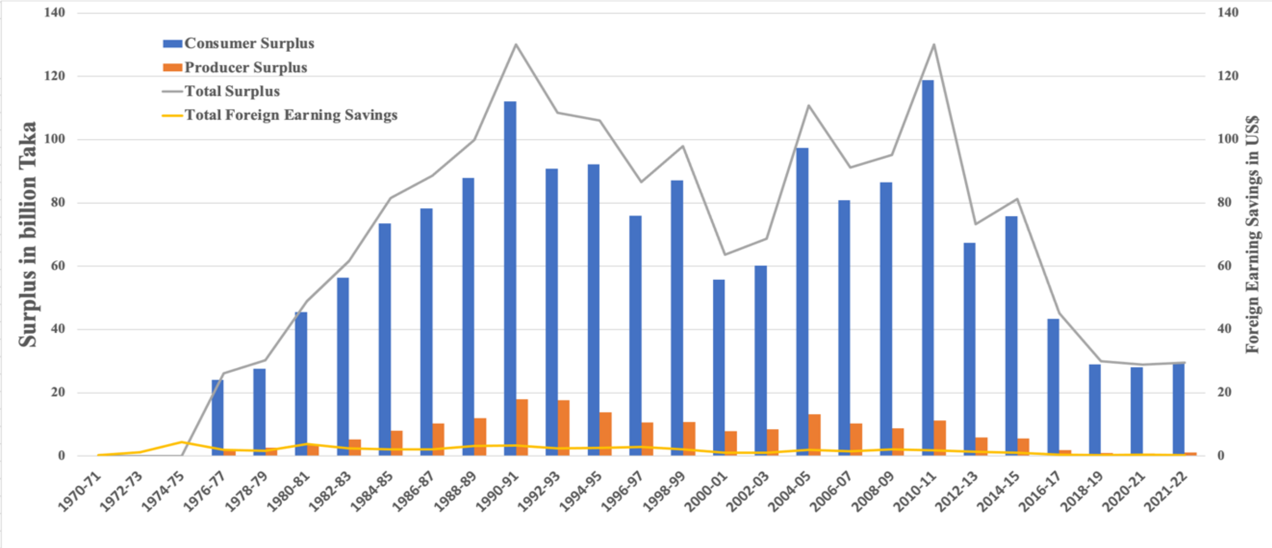

Fig. 4 Social benefits and their distribution in an open economy (The authors)

Moreover, Figs. 3 and 4 highlight that during the 1980s and 1990s, society reappeared maximum social benefits from the adoption of high-yielding modern rice cultivars such as BR 28, BR 29, and BR11. These cultivars offered advantageous traits, such as shorter plant height, improved grain quality, and shorter maturity periods, compared to varieties from the 1970s. Liberalization measures in the inputs market, including lifting bans on private-sector agricultural equipment imports and reducing import duties on machinery, further reduced farmers' irrigation costs. However, consumer benefits declined in 2000–21 due to higher rice prices. Notably, society experienced the second-highest benefit in 2010–11 due to surplus production. Unfortunately, this trend sharply declined in 2017–18 due to a devastating flash flood.

4.2. Social Rates of Return

To evaluate the efficiency of allocating public resources to rice research, it is essential to compare the annual gross social benefits with the annual cost of the research program. By examining the annual ratio of benefits to costs, policymakers can gauge the effectiveness of their investments in rice research. This analysis helps ensure that resources are allocated optimally, maximizing the societal return on investment in agricultural research. Equations (1) through (3) are used to estimate total social benefits to radish research and extension expenditures once supply shifter k is calculated. The equations were embedded in a computer spreadsheet for ease of computation. Costs for rice research are estimated to have begun in 1970–71 and finished in 2021–22; extension expenses are estimated to have begun in 1975–76; and benefits are estimated to have begun in 1975–76. To estimate return rates on investments, a 5-year R&D lag was used.

Internal rates of return (IRR), benefit-cost ratio (BCR), and net present value (NPV) rates of return in closed and open economies are displayed in Table 2. In both closed and open economies, the rates of return for investments in rice research and extension are nearly the same in terms of BCR and IRR.

Table 3 Estimated rates of return on rice research and extension in Bangladesh (The authors)

Parameter	Closed economy	Open economy
Net present value (NPV) (Billion Taka)	3538.76	3388.77
Benefit–cost ratio (BCR)	20	20
Internal rate of return (IRR) (%)	68	67

Table 3 presents the estimated net present value (NPV) of the Taka 3,538.76 billion and 3388.77 billion in closed and open economies, respectively. The findings of the aggregate NPV indicate that rice research and extension have generated a total of Taka 3,538 billion as net gains for society in a closed economy. The benefit-cost ratio (BCR) of the research was estimated at 20, which is constant for both economies.

Estimates of the benefit-cost ratio show that 1 Taka invested in rice research and extension has generated an average social benefit of Taka 20 to Bangladesh. Using the consumer price index (CPI), the IRR was estimated at 68% and 67% for closed and open economies, respectively. The internal rate of return (IRR) from rice research was 68%, implying that each

Taka 100 invested in rice research and extension produced an average annual profit of Taka 68.

Estimates of the rate of return in this study are supported by several recent global impact studies on rice research, for example [12, 31, 54, 55]. In addition, the rate of return of the study is supported by rice research and development studies [29, 38, 40].

4.3. Sensitivity Analysis

In this study, the Monte Carlo simulation technique was used for the sensitivity analysis. A Monte Carlo simulation is an analytical method that addresses uncertainty-related problems by employing random numbers and probability distributions. The proposed method finds applications across various business and scientific domains. The Monte Carlo approach estimates the expected value or outcome of the problem under investigation.

In this study, Monte Carlo simulations were conducted with 1000 trials at a confidence level of 95%. Table 4 shows that the base parameters, including a net present value (NPV) of Taka 3,538.76 billion and an internal rate of return (IRR) of 68%, were used for rice research and extension in Bangladesh from 1971 to 2022.

Table 4 Statistical characteristics of the output variable (The authors)

Statistics	Expected value NPV (eNPV), Billion Taka	Expected value of IRR (eIRR), %
Base	3538.76	68%
Trails	1000	1000
Mean	3705.65	70%
Median	3695.32	70%
Mode	-	-
Standard deviation	3510.93	30%
Minimum	3128.75	67%
Maximum	4546.21	73%
Probability of project loss	14.23%	8.7%
Skewness	0.35	0.06
Kurtosis	0.14	-0.03
Coefficient of variability	0.93	0.43

The Monte Carlo simulation technique was employed to estimate the expected net present value (NPV) of a project, revealing a standard deviation of Taka 3510.53 billion and a mean value of 3705.65 billion. This analysis indicates that the project’s uncertainty is relatively low, as the gap between the mean NPV and standard deviation is not substantial. Results assume that the project generated larger benefits than initially anticipated, with the projected NPV exceeding the base NPV. With a coefficient of variability less than 1, indicating minimal chances of project failure, there is an 85.77% likelihood of project success compared to a 14.23% probability of loss. Additionally, the Monte Carlo simulation estimated the mean value of the expected internal rate of return (IRR) at 70% with a standard deviation of 30%. The IRR ranged from 67% to 73%, with a coefficient of variability of 0.43, assuming a low risk of project failure. Based on the IRR criterion, there is a 91.3% chance of project acceptance, whereas the NPV rule indicates a 75.77% chance of success.

5. Conclusion

The findings of this study demonstrate and prove the considerably high social returns of research and extension and that rice breeding research has benefited Bangladeshi society. This study's documented high return rate (IRR of 68%, BCR of 20, and NPV of Taka 3538.76 billion) assumes underinvestment in Bangladeshi rice research and extension. Therefore, the government should invest more in rice research and extension in the future. The findings from this study show that consumers are beneficiaries, and producers are losers. However, this situation may not be conducive to economic prosperity. The government and relevant authorities should provide price support for the survival of rice producers. One potential area for further research is the annual adoption rate of modern rice cultivars, which requires a major boost given that the seeds are not readily available. Governments and non-governmental organizations should initiate seed production programs so that farmers can obtain quality seeds at a reasonable price. Therefore, the Bangladesh government and donors should allocate adequate resources to rice research and extension programs in Bangladesh to achieve sustainable food security in the future.

The academic contribution of this work lies in its comprehensive evaluation of the economic impact and returns on investment in rice breeding research in Bangladesh over the past 51 years. This study is innovative because it applies closed and open economic perspectives, providing a nuanced understanding of social and economic benefits. The original approach combines the economic surplus model with project evaluation techniques, providing robust insights that can inform future agricultural policies and funding decisions. This work fills a gap in the existing literature by demonstrating significant foreign exchange savings and a high benefit-cost ratio, underscoring the importance of sustained investments in agricultural research.

6. Limitations of the Study

This study employed the economic surplus model to assess its financial impact. Despite the various criticisms of this technique, it remains one of the most preferable methods for economic valuation studies on research and technology. This study performed an evaluation based on constant supply and demand curves with a pivotal shift in the supply curve. Future studies could include a parallel shift of the supply curve with the point elasticity of the supply and demand functions and a parallel shift of the supply curve with the constant elasticity of the supply and demand functions. Methods other than the economic surplus model can also be applied in future research. The fundamental limitation of this study is data availability; specifically, national rice research expenditure data are not available. The estimations have to rely on a manual calculation using the BRRI rice research expenditures as a benchmark, and the expenditures from other institutions are calculated under certain assumptions. Using national rice research expenditure would improve estimating the rate of return (IRR).

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References

[1] BANDUMULA N., RATHOD, S., ONDRASEK, G., PILLAI, M.P., and SUNDARAM R.M. An economic evaluation of improved rice production technology in Telangana state, India. *Agriculture*, 2022, 12(9). https://doi/org/10.3390/agriculture12091387

[2] KABIR M.S., SALAM M.U., A.S. ISLAM, SARKAR M.A.R., AL MAMUN M.A., RAHMAN M.C., NESSA B., KABIR M.J., SHOZIB H.B., HOSSAIN M.B., CHOWDHURY A., NASIM M., IFTEKHARUDDAULA K.M., HOSSAIN M.S., BHUIYAN M.K.A., KARMAKAR B., RAHMAN M.S., HAQUE M.M., KHATUN M.T., ALI M.P., RABBI S.M.H.A., BISWAS, P.L. RASHID E.S.M.H., and RAHMAN, N.M.F. Doubling rice productivity in Bangladesh: a way to achieving SDG 2 and moving forward. *Bangladesh Rice Journal.*, 2021, 24(2): 1-47. DOI: 10.3329/brj.v24i2.53447.

[3] MOHIDEM N.A., HASHIM, N., SHAMSUDIN, R., and CHE MAN H. Rice for food security: revisiting its production, diversity, rice milling process and nutrient content, *Agriculture*, 2022, 12(6): 741. DOI: 10.3390/agriculture12060741.

[4] MOTTALEB K.A., and MISHRA, A.K. Rice consumption and grain-type preference by household: A Bangladesh case. *Journal of Agricultural and Applied Economics*, 2016, 48(3): 298-319. DOI: 10.1017/aae.2016.18.

[5] RAHMAN M.M., and CONNOR J.D. The effect of high-yielding variety on rice yield, farm income and household nutrition: evidence from rural Bangladesh. *Agriculture & Food Secur*ity, 2022, 11(1): 35. DOI: 10.1186/s40066-022-00365-6.

[6] GOVERNMENT OF BANGLADESH. *Bangladesh Economic Review*: *Socio-economic indicators of Bangladesh*. Finance Division, Ministry of Finance, Government of the People's Republic of Bangladesh, 2022. https://mof.portal.gov.bd

[7] FAO. Food outlook - biannual report on global food markets, Food and Agriculture Organization, 2023. https://reliefweb.int/report/world/food-outlook-biannual-report-global-food-markets-november-2023-enarruzh

[8] CHANDIO A.A., GOKMENOGLU K.K., AHMAD M., and JIANG T. Towards sustainable rice production in Asia: the role of climatic factors. *Earth Systems and Environment*, 2022, 6(1): 1-14. DOI: 10.1007/s41748-021-00210-z.

[9] MUJERI M.K., AHMED N., and HOSSAIN M.I. Food security implications of rice value chain management in Bangladesh. In: AHMED A., ISLAM N., and MUJERI M.K. (eds.). *Securing Food for All in Bangladesh. Part Three: Food Security and Output Market, Chapter 9*. Dhaka, Bangladesh: University Press Limited, pp. 297-342

[10] SHELLEY I.J., TAKAHASHI-NOSAKA M., KANO-NAKATA, M., HAQUE, M.S., and INUKAI Y. *Rice Cultivation in Bangladesh: present scenario, problems, and prospects. International Center for Research and Education in Agriculture*. Nagoya University, 2016. DOI: 10.50907/jicad.14.0_20.

[11] BANGLADESH BUREAU OF STATISTICS. *Food Security Statistics 2023*. Bangladesh Bureau of Statistics and Informatics Division Ministry of Planning Government of the People's Republic of Bangladesh, 2023. https://bbs.gov.bd/

[12] DIKITANAN R.C., PEDE V.O., REJESUS R.M., BHANDARI, H. MONIRUL ALAM G.M., and ANDRADE R.S. Assessing returns to research investments in rice varietal development: Evidence from the Philippines and Bangladesh. *Global Food Security*, 2022, 33: 100646. DOI: 10.1016/j.gfs.2022.100646.

[13] PINGALI P.L. Green revolution: impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences (Proceedings of the National Academy of Sciences of the United States of America)*, 2012, 109(31): 12302-12308. DOI: 10.1073/pnas.0912953109.

[14] IRRI. *Bangladesh and IRRI*. International Rice Research Institute, 2024. https://www.irri.org/where-we-work/countries/bangladesh

[15] HOSSAIN, M.S., JAIM, W.M., PARIS, T.R., and HARDY B. *Adoption and diffusion of modern rice varieties in Bangladesh and Eastern India*. International Rice Research Institute (IRRI), IRRI Books, 2012. https://econpapers.repec.org/bookchap/agsirricg/164411.htm

[16] ATLIN G.N., CAIRNS, J.E., and DAS B. Rapid breeding and varietal replacement are critical to adaptation of cropping systems in the developing world to climate change. *Global Food Security*, 2017, 12: 31-37. DOI: 10.1016/j.gfs.2017.01.008.

[17] SAIKIA D. *Total Factor Productivity in Indian Agriculture: Some Conceptual and Methodological Issues*. MPRA, 2009. https://mpra.ub.uni-muenchen.de/28578/

[18] ALSTON J.M., CHAN-KANG, MARRA, M.C.,

PARDEY, P.G., and WYATT T.J. *A Meta-analysis of Rates of Return to Agricultural R&D: Ex Pede Herculem?* International Food Policy Research Institute, 2000.
[19] GRILICHES Z. Research costs and social returns: hybrid corn and related innovations. *Journal of Political Economy*, 1958, 66(5). DOI: 10.1086/258077.
[20] SCHMITZ A., and SECKLER D. Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester. *American Journal of Agricultural Economics*, 52(4): 569-577, 1970. DOI: 10.2307/1237264.
[21] AKINO M., and HAYAMI Y. Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development: Reply. *American Journal of Agricultural Economics*, 1975, 57(4): 734-735. DOI: 10.2307/1238901.
[22] ALSTON, NORTON G.W., and PHILIP G.P. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. International Service for National Agricultural Research (ISNAR), 1998. https://ebrary.ifpri.org/digital/collection/p15738coll11/id/6/
[23] HEISEY P.W., KING, J.L., RUBENSTEIN, K.D., BUCKS, D.A., and WELSH R. Assessing the benefits of public research within an economic framework, 2010. https://ageconsearch.umn.edu/record/94852/files/ERR95.pdf?ln=en&withWatermark=1
[24] SHIBLEE S. *Ex-post economic impact assessment of investment in vegetable research and extension in Bangladesh.* Doctoral dissertation. Department of Agricultural Economics. Bangladesh Agricultural University, Mymensingh, Bangladesh, 2011. http://www.saulibrary.edu.bd/daatj/public/index
[25] FLORES-MOYA P., EVENSON, R.E., and HAYAMI H. Social returns to rice research in the Philippines: domestic benefits and foreign spillover. *Economic Development and Cultural Change*, 1978, 26 (3): 591-607. DOI: 10.1086/451041.
[26] NORTON G.W., and DAVIS J.S. Evaluating returns to agricultural research: a review. *American Journal of Agricultural Economics*, 1981, 63(4): 685-699. DOI: 10.2307/1241211.
[27] WARR P. *Economic returns to agricultural research: Thailand and Indonesia*. *Asian Journal of Agriculture and Development*, 2023, 20(1). DOI: 10.22004/AG.ECON.337001.
[28] SEQUEROS T., SCHREINEMACHERS P., DEPENBUSCH L., SHWE T., and NAIR R.M. Impact and returns on investment of Mungbean research and development in Myanmar. *Agriculture & Food Security*, 2020, 9(1), Article number: 5. DOI: 10.1186/s40066-020-00260-y.
[29] DEB U.K., and MUSTAFI B.A. *Social returns to rice research in Bangladesh*. *Bangladesh Journal of Agricultural Economics*, 1997, 20(2): 1-21. DOI: 10.22004/AG.ECON.202336.
[30] MIAH, M, SHIBLEE, S., and RASHID, M. Economic Impacts of oilseed research and development in Bangladesh, *Bangladesh Development Studies*, 2015, 38(1): 1-31.
[31] ALSTON, PARDEY P.G., and RAO X. Payoffs to a half century of CGIAR research, *American Journal of Agricultural Economics*, 2022, 104(2): 502-529. DOI: 10.1111/ajae.12255.
[32] HERRUZO A.C. Returns to agricultural research: The case of rice breeding in Spain. *European Review of Agricultural Economics*, 1985, 12(3): 265-282. DOI: 10.1093/erae/12.3.265.
[33] EVENSON R.E., and GOLLIN D. Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*, 2003, 300(5620): 758-762. DOI: 10.1126/science.1078710.
[34] FAN S., HAZELL, P., and THORAT S. Government spending, growth and poverty in rural India. *American Journal of Agricultural Economics*, 2000, 82(4): 1038-1051. DOI: 10.1111/0002-9092.00101.
[35] BRENNAN J.P., and MALABAYABAS, A. *International Rice Research Institute's contribution to rice varietal yield improvement in South-East Asia*. Philippine: International Rice Research Institute, 2011.
[36] RAITZER D.A., SPARKS A.H., HUELGAS Z., MALIGALIG R., BALANGUE Z., LAUNIO C., DARADJAT A., and AHMED H.U. *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*. A report submitted to the Standing Panel on Impact Assessment (SPIA), CGIAR Independent Science and Partnership Council (ISPC), 2015. https://hdl.handle.net/10568/128929
[37] GILL, G.J. Agricultural research in Bangladesh: costs and returns. Dhaka, Bangladesh Agricultural Research Council, 1983.
[38] SIDDIQUI, M.R. *Social Returns to Rice Research in Bangladesh*. Master's thesis on economics. University of New England, Armidale, Australia, 1985.
[39] DEY, M.M., and EVENSON, R.E. *The economic impact of rice research in Bangladesh*. Bangladesh Rice Research Institute, Agricultural Research Council, Dhaka: International Rice Research Institute, 1991.
[40] NAGY J.N., and ALAM M.F. *The impact of agricultural research in Bangladesh: estimating returns to agricultural research*. *Project Report.* BARC, Dhaka and International Fertilizer Development Centre, Muscle Shoals, Alabama, 2000.
[41] DEB U. *Returns to golden rice research in Bangladesh: an ex-ante analysis*. Copenhagen Consensus Center, 2016.
[42] ALAMGIR M. and BERLAGE L.J. Estimation of income elasticity of demand for food grain in Bangladesh from cross section data: a skeptical view. *The Bangladesh Economic Review*, 1973, 1(4): 387-408.
[43] AHMED A.U., and SHAMS Y. Demand elasticities in rural Bangladesh: An application of the AIDS model. *Bangladesh Development Studies*, 1994, 22(1): 1-26.
[44] BEGUM M.E., and D'HAESE L. Supply and demand situations for major crops and food items in Bangladesh. *Journal of the Bangladesh Agricultural University*, 2010, 8(1). https://ageconsearch.umn.edu/record/208471/
[45] ALAM M.J., BUYSSE J., BEGUM I.A., and WAILES E. The welfare impact of policy interventions in the food grain markets in Bangladesh. *Journal of Economic Policy Reform*, 2011, 14(3): 215-225.
[46] HOSSAIN M. and YUNUS M. Estimates of per capita consumption of food grains in Bangladesh. *Bangladesh Development Studies*, 2016, 39(1): 103-116.
[47] SIDDIQUE, SALAM, M.A., and RAHMAN M.C. Estimating the demand elasticity of rice in Bangladesh: An application of the AIDS model. *Asian Journal of Agriculture and Rural Development*, 2020, 10(3): 721-728.
[48] REJESUS, MARTIN A.M., and GYPMANTASIRI P. *Meta-impact assessment of the irrigated rice research consortium*. Philippine: International Rice Research Institute, 2013.

[49] KUMAR P., KUMAR A., PARAPPURATHU S., and RAJU S.S. Estimation of demand elasticity for food commodities in India. *Agricultural Economics Research Review*, 2011, 24(1): 1-14. https://ageconsearch.umn.edu/record/109408/?v=pdf
[50] YEONG-SHENG T.J. NASIR M.S., ZAINALABIDIN M., MAHIR A.A., and ALIAS R. Demand analyses of rice in Malaysia, *MPRA Paper*, 2009, 15062. https://mpra.ub.uni-muenchen.de/15062/1/Demand_Analyses_of_Rice_in_Malaysia.pdf
[51] ASTI. Agricultural Science and Technology indicators: National Agricultural Research Expenditure Database. Bangladesh, 2022. https://www.asti.cgiar.org/
[52] DEY P.K and MUSTAFI B. Economic returns to investment on BR11 variety of rice in T. Aman season. *Bangladesh Journal of Agricultural Economics*, 2001, 24: 57-74.
[53] BOSRI, R. Evaluation of Managerial Techniques: NPV and IRR. *UITS Journal*, 2016, 5: 48-57.
[54] HURLEY, T., PARDEY, P.G., RAO, X., and ANDRADE R.S. Returns to food and agricultural R&D; Investments worldwide, 1958-2015. 2016. https://hdl.handle.net/10568/119583
[55] PARDEY P.G., ANDRADE R.S., HURLEY T.M., RAO X., and LIEBENBERG F.G. Returns to food and agricultural R&D investments in Sub-Saharan Africa, 1975-2014. *Food Policy*, 2016, 65: 1-8. DOI: 10.1016/j.foodpol.2016.09.009.

参考文:

[1] BANDUMULA N.、RATHOD, S.、ONDRASEK, G.、PILLAI, M.P. 與 SUNDARAM R.M. 印度特倫甘納邦改良水稻生產技術的經濟評估。農業，2022，12（9）。https://doi/org/10.3390/agriculture12091387
[2] 卡比爾 M.S.、薩拉姆 M.U.、A.S.伊斯蘭、薩卡·馬裡、阿爾·馬蒙·馬、拉赫曼·MC、內薩·B.、卡比爾·M.J.、肖茲布·H.B.、侯賽因·M.B.、喬杜里·A.、納西姆·M.、IFTEKHARUDDAULA K.M.、侯賽因·M.S.、BHUIYAN M.K.A.、卡姆卡·B.、拉赫曼·M .S.，哈克 M.M.、KHATUN M.T.、ALI M.P.、RABBI S.M.H.A.BIM.M.H.A. RASHID E.S.M.H. 和 RAHMAN, N.M.F.將孟加拉的稻米生產力提高一倍：實現永續發展目標 2 並向前邁進的一種方式。孟加拉水稻雜誌，2021，24(2)：1-47。多伊：10.3329/brj.v24i2.53447。
[3] MOHIDEM N.A.、HASHIM, N.、SHAMSUDIN, R. 和 CHE MAN H. 用於糧食安全的稻米：重新審視其生產、多樣性、碾米過程和營養成分，農業，2022, 12(6): 741。
[4] MOTTALEB K.A. 和 MISHRA, A.K.家庭米消費和穀物類型偏好：孟加拉國案例。農業與應用經濟學報, 2016, 48(3): 298-319. 多伊：10.1017/aae.2016.18。
[5] RAHMAN M.M. 和 CONNOR J.D. 高產品種對水稻產量、農場收入和家庭營養的影響：來自孟加拉國農村的證據。農業與糧食安全，2022 年，11(1)：35。
[6] 孟加拉政府。孟加拉經濟評論：孟加拉的社會經濟指標。孟加拉國人民共和國政府財政部財務司，2022 年。
[7] 糧農組織。糧食展望 - 全球糧食市場半年度報告，糧食及農業組織，2023 年。
[8] CHANDIO A.A.、GOKMENOGLU K.K.、AHMAD M. 和 JIANG T. 亞洲稻米永續生產：氣候因素的角色。地球系統與環境，2022，6（1）：1-14。多伊：10.1007/s41748-021-00210-z。
[9] MUJERI M.K.、AHMED N. 與 HOSSAIN M.I.孟加拉國稻米價值鏈管理對糧食安全的影響。見：AHMED A.、ISLAM N. 和 MUJERI M.K.（編輯）。確保孟加拉國人人享有糧食。第三部分：糧食安全與產出市場，第 9 章。
[10] SHELLEY I.J.、TAKAHASHI-NOSAKA M.、KANO-NAKATA, M.、HAQUE, M.S. 和 INUKAI Y. 孟加拉國的水稻種植：現狀、問題和前景。國際農業研究和教育中心。名古屋大學，2016。
[11] 孟加拉統計局。2023 年糧食安全統計。
[12] DIKITAAN R.C.、PEDE V.O.、REJESUS R.M.、BHANDARI、H. MONIRUL ALAM G.M. 與 ANDRADE R.S. 評估水稻品種開發研究投資的回報：來自菲律賓和孟加拉的證據。全球糧食安全，2022 年，33：100646。
[13] PINGALI P.L. 綠色革命：影響、限制和前進的道路。美國國家科學院院刊（美國國家科學院院刊），2012, 109(31): 12302-12308。多伊：10.1073/pnas.0912953109。
[14] 國際稻米研究所。孟加拉和國際稻米研究所。國際稻米研究所，2024 年。
[15] HOSSAIN, M.S., JAIM, W.M., PARIS, T.R. 和 HARDY B. 現代水稻品種在孟加拉和印度東部的採用和傳播。國際水稻研究所，国际水稻研究所書籍，2012 年。
[16] ATLIN G.N.、CAIRNS、J.E. 和 DAS B. 快速育種和品種替代對於發展中國家種植系統適應氣候變遷至關重要。全球糧食安全，2017 年，12：31-37。多伊：10.1016/j.gfs.2017.01.008。
[17] SAIKIA D. 印度農業的全要素生產力：一些概念和方法問題。骨髓纤维化患者，2009 年。
[18] ALSTON J.M.、CHAN-KANG、MARA, M.C.、PARDEY, P.G. 與 WYATT T.J. 農業研發報酬率的統合分析：埃克斯佩德赫拉克勒姆？國際糧食政策研究所，2000。
[19] GRILICHES Z. 研究成本與社會回報：雜交玉米與相關創新。政治經濟學雜誌，1958，66（5）。多伊：10.1086/258077。
[20] SCHMITZ A. 和 SECKLER D. 機械化農業和社會福利：番茄收割機案例。美國農業經濟學雜誌，52(4)：569-577，1970。
[21] AKINO M.和 HAYAMI Y.公共研究的效率和公平：日本經濟發展中的水稻育種：答案。美國農業經濟學雜誌，1975，57(4)：734-735。多伊：10.2307/1238901。
[22] 阿爾斯通、諾頓 G.W. 與菲利普 G.P. 稀缺下的科學：農業研究評估和優先事項設定的原則和實踐。國家農業研究國際服務，1998。
[23] HEISEY P.W.、KING、J.L.、RUBENSTEIN, K.D.、BUCKS, D.A. 和 WELSH R. 評估經濟框架內公共研究的效益，2010 年 https://ageconsearch.umn.edu/record/94852/files/ERR95.pdf?ln=en&withWatermark=1
[24] SHIBLEE S. 孟加拉國蔬菜研究和推廣投資的事後經濟影響評估。博士論文。農業經濟系。孟加拉農業大學，孟加拉邁門辛，2011 年。http://www.saulibrary.edu.bd/daatj/public/index
[25] FLORES-MOYA P.、EVENSON, R.E. 和 HAYAMI H. 菲律賓水稻研究的社會回報：國內效益和國外溢出。經濟發展與文化變遷，1978，26（3）：591-607。多伊：

10.1086/451041。
[26] 諾頓 G.W.和戴維斯 J.S.評估農業研究的回報：綜述。美國農業經濟學雜誌，1981，63(4)：685-699。多伊：10.2307/1241211。
[27] WARR P. 農業研究的經濟回報：泰國和印尼。亞洲農業與發展雜誌，2023，20(1)。多伊：10.22004/AG.ECON.337001。
[28] SEQUEROS T.、SCHREINEMACHERS P.、DEPENBUSCH L.、SHWE T. 與 NAIR R.M. 緬甸綠豆研發的影響和投資回報。農業與糧食安全，2020，9(1)，文章編號：5。
[29] DEB 英國和 MUSTAFI B.A. 孟加拉國水稻研究的社會回報。孟加拉農業經濟雜誌，1997，20(2)：1-21。多伊：10.22004/AG.ECON.202336。
[30] MIAH, M, SHIBLEE, S., 和 RASHID, M. 孟加拉國油籽研發的經濟影響，孟加拉國發展研究，2015, 38(1): 1-31。
[31] ALSTON、PARDEY P.G. 和 RAO X. CGIAR 研究半個世紀的回報，美國農業經濟學雜誌，2022, 104(2): 502-529。多伊：10.1111/ajae.12255。
[32] HERRUZO A.C. 重返農業研究：西班牙稻米育種案例。歐洲農業經濟評論，1985，12(3)：265-282。多伊：10.1093/erae/12.3.265。
[33] EVENSON R.E.和 GOLLIN D. 評估 1960 年至 2000 年綠色革命的影響。多伊：10.1126/science.1078710。
[34] FAN S.、HAZELL, P. 和 THORAT S. 印度農村的政府支出、成長和貧窮。美國農業經濟學雜誌，2000，82(4)：1038-1051。多伊：10.1111/0002-9092.00101。
[35] BRENNAN J.P. 和 MALABAYABAS, A. 國際稻米研究所對東南亞稻米品種產量提高的貢獻。菲律賓：國際稻米研究所，2011 年。
[36] RAITZER D.A.、SPARKS A.H.、HUELGAS Z.、MALIGALIG R.、BALANGUE Z.、LAUNIO C.、DARADJAT A. 與 AHMED H.U.水稻改良仍能發揮作用嗎？評估 1989 年至 2009 年孟加拉、印尼和菲律賓推出的稻米品種對經濟、貧窮和糧食安全的影響。向国际农业研究磋商组织獨立科學與夥伴關係理事會影響評估常設小組提交的報告，2015 年。
[37] 吉爾，G.J. 孟加拉的農業研究：成本和回報。達卡，孟加拉農業研究委員會，1983 年。
[38] SIDDIQUI, M.R. 孟加拉國稻米研究的社會回報。經濟學碩士論文。新英格蘭大學，澳洲阿米代爾，1985 年。
[39] DEY, M.M. 和 EVENSON, R.E. 孟加拉水稻研究的經濟影響。孟加拉稻米研究所，農業研究委員會，達卡：國際稻米研究所，1991 年。
[40] NAGY J.N. 和 ALAM M.F. 孟加拉農業研究的影響：估計農業研究的回報。項目報告。巴拿马研究与创新中心，達卡和國際肥料開發中心，馬斯爾肖爾斯，阿拉巴馬州，2000 年。
[41] DEB U. 回顧孟加拉的黃金米研究：事前分析。哥本哈根共識中心，2016。
[42] ALAMGIR M. 和 BERLAGE L.J. 根據橫斷面資料估算孟加拉糧食需求收入彈性：懷疑。孟加拉經濟評論，1973 年，1(4)：387-408。
[43] AHMED A.U. 和 SHAMS Y. 孟加拉農村地區的需求彈性：愛滋病模型的應用。孟加拉發展研究，1994，22(1)：1-26。
[44] BEGUM M.E. 和 D'HAESE L.孟加拉國主要農作物和食品的供需情況。孟加拉農業大學學報，2010，8(1)。https://ageconsearch.umn.edu/record/208471/
[45] ALAM M.J.、BUYSSE J.、BEGUM I.A. 和 WAILES E. 孟加拉國糧食市場政策幹預的福利影響。經濟政策改革雜誌，2011，14(3)：215-225。
[46] HOSSAIN M. 和 YUNUS M. 孟加拉人均糧食消費量估計。孟加拉發展研究，2016，39(1)：103-116。
[47] SIDDIQUE, SALAM, M.A. 與 RAHMAN M.C. 估計孟加拉米的需求彈性：愛滋病模型的應用。亞洲農業與農村發展雜誌, 2020, 10(3): 721-728。
[48] 拒絕， MARTIN A.M. 和 GYPMANTASIRI P. 灌溉水稻研究聯盟的元影響評估。菲律賓：國際稻米研究所，2013 年。
[49] KUMAR P.、KUMAR A.、PARAPPURATHU S. 和 RAJU S.S. 印度食品商品需求彈性估計。農業經濟研究評論，2011，24(1)：1-14。https://ageconsearch.umn.edu/record/109408/?v=pdf
[50] 永盛 T.J. NASIR M.S.、ZAINALABIDIN M.、MAHIR A.A. 和 ALIAS R. 馬來西亞稻米需求分析，MPRA 文件，2009 年，15062。
[51] 阿斯蒂。農業科技指標：國家農業研究經費資料庫。孟加拉國，2022 年。
[52] DEY P.K 和 MUSTAFI B. T. 阿曼季節巴西雷亚尔 11 品種水稻投資的經濟回報。孟加拉農業經濟雜誌，2001 年，24：57-74。
[53] BOSRI, R. 管理技術評估：净现值和內部收益率。联合交通运输系统雜誌，2016 年，5：48-57。
[54] HURLEY, T.、PARDEY, P.G.、RAO, X. 與 ANDRADE R.S.食品農業研發回報；全球投資，1958 年至 2015 年。2016。
[55] PARDEY P.G.、ANDRADE R.S.、HURLEY T.M.、RAO X. 與 LIEBENBERG F.G. 1975-2014 年撒哈拉以南非洲糧食與農業研發投資回報。糧食政策，2016，65：1-8。多伊：10.1016/j.foodpol.2016.09.009。