INDUCED INNOVATION THEORY AND TECHNOLOGICAL PROGRESS IN BANGLADESH AGRICULTURE IN THE TWENTIETH CENTURY

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Abstract

This paper explores the relationship between factor price ratios and factor intensities during the period of rapid spread of high yield variety (HYV) technology of cereal production in Bangladesh agriculture. The theory of induced innovation suggests that an increase in the relative price of a factor would lead farmers to adopt technologies that minimize the usage of that factor, and conversely. However, available data from Bangladesh agriculture indicate that although the price of fertilizer, a key factor in HYV cultivation, relative to land and labor, rose substantially during the study period, the fertilizer-labor and fertilizer-land intensities in cultivation also rose very steeply. It is shown that minimizing the use of the expensive factor is neither necessary nor sufficient for profit maximization in agricultural production.

Keywords: Technological innovation, factor-price ratio, productivity, agricultural development.

Introduction

Technological innovation in agriculture has been the subject of much discussion. In a pioneering work on the subject published in 1971 Hayami and Ruttan (henceforth HR) outlined a theory of induced innovation and applied it to the history of agricultural development of USA and Japan. They advanced the hypothesis that technological (as well as institutional) changes were a response to changing conditions of relative factor supply and product demand (see section III). Thus, they explicitly regarded the process of technological and institutional changes as endogenous to the economic environment in which these occurred. This was a significant contribution to the literature in view of the fact that mainstream economics was still wedded to Solow's (1962) view of technological change as largely an exogenous phenomenon in economic growth.

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Despite the popularity of HR propositions, some concern has been expressed about the empirical robustness of their findings. In their critique, Olmstead and Rhode (1993) re-examined US agricultural data and claimed that "… over the entire span for which we have data, two of the relative factor price indices that represent the empirical foundation of the induced innovation model are almost always moving in the wrong direction." (p. 106). They also pointed out that many of the generalizations of HR were regional, and not national. Machado's (1995) econometric analysis of US data led him to conclude that no clear support could be found for the induced innovation theory. These claims are credible enough to merit a reconsideration of the main propositions of the theory and further tests with data of other countries.

This paper examines the agricultural trends of a developing country, Bangladesh, which has undergone significant technological changes during the last quarter of the last century (Islam and Taslim 1996). In many ways Bangladesh was typical of the densely populated developing countries of the world. It had an adverse agricultural land-person ratio that was growing more adverse over time due to a diminishing cropland area and a rapidly increasing population. Technological innovations have taken the form of the so-called high yield variety (HYV) technology that permits higher production per unit of land. This paper attempts to determine if the technological and associated changes that have occurred are consistent with the propositions of the theory of induced innovation. It finds that the movements of some of the factor price ratios and factor intensities did not always follow the pattern predicted by HR. It invokes Salter's (1966) criticism of Hicksian theory of innovation to argue that the main proposition of HR that technological innovations are developed and adopted in order to economise the relatively scarce, and hence, more expensive, factor is a special case of the more general proposition that innovations are adopted to maximize profit. While the latter may sometimes imply the former, it does not always have to be the case, particularly in the longer term. Indeed, economizing on the use of the relatively expensive factor is neither necessary nor sufficient for the optimum cultivation practices over time.

This paper is organized as follows. Section II provides a brief description of the evolution of the HYV technology in the agriculture of Bangladesh and associated changes in input use. Section III summarizes the theory of induced innovation and demonstrates that two of the key relative factor prices and factor intensities in Bangladesh agriculture during a period of rapid technological change did not move in the direction predicted by HR. Section IV concludes.

Technological change and input-use in Bangladesh agriculture

The main physical constraint confronting crop agriculture in Bangladesh is the inelastic supply of the principal input, arable land. Severe population pressure has meant that virtually the entire arable land is already under cultivation as evidenced by the fact that the cropped land area had mildly oscillated around 19.5 million acres ever since the early 1990s. (Statistical Yearbook of Bangladesh, various issues). In future it will be increasingly difficult to retain land under cultivation as competing demand for residential and urban/industrial development increases with a rising population and income. This small area of cropland was required to produce an agricultural output, particularly food, for a staggering population which had reached nearly 130 million by the end of the twentieth century. The only way the crop agriculture could address this formidable challenge was the adoption of a land-saving technological innovation. Fortunately, by the time land-scarcity became severe, international research effort, particularly at International Rice Research Institute in Philippines (IRRI), and CIMMYT in Mexico, had developed modern varieties of rice and wheat crops that that produced much higher yields in controlled environment (Herdt and Capule 1983). These were introduced to the agriculture of Bangladesh in the late sixties, but rapid expansion occurred after independence (in 1971) with extensive support from such government organisations as Bangladesh Water Development Board (BWDB) and Bangladesh Agricultural Development Corporation (BADC). The former was responsible for the development of water resources through flood control schemes, irrigation and drainage projects. The latter provided farms with chemical fertilizers, irrigation equipment, pesticides and new varieties of seeds at subsidized prices. Several research institutes such as Rice Research Institute at Joydevpur and Bangladesh Agricultural Research Council engaged in research to improve the HYV seeds by adapting these to local conditions.

At the time of the emergence of Bangladesh as a sovereign country, the HYVs had not yet made their mark in the country's agriculture. Only 1.5 million acres of land, i.e. less than 7 per cent of the total rice area, was devoted to HYV rice crops in 1971-72 (see Table 1 for crop and acreage data over the study period). The acreage rose rapidly to 3.8 million acres by 1975-76, but stagnated till 1978-79.3 Thereafter, the HYV rice acreage rose rapidly. By 1998-99, more than three-fifths of the total rice area was under HYV rice crops.

[3] This apparent stagnation may be due to statistical errors. See Hossain (1988).

Table 1: Area and yields of crops

year	1971-72	1972-73	1976-77	1981-82	1986-87	1991-92	1996-97	1998-99
Local *aman* area*	12746	12742	13309	12493	11873	8858	8232	6675
Production	4999	4607	6008	5542	5742	4614	4192	2995
yield	0.392	0.362	0.451	0.444	0.484	0.521	0.509	0.449
HYV *aman* area	626	1379	1046	2361	3085	5210	6107	6087
Production	696	980	898	1667	2525	4655	5360	4741
yield	1.112	0.711	0.859	0.706	0.818	0.893	0.878	0.779
Local *aus* area	7297	7077	7050	6608	5834	3710	2753	2429
Production	2212	2107	2185	2248	2163	1409	1027	889
yield	0.303	0.298	0.310	0.340	0.371	0.380	0.373	0.366
HYV *aus* area	121	164	901	1166	1342	1025	1176	1090
Production	129	167	825	1022	967	770	847	728
yield	1.066	1.018	0.916	0.877	0.721	0.751	0.720	0.668
Local *boro* area	1390	1346	897	1001	771	743	582	607
Production	772	731	456	637	430	437	355	399
yield	0.555	0.543	0.508	0.636	0.558	0.588	0.610	0.657
HYV *boro* area	795	1088	1215	2218	3311	5768	6294	8108
Production	966	1340	1194	2515	3580	6367	7105	10153
yield	1.215	1.232	0.983	1.134	1.081	1.104	1.129	1.252
Wheat area	315	270	395	1320	1445	1420	1749	2180
Production	115	90.964	265	856	1092	1065	1454	1908
yield	0.366	0.337	0.670	0.649	0.755	0.750	0.831	0.875
All local rice area	21433	21165	21256	20102	18478	13311	11567	9711
Production	7983	7445	8649	8427	8335	6460	5574	4283
yield	0.372	0.352	0.407	0.419	0.451	0.485	0.482	0.441
All HYV rice area	1542	2631	3162	5745	7738	12003	13577	15285
Production	1791	2487	2917	5204	7072	11792	13312	15622
yield	1.161	0.945	0.923	0.906	0.914	0.982	0.980	1.022
All rice area	22975	23796	24418	25847	26216	25314	25144	24996
Production	9774	9932	11566	13631	15407	18252	18886	19905
yield	0.425	0.417	0.474	0.527	0.588	0.721	0.751	0.796

* Area in ‘000 acres, production in’000 tons and yield in tons per acre.

Source: Bangladesh Bureau of Statistics, *Statistical Yearbook of Bangladesh*, various issues.

The three main rice crops grown in the country are aus, aman and boro. The first two are wet season crops while the last is a dry season crop. During the pre-independence period, most of the rice crops were grown during the wet season because of a lack of irrigation facilities that restricted expansion of dry season crops. The most important crop was aman. In 1971/72 it covered about 58 per cent of the total rice area. Aus crop covered another 32 per cent of the rice acreage. The rest of the land was devoted to the dry season crop boro (see Table 1). Almost all rice crops grown were of the local variety. The high yield varieties of crops were still at the experimental stage and were grown on a mere two and a half per cent of the total rice acreage. Since independence, the cultivation of the HYV crops expanded rapidly with the government actively supporting the expansion with subsidized irrigation, seed and fertilizer inputs. During the period 1971/72 to 1998/99, HYV aman area expanded at a rate of 8.8 per cent. HYV boro area grew at a marginally higher rate. HYV aus area expansion showed a great deal of variability. Its acreage rose rapidly until 1978/79 when about a million acres of land was devoted to it. Since then the acreage declined, and by 1998/99 only 0.7 million acres were devoted to HYV aus. Taken together, all HYV rice crop acreage grew at a rate of about 9 per cent per annum.

The HYV rice acreage expansion was achieved by a reduction of the acreage of local crops. Between 1971/72 and 1998/99, local rice acreage declined by about 11.7 million acres while HYV rice area increased by 13.7 million acres. Since the end of the seventies the HYV rice acreage rose steadily while the acreage under local varieties declined. The trend decline of the local rice area for the entire post-liberation period is about two and a half per cent, but during the last decade the trend rate of decline jumped to about 5 per cent mainly because of the smaller base in the later years.

The cultivation of the other important cereal crop, wheat, also gained momentum during the seventies. In 1971/72, only about 0.3 million acres of land grew wheat, but by 1980/81, the acreage rose to nearly 1.3 million - a growth rate of 15.4 per cent per annum. Since then wheat acreage grew by a more sedate 3 per cent. Wheat, being a dry season crop, has to compete against boro and several other winter crops for acreage.

The total output of rice crops stood at only 9.8 million tons in 1971/72. By 1998/99 it rose to nearly 20 million tons. The increase was due to an increase in the HYV rice crop production from only 1.8 million tons to 15.6 million tons. HYV boro contributed most to this increase - from 1 million to 10.2 million tons. Substantial increase was also achieved by HYV aman whose output rose from 0.7 million to 4.7 million tons. The production of HYV aus increased from 0.1 million to 0.7 million tons. These increases in HYV rice production were partly offset by a

reduction in the output of all local varieties of rice. Local aus output fell from 2.2 to 0.9 million tons, that of local aman from 5 to 3 million tons and boro from 0.8 to 0.4 million tons. The rate of growth of production of all HYV rice during 1971/72 to 1998/99 was 8.4 per cent, while the production of local rice declined at a rate of 2.3 per cent. Over-all rice output increased at a rate of 2.7 per cent.

Wheat production showed tremendous promise in the seventies. During the first decade of independence, production increased at the phenomenal rate of 22.2 per cent, but since then the growth rate fell. During the period 1981/82 and 1998/99, wheat output increased at the rate of 4.8 per cent to reach 2 million tons. The production pattern is consistent with the time trend of wheat acreage that showed very rapid increase during the first decade but fell off subsequently.

The yield rates of the crops are also shown in Table 1. The yield rates of all local varieties of rice declined in the aftermath of the liberation war, but since independence all varieties showed a moderate upward trend. There were large declines in the yields of all HYV rice crops. A closer inspection of the time series of yield rates reveals that the yield rates of all three crops declined during the seventies. Since then the yields of aman and boro increased moderately, but the yield of aus continued its downward trend such that by 1998/99 it was less than two-thirds of its 1971/72 value. Aggregating, the yield rates of all local varieties rose during the 1971/72 to 1998/99 period, while that of all HYVs declined. Since the yields of the HYV crops are much greater than that of the local varieties, and farmers have steadily switched to the HYV, the yield of rice crops as a whole rose by nearly 90 per cent during the period.

Wheat experienced the highest increase in yield since its independence. Its yield more than doubled during the period from only 0.366 tons per acre to 0.875 tons per acre. This increase in yield was made possible by a progressive substitution of HYVs of wheat for the older varieties. Most of the wheat area is now sown with HYV seeds (Hossain 1988, p.26).

Irrigation

The performance of the new varieties of cereal crops is greatly susceptible to a controlled water regime and the application of chemical fertilizers, so much so that the new cultivation practices were sometimes called the seed-fertilizer-water technology (Islam and Taslim 1996). The success of the new technology depended crucially on the availability of these inputs. Traditional irrigation methods, such as swing baskets and *dhoons* (as well as canals) have been used for a long time for dry season cropping. However, the lack of technical sophistication of these methods severely restricted the scale of irrigation. In the late fifties when modern methods of irrigation were virtually unknown, less than 7 per cent of the total

cultivated land could be irrigated (by the traditional techniques) but by 1998/99, nearly two-fifths of the total cultivated area was under irrigation (Table 2). This was made possible by a rapid expansion of modern irrigation methods since independence. Various types of power pumps and tube wells (that constitute the modern methods) irrigated less than one million acres of land in 1971/72 while another 1.7 million acres were irrigated by traditional methods. By 1998/99, the modern techniques irrigated 8.6 million acres of land, but the share of the traditional methods declined to 1.2 million acres.

Table 2: Area irrigated by different methods

Area irrigated by*	1971/72	1975/76	1981/82	1986/87	1989/90	1994/95	1998/99
Power pump	830	1363	1740	1630	1624	1651	1767
Tubewell	84	263	670	2426	4141	5199	6850
Canal	217	229	403	384	436	383	-
Other	1456	1602	1451	994	1054	893	-
Total	2587	3457	4264	5434	7255	8126	9846

* Area in ‘000 acres

Source: Bangladesh Bureau of Statistics, *Statistical Yearbook of Bangladesh*, various issues.

The expansion of irrigation was facilitated by two government organizations, BWDB and BADC. The former carried out large-scale multipurpose flood control, drainage and irrigation schemes. While successful to some extent in protecting coastal and riverbank areas from salinity and flooding, these capital-intensive and costly schemes did not play a significant role in irrigation development and accounted for only about one-tenth of the total irrigated area (Hossain 1988, p.26). BADC played a much more important role in developing irrigation. It was responsible for marketing all modern inputs needed for HYV cultivation such as irrigation equipment, chemical fertilizers, pesticides and seeds. The irrigation equipment such as deep and shallow tube wells and low-lift pumps permitted small-scale irrigation. These were provided at a greatly subsidized cost specifically to increase the adoption rate of HYV crops. Initially, the equipment was given to farmers' co-operatives on subsidized rentals, but since 1978/79, these were sold to individual farmers and co-operatives at reduced rates. The subsidies were later withdrawn under budgetary pressures.

Chemical fertilisers

Along with an expansion of irrigated area, the consumption of chemical fertilizers also soared. In 1971/72, only a quarter of a million tons of fertilizers was sold (Table 3). More than two-thirds of the sales were urea and about a quarter, triple super phosphate (TSP). By 1994/95, the sale of fertilizers increased more than ten times to 2.56 million tons. The sale of urea also increased more than ten-fold to 1.75 million tons, while that of TSP only doubled. What is noteworthy is that until 1990/91, the sale of TSP increased at a much faster rate than urea, but since then it plummeted. Total sale of TSP in 1997/98 was a mere one-eighth of the sale in 1989/90. This large reduction in the sale of TSP was no doubt caused to a large extent by the steep rise in the TSP price. In 1989/90, urea and TSP prices were about the same, but by 1994/95 the TSP price was more than 50 per cent higher than the urea price. The price of muriate of potash (MP) also rose sharply after 1989/90, which may have contributed to a sharp reduction in sale from 150,000 tons in 1990/91 to only 104,000 tons in 1993/94. In 1994/95, the price fell and there was a rebound in sales.

Table 3: Total sale of fertilizers

Fertilizer	1971/72	1975/76	1981/82	1986/87	1989/90	1994/95	1997/98
Urea	170	312	519	795	1068	1748	1867
TSP	60	110	208	297	481	123	62
MP	14	22	44	60	119	154	194
Total	250	448	771	1157	1967	2558	2727

*Sale in ‘000 tons

Source: Bangladesh Bureau of Statistics, *Statistical Yearbook of Bangladesh*, various issues.

The use of fertilizers was promoted during the early years by very large subsidies. It is estimated that the average rate of subsidy was about 58 per cent for urea and phosphate and 67 per cent for potash (Hossain 1988, p.29). As the consumption of fertilizers gained momentum, a heavy burden was imposed on government budgets in financing subsidies. The government responded by reducing them to 25 per cent of cost in 1983/84 and subsequently eliminating them altogether.

Labour

The new varieties of crops are not only modern input-intensive, they also require substantially more labour per unit of land than the local varieties. Table 4 and 5 below reproduce survey findings of Ahmed (1977) and Hossain (1988). They show that each HYV rice crop requires more labour than the corresponding traditional variety. According to the findings reported by Hossain, *aus* HYV absorbed 41 per cent and *aman* HYV 38 per cent more labour than the respective local varieties; but *boro* HYV required only 6 per cent more labour than *boro* local.

Taken together, all HYV rice crops utilised 47 per cent more labour than the local varieties of rice. There is little doubt that the cultivation of HYV rice crops substantially raised the demand for total as well as wage labor.

Table 4: Labour use per acre under local and HYV crops

Crops		1975 (Ahmed)			1982 (Hossain)		
		Hired labor	Family labor	Total labor	Hired labor	Family labor	Total labor
		8 hour days			8 hour days		
Aman	Local	29	32	61	22	32	53
	HYV	43	36	79	30	43	73
Aus	Local				16	40	56
	HYV				33	47	79
Boro	Local	39	43	82	20	62	83
	HYV	64	56	120	30	58	88
All rice	Local				20	36	55
	HYV				30	50	81

Sources: Ahmes,I. (1977), and Hossain (1988)

Animal and mechanical power

The HYV crops also require more animal and mechanical power for land preparation, irrigation, harvesting and threshing. Table 5 shows the pattern of usage of power by different crops. *Boro* HYV is the most intensive in the usage of power among all crops. It uses up about 12 per cent more animal power and 130 per cent more mechanical power than the local variety of *boro*. Most of the mechanical power is used for irrigation. In contrast, mechanical power was used almost exclusively for threshing in the case of both varieties of *aus* and *aman*. These crops being essentially rain-fed crops did not require much artificial irrigation. Overall, the HYV rice crops utilized about 15 per cent more of animal power and 200 per cent more of mechanical power than the local varieties.

Table 5: Use of animal and mechanical power

		Animal power Hours/pair/acre	Mechanical power Hours/acre
Aman	Local	138	6
	HYV	149	16
Aus	Local	125	8
	HYV	139	10
Boro	Local	138	17
	HYV	154	39
All rice	Local	127	8
	HYV	147	24

Source: Hossain (1988)

It is abundantly clear that the cultivation of the HYV rice crops was biased toward the variable inputs. Although there was a great deal of variation in estimates, there is little doubt that the HYVs utilized substantially more of labor, chemical fertilizers and irrigation per unit of cropped land. The more widespread use of irrigation facilities relaxed the extreme land-scarcity by permitting multiple cropping. Cultivation of dry-season crops, particularly *boro*, became increasingly prevalent. This raised the cropping intensity from 1.38 in 1971-72 to 1.75 by 1997-98. This is equivalent to an increase in effective cultivated area by more than 28 per cent. The more intensive use of labor, chemical fertilizers and mechanical power resulted in substantial increases in yields. The aggregate yield of all varieties of rice rose from 0.43 tons per acre to 0.80 tons between 1971/72 to 1998/99, i.e. an increase of nearly 90 per cent in twenty-seven years. The yield of the other important cereal, wheat, increased even more markedly; it more than doubled from only 0.37 tons per acre in 1971/72 to 0.88 tons in 1998/99. The diffusion of the HYV crops resulted in the cereal output (rice and wheat) increasing from less than 10 million tons in 1971/72 to nearly 22 million tons in 1998/99.

Induced Innovation: Evidence from Bangladesh Agriculture

The introduction of the HYV crops has been a momentous event in the agricultural development of Bangladesh. Until the fifties, the agriculture of the country experienced little technological change. The cultivation practices were old and time-tested: human and animal labour combined with the bounties of nature to produce the same crops year in, year out. There were few innovative activities and the productivity of land and labour were low and stagnant. The situation started changing since the introduction of the HYV crops in the mid-sixties. There has been a steady diffusion of the new technology that has been described as *land-saving* or *land-augmenting* because of the fact that it utilizes a greater amount of the non-land variable inputs to produce a higher output per unit of land. An interesting question of agricultural development of Bangladesh is what induced the farmers to adopt the HYV technology. As discussed above, this is the issue at the core of the theory of induced innovation.

The theory of induced innovation advanced by Hicks (1932) suggested that a change in the relative factor prices could influence the direction of innovation as firms search for techniques of production that economize the use of the relatively expensive factor. The idea was further refined and elaborated by Ahmad (1966) among others. However, its popularity is due largely to the monumental work of HR (1971) that utilized the theory to explain the different processes of agricultural development of Japan and the USA. The importance and appeal of their work were undoubtedly greatly enhanced by the meticulous and massive empirical data they adduced in support of their theory.

According to the HR interpretation of the theory, the impetus to develop and adopt new technology comes from changing demand and supply situations in the product and factor markets. With the growth of an economy over time, certain factors may become relatively more abundant while others become scarcer. The increased relative scarcity of a factor will raise the price of that factor relative to the prices of other factors. Farmers are then forced to consider economizing the use of the scarce factor. Marginal changes in factor proportions in response to small changes in factor-price ratios could perhaps be accommodated without much change in the current technique of production. For large changes in the factor-price ratio there will be a sufficient inducement to develop and adopt new techniques that economize on the use of the relatively scarce factor.

A narrow interpretation of the theory of induced innovation that it applies only to the development of new technology would greatly reduce its scope and importance as only a handful of countries, such as the USA, actually engage in original research to develop technical innovations. Many countries, particularly developing countries, import technologies that suit their conditions best. Some research is done to adapt the techniques to the local environment. Thus, a broader interpretation of the theory would imply that farmers adopt an innovation that economizes on the use of the more expensive inputs.[4] It would seem that HR included the broader interpretation within the scope of their theory as they liberally used examples of technological changes in many developing countries including Bangladesh.

Can the theory of induced innovation explain the technological change of the last three decades of the last century in the agriculture of Bangladesh? The narrow interpretation is unlikely to apply since Bangladesh did not do much of the original research to develop the HYV crops and some of the inputs during the 1960s or 1970s when it was introduced (Dalrymple 1986). There was little research infrastructure in those days. However, the broader interpretation could be applicable as it is conceivable that the switch to labor-intensive technology by the farmers was encouraged by changing factor prices in addition to higher yields. It is undeniable that over the years land had become a scarce factor. The amount of arable land had reached a physical limit long ago as evidenced by the steady decline of cultivated land since 1969-70. The population was growing, and in the absence of adequate dynamism of the other sectors of the economy, much of the

[4] It is in general true that in developing countries it is the public sector that imports the technology and carries out research to adapt it to local conditions. They may take a long term view of the economic feasibility of the available technologies when deciding on which of these to promote. But farming is almost entirely a private sector activity, and it is the farmers who must decide whether or not to adopt the proffered technology. It is plausible that their decision will be based on the actual prices they pay and receive rather than the considerations that concern the public sector.

increase in population had to be absorbed in agriculture resulting in a rapid decrease in the land-man ratio. The abundance of agricultural labor had kept the agricultural wage stagnant at about the minimum subsistence level, while the increased tightness of the land market has caused the land price to soar (Taslim and Taslim 2018). The increased scarcity of land relative to labor had led to the fall of the wage rate relative to the land price (Table 6). According to the induced innovation theory, this change in the relative price of land should have encouraged substitution of land for labor resulting in more labor-intensive cultivation.

Table 6: Input price relatives and input utilization indices

Input price ratio and input intensity	1969-70	1972-73	1975-76	1981-82	1986-87
Agricultural wage-rural land price ratio	100.0	75.6	69.0	42.0	70.0
Urea-rural land price ratio	100.0	93.7	114.4	104.8	113.1
TSP-rural land price ratio	100.0	67.9	91.4	91.2	117.8
Fertilizer-rural land price ratio	100.0	90.2	112.3	104.3	119.7
Fertilizer-agricultural labor price ratio	100.0	119.3	162.9	248.3	171.0
Urea per net cropped acre	100.0	146.5	164.8	270.9	402.5
Fertilizers per net cropped acre	100.0	144.7	168.5	286.6	416.5
Fertilizers per agricultural labor	100.0	128.2	138.5	223.5	268.9
Agricultural workers per net cropped acre	100.0	112.9	121.2	139.9	154.4

Source: Bangladesh Bureau of Statistics, *Statistical Yearbook of Bangladesh*, various issues.

There is data on land prices for the period 1972/73 to 1986/87 with 1969/70 as the base year. Thereafter, the Bangladesh Bureau of Statistics discontinued publishing land price data. There is no other source for rural land price. Hence, a test of the theory has to be restricted to this relatively short period. This is a hindrance to a rigorous test of the theory that essentially explains long term changes in agriculture. However, on a more positive note, there was a very rapid diffusion of HYV cultivation during this period: HYV acreage increased nearly 12 fold

between 1969/70 and 1986/87. HYV cultivation became entrenched in the farming culture of the country. It is not altogether unreasonable to expect that the HR theory of induced innovation, if valid, should provide a framework for understanding the pattern of this impressive growth. Furthermore, there are longer term data for other input price ratios which could be used to test the theory more convincingly.

The price of labor relative to land fell steadily from 1969/70 and reached the lowest level in 1980/81 when it lost 58 per cent of its 1969/70 value (Table 6). Thereafter, it recovered somewhat and by 1986/87, the decline (relative to 1969/70) had been reduced to 30 per cent. This substantial reduction in the relative price of labor, or alternatively the increase in the relative price of land, was accompanied by a rapid increase in the rate of diffusion of the HYV technology that made a more intensive use of the variable inputs which were in relatively abundant supply. The absorption of labor per net cropped acre increased by more than one-half between 1969/70 and 1986/87. This was achieved by both an increase in the labor requirement of individual crops with a switch to HYV crops as well as an increase in the cropping intensity which rose from 1.50 to 1.68 during the period. Thus, the movement of land-labour factor prices and intensities appear to be quite consistent with the predictions of the HR theory.

HR also suggested that a decline in the fertilizer prices relative to land would encourage a greater diffusion of the HYV crops that are more responsive to fertilizers relative to the traditional crops. The yield of the latter does not respond much (and sometimes responds negatively) to the application of fertilizers; but the yield of the former can be raised substantially by an appropriate dosage of fertilizers (and other inputs such as water). This provides an incentive to substitute HYVs for local crops as fertilizer prices declined. HR stated categorically: "The enormous changes in fertilizer input per hectare, as observed in Japan since 1880 and in the United States since the 1930s, reflect not only the effect of a decline in the price of fertilizer but the development of fertilizer-responsive varieties in order to take advantage of the decline in the real price of fertilizer" (1985, pp. 177-78).[5]

As mentioned earlier, the prices of chemical fertilizers were highly subsidized during the sixties and early seventies in order to encourage farmers to switch to the cultivation of the new crops. As the rate of subsidy was progressively withdrawn, the prices of fertilizers actually paid by farmers rose steeply. Even though the price of land was also increasing rapidly, the prices of fertilizers relative to the price of land exhibited an upward trend over the period 1972/73 to 1986/87 (Table 6). This was true of both individual fertilizer prices as well as the weighted

[5] Their regression analysis showed that fertilizer input per hectare was significantly inversely related to fertilizer-land price ratio in both USA and Japan.

average of prices of all fertilizers. But the increase in the prices of fertilizers did not reduce fertilizer use; on the contrary, the sale of fertilizers increased more than four-fold between 1969/70 and 1986/87 as the cultivation of HYVs spread. Fertilizer application per acre of net cropped land also increased more than four-fold during the same period. The prices of chemical fertilizers relative to the price of labor also rose sharply. The ratio of the weighted average of the fertilizer prices to the agricultural wage rate increased by nearly 150 per cent between 1969/70 and 1981/82. It started declining after 1982/83; but it was still more than 70 per cent higher in 1986/87 than the 1969/70 level. Despite the large increase in the prices of fertilizers relative to agricultural wage, the use of fertilizer relative to labor increased. The fertilizer-labor intensity rose steeply by 124 per cent between 1969/70 and 1981/82, and a further 45 per cent during the next 5 years. Indeed, it was during the short periods spanning 1971/72 to 1973/74 and 1978/79 to 1980/81 when the price of fertilizer relative to land and labor increased very sharply that there was the most rapid increase in the HYV acreage. Thus, two of the three relative factor prices and factor intensities in Bangladesh agriculture during a period of very rapid technological change had apparently moved in a direction opposite to the prediction of the HR induced innovation theory.

Conclusion

Technological innovation in agriculture in the form of HYV crops was introduced in the agriculture of Bangladesh with the active support of the government (and development agencies). As the cultivation of HYV spread during the seventies and the eighties, the government withdrew subsidies on modern inputs such as chemical fertilizers. Consequently, their prices relative to the prices of other inputs such as land and labor rose markedly. This increase in the relative prices of fertilizers paid by farmers did not reduce their usage; on the contrary, per acre application of fertilizers increased manifold. The fertilizer-labor input ratio also rose substantially. These findings are apparently not supportive of the implications of the HR theory of induced innovation. This paper argues that technological innovations are adopted to maximize profit (surplus); and there need be no unique relationship between technological innovation, relative factor prices and factor intensities. If the innovation is sufficiently biased toward a factor, an increase in the relative price may be accompanied by an increase in the intensity of use of the factor. As Salter had correctly noted, any innovation that reduces cost and raises profit is welcome regardless of the movement of relative factor prices. However, the empirical findings of this research should be viewed with some caution. The theory of induced innovation applies basically to long-term trends; and a shortcoming of this paper is the relatively short duration of the study period. It is possible that some of the long-term trends may not be apparent in the shorter period.

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