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Technical Change and Wheat Productivity in Post-Green Revolution Punjab

D S Sidhu
Derek Byerlee

What have been the major sources of growth in wheat productivity in the post-green revolution period following the widespread adoption of HYVs? To what extent does the slower growth in productivity reflect changing input-output price ratios? How are increased yields and changing practices reflected in changes in costs of production and total factor productivity in wheat? This paper seeks to answer these questions based on an analysis of trends in micro-level data on the Punjab wheat economy.

PUNJAB is one of the most important wheat producing states in India. It covers 14 per cent of national wheat area, accounts for 25 per cent of national wheat production, and provides more than 50 per cent of the wheat procured by the government food distribution scheme. It also has the highest wheat yield in the country, averaging 3.6 t/ha in 1986-88 compared to 2 t/ha for India as a whole.

Punjab was the first state to widely adopt the new wheat technology associated with the green revolution of the late 1960s. By the mid-1970s, the process of adoption of new high-yielding wheat varieties (HYVs) was essentially complete. During this decade (1966-75), wheat production increased at the extraordinarily high rate of 10 per cent annually, with over half this increase contributed by yield gains (Figure 1). In the following decade, the rate of production increase declined to 4.8 per cent per year, with yield gains slowing to 2.7 per cent per year.

To maintain rapid increases in productivity, especially for wheat, is a matter of great concern to researchers and policy-makers alike. The lower rate of increase in wheat yields in recent years raises a number of questions. First, what have been the major sources of growth in wheat productivity in the post-green revolution period after HYVs were widely adopted? Second what are the prospects for continuing to exploit these sources of growth? Third, to what extent does the slower growth in productivity reflect changing input-output price ratios that provide a disincentive for investing in improved technology? Fourth, how are increased yields and changing practices reflected in changes in costs of production and total factor productivity in wheat? And finally, to what extent has increased productivity in wheat been captured by producers or passed on to consumers in the form of lower prices?

Finding answers to these questions was the major motivation for this study, which provides a descriptive analysis of major changes in the Punjab wheat economy since 1971-72, after the widespread adoption of HYVs. The paper is based upon an analysis of trends in micro-level farm data collected under the project—Comprehensive Scheme for the Study of Costs of Cultivation of Principal Crops in the Punjab. This data set enables us not only to trace changes in input use and prices but also to compute an index of total factor productivity that considers changes in output in relation to changes in *all* inputs. This index is superior to the usual approach in India of equating productivity with yield per unit of land area, which does not account for the increasing importance of purchased inputs in substituting for land in wheat production (Figure 2). In addition, the total factor productivity index has been proposed as way of measuring sustainability—an issue of concern in the intensive production systems of the Punjab [Chopra 1990; Byerlee and Siddiq 1990].

Data Sources and Methods

The Study of Costs of Cultivation has run continuously since the 1960s. However, prior to 1972 the sample size was often small or restricted to certain districts. Because of this limitation and our interest in the post-green revolution period, only data since 1971-72 are analysed in this study.[1] In these surveys, enumerators residing in the villages keep daily records of farm operations under the close scrutiny of supervisory staff. The sampling method and approach have varied over the years (see Appendix A), but the surveys have generally included 200 farmers for all the Punjab up to 1985-86, and 300 farmers thereafter. The variation in sampling approach and coverage implies that some caution should be used in interpreting time trends in variables. However, the correlation between surveyed yields and official yield statistics was 0.92. Similarly, in the case of fertiliser the correlation between survey estimates and statistics on fertiliser off-take in the rabi (winter) cycle is also very high ($r = 0.95$).[2]

The survey data provide information on yields, human labour, machine costs, animal labour, fertiliser use, irrigation charges, pesticide use (mainly herbicides), and land rental charges (for full details see Appendix A). Price variables were deflated by the wholesale price index to a 1987 base. Trends in variables were computed through log-linear time trend regressions.

Finally, a total factor productivity index (TFPI) was computed. It is defined as the ratio of the output index to the input index. The input index was constructed as an index of all input quantities valued by their prices in a base year. That is

$$\text{INDEX (Input)} \quad \sum_i p_{i,0} X_{i,t} / \sum_i p_{i,0} X_{i,0}$$

where $p_{i,0}$ is the price of input i in period $t = 0$ and $X_{i,t}$ is the physical quantity of input i used in period t. The output index was estimated simply as the yield in period t divided by the yield in the base period. The TFPI was then calculated as the ratio of the output index to the input index.

As with all methods using index numbers, the results may be sensitive to the choice of base year. In this case we computed the input index using both 1972 and 1987 prices as the base but the differences were very small; hence only the index based on 1987 prices is reported.

Changes in the TFPI are a measure of the effects of technological change. Since purchased inputs, such as fertilisers make up an ever increasing share of the total cost of wheat production, it is superior to the usual method of computing productivity as yield per unit of land.

Normally the TFPI is calculated for all farm enterprises combined, although some authors have argued for more disaggregation by type of enterprise [Huffman 1988]. In our case, we have computed the TFPI for the major crop, wheat, which occupies over 80 per cent of the area sown in the 'rabi' cycle. This may over- or underestimate TFPI for all farm enterprises to the extent that there are differential rates of technical change across the major farm enterprises or changes in TFPI for wheat have negative or positive effects on other crops in the system (through delayed planting of the subsequent crop in the rotation, e g, delayed sowing of wheat due to potato-wheat, paddy-wheat rotations). Also, the TFPI for what will underestimate the TFPI for all enterprises if cropping intensity has increased significantly.

Trends in Inputs and Outputs

Overall trends in inputs and yields are summarised in Table 1. Inputs can be broadly classified as follows:

	Land Saving	Labour Saving
Traditional	Seed quantity Organic manure	Bullocks
Modern	HYV Fertiliser Pesticide	Machine labour (tractorisation)

Pesticides may also be classified as labour saving inputs if their primary role is to substitute for labour without an associated increase in yields (e g, use of herbicides instead of hand weeding).

FIGURE 1: TRENDS IN WHEAT AREA AND YIELD

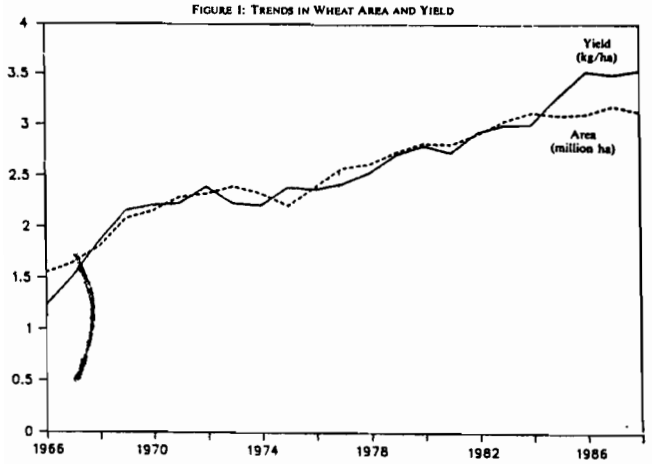
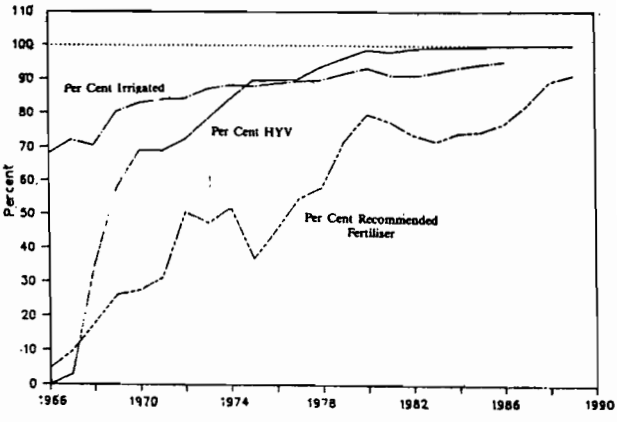


FIGURE 2: TRENDS IN INPUT USE IN WHEAT



It is clear from Table 1 and Figure 2 that modern inputs have substituted for traditional inputs. In the period under analysis, Punjab farmers completed the switch from local varieties to HYVs. In 1972, 73 per cent of farmers used HYVs and by 1976 this percentage had increased to 90 per cent (Figure 2). The transition to HYVs was essentially completed by 1980 although farmers have adopted several newer higher yielding varieties, such as WL711 and HD2309 since the original HYVs were introduced. Also, the wheat area under irrigation increased from 84 per cent in 1972 to over 95 per cent at the end of the period. Finally, by 1987 average fertiliser use reached over 90 per cent of the recommended dosage.

In contrast to the use of HYVs and growth in irrigated area, which had reached almost saturation levels early in the period, fertiliser use continued to increase rapidly, from about 100 kg nut/ha in 1972 to 180 kg nut/ha in 1987—a growth rate of 4.4 per cent per year. The general fertiliser recommendation for wheat in the Punjab is 125-62-30 kg/ha of N-P-K, or a total of 217 kg/ha. Advanced districts, such as Ludhiana, have already exceeded this recommendation, at least for nitrogen. In addition, the marginal productivity of additional fertiliser use has also slowed and was estimated to be 5.6 kg wheat per kilogram of nutrient [Grewal and Rangi 1983]. Hence, growth in fertiliser use and its marginal contribution to yield increases is expected to be substantially lower in the future than during the period under study.

In the 1980s, the use of pesticides, largely herbicides, expanded rapidly. The widespread losses caused by the weed Phalaris minor have been a major impetus for increased herbicide use. In Ludhiana district it is estimated that over two-thirds of the wheat area is now treated with herbicide. Since Phalaris is difficult or impossible to control manually and has caused serious yield losses, it is reasonable to assume that using herbicides to control Phalaris has been a land saving rather than a labour saving innovation.

Of the traditional inputs only seed rate has shown a steady increase from about 80 kg/ha in 1972 to 110 kg/ha in 1987. A marginally higher seed rate (which surpasses the recommended rate of 100 kg/ha) has been observed in other post-green revolution settings [Byerlee and Siddiq 1990; Traxler 1990]. Higher seed rates probably reflect the complementarity between good plant stand and inputs such as fertiliser and water and also provide insurance against poor germination.

In contrast there is evidence that use of organic manure has declined over time (Table 1), a finding that is in accord with other reports [Chopra 1990]. This decline has occurred in part because cropped area has expanded faster than livestock numbers, since bullocks have been replaced by tractors. As the human population has grown, a higher proportion of organic manure may now also be used for fuel. The use of chemical fertilisers has partly substituted for the application of organic manure, by providing nutrients, but the reduction in use of organic manure may have negatively affected soil physical properties such as the rate of water infiltration.

Turning now to the labour saving inputs, it is clear that machinery labour has rapidly substituted for human and animal labour over the period under analysis. The most dramatic change has occurred in animal labour, which declined by about 80 per cent

TABLE 1: TRENDS IN INPUT USE AND WHEAT YIELDS, 1972-87, PUNJAB

	Period				Trend
	1972-75	1976-79	1980-83	1984-87	1972-87
Traditional inputs					
Seed (kg/ha)	81	92	96	106	2.16*
Manure (t/ha)	1.41	1.19	0.74	0.92	-4.11
Modern inputs					
Fertiliser (kg nut/ha)	102	125	164	168	4.36*
Pesticide (Rs 1987/ha)	11	5	35	92	27.61*
Labour and machinery					
Human labour (h/ha)	522	457	393	431	-1.71*
Animal labour (h/ha)	101	76	37	26	-12.24*
Human labour less animal labour (h/ha)	421	381	356	405	-0.30
Machine labour (Rs 1987/ha)	407	484	643	679	4.76*
Wheat yield (100 kg/ha)	25.2	24.0	28	32.3	2.32*

Note: * denotes significance at the 1 per cent probability level.

TABLE 2: TRENDS IN REAL INPUT AND OUTPUT PRICES IN WHEAT PRODUCTION, 1972-87

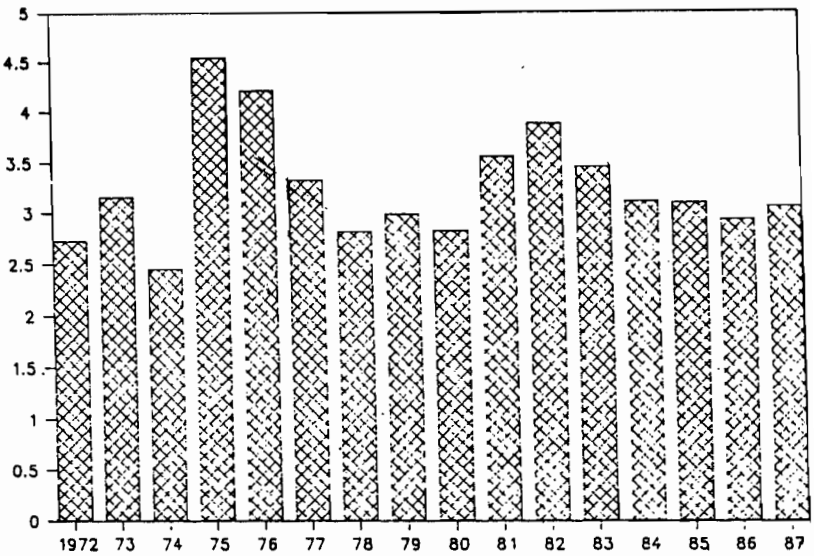
	Period				Trend
	1972-75	1976-79	1980-83	1984-87	1972-87
Traditional inputs					
Seed (Rs/kg)	2.92	2.95	2.54	2.17	-2.46*
Manure (Rs/100 kg)	31.4	27.2	19.4	18.3	-4.89*
Modern inputs					
Fertiliser (Rs/kg)	8.44	7.75	6.65	5.32	-3.48*
Labour and machinery					
Human wage (Rs/h)	2.04	2.21	2.02	1.98	-0.43
Animal wage (Rs/h)	4.99	6.14	5.58	5.84	0.83
Land rental (Rs/ha)	1747	1599	1517	1687	-0.48
Wheat					
Grain (Rs/kg)	2.65	2.32	1.94	1.74	-3.47*
Straw (Rs/kg)	0.22	0.26	0.20	0.24	-0.20

Note: * denotes significance at the 1 per cent level.

over the period after tractors largely replaced the use of bullocks in preparing land, planting, and threshing. The number of tractors in the Punjab increased from only 10,000 in the mid-1960s to 2,30,000 in the late 1980s. In addition, electric and diesel tubewells have completely replaced animal power in pumping water throughout the Punjab.

Although the green revolution was widely associated with an increase in employment, the labour input per hectare has actually fallen by 1.7 per cent annually in the post-green revolution period (Table 1). This decline appears to be largely associated with the decline in animal power. Assuming that one tractor hour is equivalent to eight animal hours in land preparation, the calculated trend in labour use net of animal power is nonsignificant. Human labour is now mainly used for irrigation and harvesting. Irrigation labour is independent of yields and, although labour required for harvesting is expected to have increased with yields, the spread of threshers, and more recently combine harvesters, may have negated this effect.[3]

FIGURE 3: RATIO OF FERTILISER PRICE TO WHEAT PRICE



TRENDS IN INPUT AND OUTPUT PRICES

The real prices of most inputs declined from 1972 to 1987. In the case of fertiliser this partly reflects the high prices prevailing in 1975 and 1976. Excluding these years, however, the ratio of fertiliser prices to wheat prices has been remarkably constant over the period (Figure 3).

Although real wage rates increased significantly in the Punjab during the green revolution period of the late 1960s [Jose 1988], this trend has been reversed since then. However, the decline in real wages (Table 2) is small and not statistically significant. Stagnating real wages are consistent with the fall in labour input per hectare as a result of mechanisation, coupled with net immigration from other states to rural Punjab.

Likewise the real cost of animal power has not changed over the period. However, the price of machinery services has fallen and together with increased cropping intensity has provided the impetus to substitute machinery services for animal power.

Finally, the lack of a significant trend in land rental values is interesting (Table 2). It is often assumed that the surplus generated by technical change will be capitalised in increased prices for production factors whose supply is inelastic, especially land. But in the case of the Indian Punjab there is no evidence of this effect [Kahlon and Kurien 1984]. However, real land rental values do seem to have increased significantly in the Punjab of Pakistan [Renkow 1990].

Against these changes in input prices, real wheat prices have fallen consistently every year except 1974, at an average rate of 3.5 per cent annually. A declining real output price is consistent with rapid technical change in a closed economy and suggests that the benefits of technical change have been captured more by consumers than producers, a theme which is explored more fully below.

Note, however, that there has been no trend in the real price of straw (Table 2), so that the grain-to-straw price ratio has decreased over time. In contrast, in the Punjab of Pakistan real straw prices declined over this period as straw production increased faster than animal numbers [Byerlee and Iqbal 1987].

TABLE 3: TRENDS IN COST STRUCTURE FOR WHEAT, 1972-87

	Period			
	1972-75	1976-79	1980-83	1984-87
Per cent of total costs due to				
Seed and manure	5.0	5.3	4.8	4.5
Fertiliser and pesticides	15.2	16.6	21.1	18.0
Human labour	19.1	17.5	14.9	15.6
Animal labour	9.1	8.0	3.9	2.7
Machine labour[a]	12.6	17.8	22.2	22.8
Irrigation charges	5.9	5.0	2.7	3.8
Land rent	31.2	27.7	28.4	30.7
Total	100	100	100	100
Per cent cash costs	50.1	55.0	62.9	61.2
Per cent non-cash costs[b]	49.9	45.0	37.1	38.8
	100	100	100	100

a Includes depreciation and interest.
b Includes seed, manure, family labour, animal labour, own machines, and own land.

TRENDS IN COST STRUCTURE

Given the input use and price trends noted earlier, one would expect to see significant shifts in the cost structure for wheat production. In particular, the share of animal labour in the total cost of wheat production decreased sharply in the period 1972-87 from 9.1 per cent to 2.7 per cent and the share of labour decreased from 19.1 per cent to 15.6 per cent while the share of machinery labour increased from 12.6 per cent to 22.6 per cent (Table 3). Likewise the share of chemical inputs also increased over the period.

The substitution of chemical inputs and machinery for labour and land also increased the share of cash costs in total production costs from 50 per cent in 1972-75 to 61 per cent in 1984-87. Cash costs rose most rapidly in the 1970s with the rapid adoption of machinery services and increased fertiliser inputs. Even for the traditional inputs of land and labour there has been a tendency towards increased cash expenditures, with hired labour increasing its share relative to family labour and a tendency for a higher share of land to be rented. Hired labour accounted for 50 per cent of total labour in 1971-72 and 59 per cent in 1986-87. The leased-in land on rental basis was 11 per cent in 1971-72 and increased to 19 per cent in 1986-87.

COSTS, PRICES AND MARGINS

As expected with rapid technical change, the cost of production in real terms decreased steadily at a rate of 2.9 per cent annually (Tables 4 and 5, Figure 4 and Appendix B). (The cost of production used here is what is known as 'measure C', which is calculated with all costs, including the imputed value of family labour and land.) Although some have questioned whether the cost of wheat production has indeed declined [Kahlon 1984], more recent data suggest the decline

FIGURE 4: PROCUREMENT PRICE AND COST OF PRODUCTION FOR WHEAT PRODUCTION

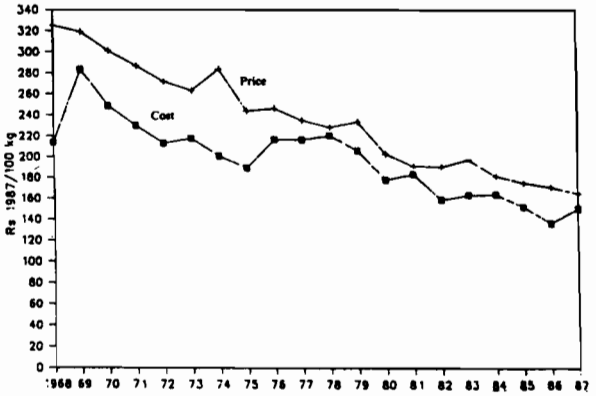
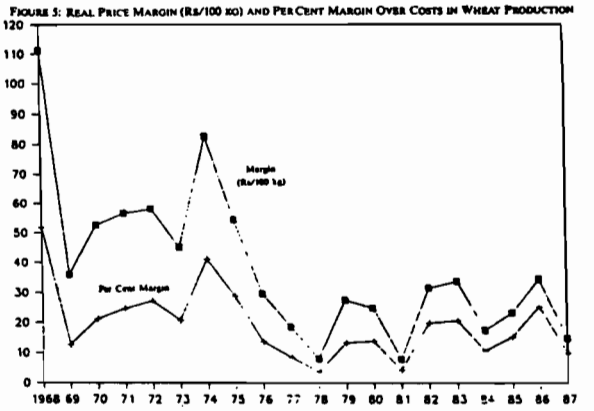


FIGURE 5: REAL PRICE MARGIN (RS/100 KG) AND PER CENT MARGIN OVER COSTS IN WHEAT PRODUCTION



observed here is consistent with observations for wheat in other states of India but not generally for other crops [Mruthyunjaya and Kumar 1989]. Nonetheless, a declining real cost of production of 2.9 per cent annually against a decrease in real wheat prices of 3.6 per cent annually implies some squeezing of the profit margin to farmers. Hence the real margin per 100 kg of wheat produced (in 1987 rupees) has fallen from Rs 60/100 kg in 1972-75 to only Rs 22/100 kg in 1984-87 (Table 4). Despite a significant increase in yield, the real margin/hectare has also fallen by half over this period.[4] Likewise, the percentage margin of the sales price of wheat over the production cost fell from 36 per cent in 1968-71 to less than 20 per cent for the recent decade, 1976-87 (Figure 5).

These changes are consistent with the hypothesis that farmers initially gained most of the benefits of using the new wheat technology, especially between 1968-1975. However, since 1975 government policy appears to have favoured consumers, with the procurement price being set to exploit the downward trend in production costs brought about by technical change. The lack of increase in land rental values also supports the conclusion that over the long run farmers have not been able to capture the benefits of technical change.

Another observation that can be made from the data is that although producer prices have been quite stable (with an average coefficient of variation around trend of 3.8 per cent) and average yields have also shown low variability (CV=9 per cent), the returns to wheat production have shown a high variability of 55 per cent around trend (Table 5).[5] Much of this variability occurred during the early 1970s when fertiliser, fuel and grain prices were particularly volatile. Since 1976 the CV of net returns in wheat production has still averaged a high 44 per cent. Hence, stabilisation of producer prices does not appear to have been very effective in reducing variability in farmers' incomes.

FACTOR PRODUCTIVITY

Figure 6 and Table 6 provide partial productivity measures—that is, wheat production per unit of a given input. During the green revolution period the use of the new seed-fertiliser technology tended to increase land productivity—that is, it was a labour intensive, land saving technology [Hayami and Ruttan 1985; Sidhu 1974]. In the more recent period under study, land productivity has continued to increase at a slower rate of 2.3 per cent per year but the largest gain has been in labour productivity which has increased by 4 per cent per year, reflecting the dramatic increase in mechanisation. At the same time productivity per unit of fertiliser applied has tended to decline as the marginal returns to additional fertiliser use have fallen.[Grewal and Rangi 1983].

The estimated total factor productivity index (TFPI) is also given in Table 6 and Figure 7. The interesting result of these calculations is that the input index has hardly changed over the period and shows no significant trend. The increase in chemical and machinery inputs has been more than cancelled by a decline in labour and animal power inputs.

Because the input index has changed little, the total factor productivity index is highly correlated with yield. Overall the TFPI has risen by 1.7 per cent per year which is consistent with long-term changes in total factor productivity of 1-2 per cent annually in the US [Ball 1985; Huffman 1988] and overall estimates for India [Evenson and McKinsey nd] and for Pakistan [Wizarat 1981].

Nonetheless, about half of the increase in productivity has been due to increased labour productivity as a result of mechanisation. This can be seen by assuming that mechanisation has not led to any increase in yields, an assumption consistent with the evidence from Agarwal (1984) and Binswanger (1978) and by recalculating the TFPI using constant animal and machinery inputs of 1972. The result is a much slower increase in productivity of 1 per cent per year. It is sobering that practically all this increase occurred during the latter part of the period 1983-87. That is, the land augmenting components of technical change—new varieties, increased fertiliser use and adoption of pesticides—have had relatively little impact of TFP for much of the period. It is still too early to determine the factors which have reversed stagnating productivity in recent years without a dramatic change in input use or new HYVs, but this reversal may relate to an increase in input efficiency as farmers have learned how to manage the new technology better [Byerlee 1987].

TABLE 5: TRENDS IN PROCUREMENT PRICE, COST OF PRODUCTION AND MARGINS IN WHEAT PRODUCTION, 1972-87

Trend in Real Price/Cost	Per Cent/ Year	Coefficient of Variation
Total cost/100 kg	−2.93*	7
Procurement price	−3.58*	5
Profit margin/100 kg	−6.64**	55
Profit margin/ha	−4.32	43
Percentage margin	−3.72	56

Notes: **, * denote significance at the 5 per cent and 1 per cent levels, respectively.

TABLE 4: COSTS AND RETURNS IN WHEAT CULTIVATION, 1968-87

	Period				
	1968-71	1972-75	1976-79	1980-83	1984-87
1 Gross income (Rs/ha)	2073	2586	2955	4207	5859
2 Total cast (Rs/ha)	1518	2034	2672	3696	5055
3 Profit margin (Rs/ha)	555	552	283	511	834
4 Per cent profit margin[a]	38	28	10	15	15
5 Cost/100 kg (Rs/100 kg)	60	72	103	118	138
6 Procurement price (Rs/100 kg)	76	94	113	135	159
7 Profit margin (Rs/100 kg)	16	22	10	17	21
8 Real margin/100 kg (Rs/100 kg)	61	60	21	24	22
9 Real margin/ha (Rs/100 kg)[b]	1724	1522	509	714	739

Notes : a Per cent profit margin over cost.
b Constant 1987 Rs.
Source: Sidhu (1979).

FIGURE 6: PARTIAL PRODUCTIVITY MEASURES FOR LAND, LABOUR, AND FERTILISER

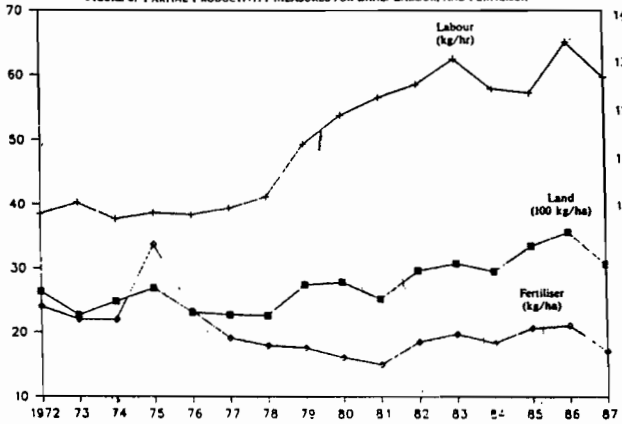
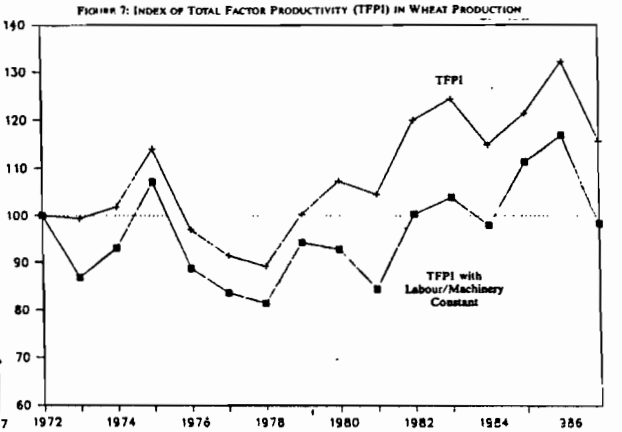


FIGURE 7: INDEX OF TOTAL FACTOR PRODUCTIVITY (TFPI) IN WHEAT PRODUCTION



CONCLUSION

This review of technical change and wheat productivity in the 1970s and 1980s reveals a number of interesting trends. First, the green revolution has been consolidated through further intensification in the use of modern land-saving inputs, especially fertiliser and herbicides. Use of those inputs continued to increase strongly even after the full adoption of high yielding varieties. However, the use of labour saving technologies, especially tractors, has expanded even more rapidly in this period. Labour saving technologies have reversed the trend toward higher labour inputs in wheat production that was observed when the new wheat technology was first introduced.

No major changes in relative input prices were observed over the period. However, the trend toward high real wages that characterised the green revolution period is no longer evident. The reduced labour input in wheat production may be one reason for this change.

A striking trend is the consistent fall in the real price of wheat received by producers. Although the falling cost of production induced by technical change has partly compensated for the decline in real wheat prices the real margin to wheat producers has also fallen sharply. There is evidence that during the green revolution period farmers were the beneficiaries of much of the surplus generated by increased wheat productivity, but in the 1970s and 1980s wheat consumers have received the bulk of the benefits.

The calculated changes in total factor productivity support these findings. The most important source of productivity increases has been labour saving technology. The use of biochemical technologies has only modestly increased total productivity and that occurred mostly in the latter part of the study period, although it is too early to conclusively identify the specific source of this productivity gain.[6] We have not analysed changes in the resource base (except for an observed decrease in use of organic manures), but there seems little reason at this stage to be concerned about the sustainability of productivity levels that have been achieved in wheat production. However, given the high level of inputs used and the narrowing gap between the highest and lowest wheat yields obtained by farmers [Singh et al, 1987] and between farmers yields and yields on the research station, future sources of yield gains are not readily evident, at least at the rate observed in the recent past. Undoubtedly further productivity gains in wheat production will have to be achieved by more efficient use of inputs such as fertiliser and water.

Appendix A

SAMPLING METHOD

To analyse wheat productivity, farm-level production data from 1971-72 to 1986-87 for 300 randomly selected farmers[7] were collected from the project. The data were collected through the cost accounting method; full-time field investigators residing in the villages kept daily records of farm operations.

TABLE 6: TRENDS IN INDICES OF PARTIAL PRODUCTIVITY AND TOTAL FACTOR PRODUCTIVITY

	Period				Trend
	1972-75	1976-79	1980-83	1984-87	1972-87
Partial productivity					
Land (100 kg/h)	25	24	28	32	2.32***
Labour (kg/ha)	39	42	58	60	4.03***
Fertiliser (kg/kg nut)	25	20	17	19	-2.03**
Total factor productivity (TFPI)					
Input index	92	96	93	100	0.57**
Output index	95	91	107	122	2.32***
TFP index	104	95	115	122	1.75***
Adjusted TFPI	102	89	102	110	1.05*

Notes: *, **, *** denote significance at the 10 per cent, 5 per cent and 1 per cent level, respectively.

Prior to 1985 the sample was selected by three-stage stratified random sampling with a tehsil (sub-district) as the primary sampling unit, a cluster of three villages as the second stage unit and an operational holding within the cluster as the third stage. From 1985 the state of Punjab was demarcated into three homogeneous zones based on cropping pattern, irrigation facilities, rainfall, and soil type. The first zone is the rice-wheat area, located in the northern part of the state. It includes 22 tehsils and covers 41.8 per cent of Punjab's cultivated area. The second zone is the maize-wheat area, which comprises the central part of the state and includes 13 tehsils and covers 27.6 per cent of the cultivated area. The third zone is the cotton-wheat area, located in the south-western part of the state. It includes 10 tehsils and covers 30.5 per cent of cultivated area.

Thirty tehsils were selected from these three zones on the basis of the area planted to four crops (one of which was wheat). One village from each of those tehsils was selected with probability proportional to area under the four study crops. Then a cluster of three villages was formed by selecting one contiguous village to the south and one to the west of the nucleus village. All operational holdings of the villages in each cluster were enumerated and classified into five farm size classes. From each size class two cultivators were selected randomly to create a sample of 10 cultivators from each cluster and a total sample of 300 holdings for this study.

Prior to 1985-86 a rotational sample of 200 holdings was randomly selected throughout the state. During 1971-72 wheat was the principal crop under study. Only a sub-sample of wheat producers was used in the 1972-73 and 1973-74 surveys. However, data on wheat continued to be collected from cotton and sugarcane farmers to form 200 observations each year.

VARIABLES FOR WHICH DATA WERE COLLECTED

Wheat Yield: The total production of wheat in the sample was divided by area under wheat to give the yield per hectare.

Human Labour: This input was measured

in adult units of hours spent in wheat production operations. A full account of day-to-day field operations done by family or casual and permanent hired labour was kept for each farm. Casual and permanent hired labour were valued at the actual wages paid and the value of family labour was imputed at the rates paid to permanent labourers.

Bullock Labour: Bullock labour was also measured in hours of work in each operation in wheat production. Bullock labour was valued at the market rate.

Machine Labour: Since different types of machines with different horse power were used, machine labour was recorded in value units to obtain a uniform unit of measurement over time. Machine inputs were estimated by deflating the value of machine expenditures by the wholesale price index for tractors.

Fertiliser: The quantities of fertilisers in nutrient form were totalled to form one variable. Potassium accounted for only a small proportion of the total.

Irrigation: Irrigation was provided by tubewells and canals. To put this variable on a measurable basis, it was decided to specify it in value terms. For farmers irrigating their crop with tubewells, the variable costs and the fixed cost of irrigation equipment in terms of depreciation and interest were taken into account. The expenditure on irrigation was apportioned according to the number of hours spent irrigating each crop. For canal-irrigated farms the water charges for wheat were taken. However, tubewells run by electricity were the main source of irrigation and farmers were charged a flat rate that does not reflect true irrigation costs.

Pesticides: Farmers used several chemicals on wheat but herbicides predominated. The value of each chemical applied by the farmer was summed to arrive at the total expenditure on chemicals. Changes in input use were estimated by deflating by the price index for agricultural chemicals.

Land: Owned land was valued through imputing land rent on the basis of leased-in land. Land rent was, however, subjected to a maximum limit of one-third of the total value of the main crop and by-products. Thus a rent known as 'fair rent' was entered in the records rather than the true market rent. However, in most cases the difference between the two rent figures is believed to be small.

Appendix B

COST OF PRODUCTION, PROCUREMENT PRICE, AND PROFIT MARGIN FOR WHEAT, 1968-87

Total Cost (Rs/100 kg)	Procurement Price (Rs/100 kg)	Profit Margin (Rs/100 kg)	Per Cent Margin	Real Cost[a] (Rs/100 kg)	Real Margin[a] (Rs/100 kg)
50.0	76	26.0	51.9	214.1	111.2
67.5	76	8.5	12.7	283.3	35.9
62.7	76	13.3	21.2	248.2	52.7
61.0	76	15.0	24.7	229.9	56.7
59.7	76	16.3	27.3	213.2	58.2
67.1	81	13.9	20.7	217.8	45.1
74.3	105	30.7	41.2	200.7	82.8
87.8	113	25.2	28.8	189.2	54.4
99.5	113	13.5	13.6	216.8	29.5
101.4	110	8.6	8.5	216.5	18.4
108.6	113	3.9	3.6	220.4	8.0
101.5	115	13.5	13.4	205.9	27.5
102.8	117	14.2	13.9	178.1	24.7
124.7	130	5.3	4.3	183.5	7.8
118.5	142	23.5	19.8	158.9	31.5
125.2	151	25.8	20.6	163.5	33.7
137.5	152	14.5	10.6	164.1	17.3
136.3	157	20.7	15.2	151.9	23.0
129.3	162	32.7	25.3	136.3	34.5
150.4	165	14.6	9.7	150.4	14.6

Note: a Deflated by wholesale price index to 1987 Rs.

Notes

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1 For an analysis of earlier years, see Sidhu (1979).

2 The differences between survey yields and official statistics were most pronounced in the 1970s. In the period 1972-75, survey yields were 9 per cent above official yields and in 1976-78 there were 7 per cent under. Since 1978 this difference has not exceeded 2 per cent. This variation undoubtedly reflects the varying sampling methods used in the 1970s in the cost of production surveys; sampling was standardised in the last decade.

3 The additional area under wheat in period 1972-90 has been about 8,00,000 ha which is 25 per cent of the total area under wheat (3.2 millions ha); harvest combines had a capacity of harvesting about 10 per cent of total wheat area in 1989-90.

4 See also Singh et al 1987 and George et al 1983.

5 The CVs here are calculated around the linear time trend.

6 Also, the analysis has not taken into account the effect of marginal lands coming under wheat and the effect of delayed sowing of wheat due to new rotations that were followed over time. As such it is a partial analysis of wheat productivity and not of the farming system as a whole.

7 The number of farmer respondents was 200 from 1971-72 to 1980-81. After each three-year-period, the sample was completely changed. Since 1980-81 the number of farmer respondents has increased to 300 and the sample continued to be changed after three years.

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