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GREEN REVOLUTION AND FARM INCOME DISTRIBUTION

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The problems that have attended the productive success of the Green Revolution have, however, yet to be surmounted. Among these, one of the most serious for economic and political stability is the unequal distribution of the gains from change and the perverse distribution of the burdens of change among those who gain least from it.

This paper examines the problem of inequitable distribution by a theoretical analysis. It centres on the distribution of income, as revealed in the changes in production-functions and derived supply-functions for farms and for the sector as a whole. The impact is discussed as it relates to (1) changes in factor shares and (2) changes in the relative income positions of farms in the different income classes. A quasi-empirical demonstration is included to assist in the exposition of the logic.

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Green Revolution and Farm Income Distribution

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The hope had been cherished that the rapid increases in agricultural output especially foodgrains, as a result of the Green Revolution, would help trigger off general economic growth by raising the level of available savings. There was also good reason for such a hope. But crucial to its realisation is the capacity of government policy to use the Green Revolution's potential benefits to greatest advantage.

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THE Green Revolution has raised the hope in India and other Asian countries that, finally, rapid increases in agricultural output [22], especially foodgrains, will make it possible for more general economic development to proceed. There is hope that domestic production will eliminate the countries' dependence on United States for food aid, that surpluses might exist which could be sold abroad as a means of financing needed imports of strategic capital and maintenance goods, and that if the spectre of the Malthusian dilemma can be held in check long enough surpluses would exist to finance domestic non-agricultural growth simultaneously with a rise in rural per-capita living standards.

Early signs show that these hopes are not groundless [8, 9] if government policy is appropriate to reap the potential benefits. It is true that, both farm-sector employment and farm-sector income have risen [15, 16, 17]. But economists realise that boons generally are not given free, and this has become obvious in the second and third generation problems that the Green Revolution has created [11, 24, 25].

Of these, one of the most serious from the standpoint of stability—economic and political—is the high probability that, in spite of measurable benefits for the agricultural sector and the country's economies as a whole, the Green Revolution does not hold benefits for all the farm families which make up the sector. Thus, the Green Revolution poses the same problem for Asian countries, and India in particular today, as have all major technological changes in the history of agriculture. That is, it will create an unequal distribution of the gains from change, as well as an unequal and perverse distribution of the burdens of change among those who gain least from it.

This paper examines the problem of inequitable distributions by a theoretical analysis. The paper centres on the distribution of income, as revealed in the changes in production functions and derived supply functions for farms and for the sector as a whole. The effect of the Green Revolution is traced through these tools, and its impact is discussed as it relates to (1) changes in factor shares and (2) changes in the relative income positions of farms in the different income classes. A quasi-empirical demonstration is included to assist in the exposition of the logic.

Nature of the Green Revolution

Technological innovations in agriculture can be divided into two broad types: (1) biological and (2) mechanical. Biological innovations refer mainly to inputs that increase the productivity of a given land base. High-yielding plant varieties and fertiliser are examples. Biological innovations tend to raise total farm costs. Mechanical innovations mainly are those that cause a reduction in total cost. While biological innovations are labour-absorbing, mechanical innovations are mainly labour-saving [13].

The Green Revolution is frequently described as a seed-fertiliser technology [21]. In this sense, it falls in the class of biological innovations. But when classified so simply, its basic technological nature is obscured. Biological innovations of the seed-fertiliser type became more effective, and in some instances were possible, only with the support of mechanical innovation. Hence, the Green Revolution is better characterised as a biological-mechanical innovation. Whether the green revolution is labour-saving or capital-saving depends on the net effect of the forces simultaneously generated by the two different types of innovations. Similarly, whether total costs of production are increased or decreased depends on whether the cost increases due to biological innovation are greater or less than the cost decreases due to mechanical innovations. Based on data presented in Tables 1 and 2, Figure 1 can be used to illustrate this proposition. Figure 1 shows total cost, total revenue, and total output, with old and new techniques for agriculture taken as a single industry. The curve TR represents total revenue, C_1 represents the cost before the innovation and C_2 represents the cost after the innovation. Per-unit costs are lower with C_2 than with C_1, as shown by the lesser slope of OC with respect to OA. We assume that the normative profit maximisation motive prevails, hence the equilibrium for the industry, total cost, total revenue, and total output are U_1A, U_1B and OU_1, respectively, before the innovation. Total revenue increases as might total cost, at equilibrium under the new technique (C_2), but net profit (CD) is much larger than profit under

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Table 1: Selected Indicators of Indian Agriculture

Years	Production Index Numbers (1961-62=100)			Yield Index Numbers (1961-62=100)			Area under Crops Index Numbers (1961-62=100)			Prices Index Numbers (1961-62=100)		
	Total Cereal	Wheat	Rice	Total Cereal	Wheat	Rice	Total Cereal	Wheat	Rice	Total Cereal	Wheat	Rice
1961-62	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1962-63	96.7	89.3	93.1	88.0	98.3	90.6	100.6	96.5	102.8	102.9	98.4	105.3
1963-64	99.4	81.6	103.7	81.0	104.1	100.5	100.2	99.5	103.2	112.0	105.7	118.5
1964-65	108.4	101.5	110.2	101.7	108.7	104.8	101.3	98.9	105.1	135.2	137.8	127.3
1965-66	87.7	86.3	85.9	92.7	89.1	84.5	97.9	93.2	101.7	206.4	149.2	136.7
1966-67	82.8	94.4	85.3	97.2	91.9	83.9	100.1	94.6	101.6	173.7	177.7	168.6
1967-68	116.9	137.0	105.5	120.9	106.8	100.4	106.2	110.5	105.0	206.4	213.7	200.5
1968-69	117.8	154.5	111.5	124.8	106.1	104.7	106.6	117.6	106.5	195.3	204.3	196.4

Sources: [18, 19].

the old technique (AB). Thus, the agricultural sector increases its output and improves its income because of the new technology. The distribution of this gain among the various factors and among farms of various sizes, is the subject of the next sections.

Changes in Relative Factor Shares

With the greater use and cost of inputs, the absolute income of all production factors increases. The change in factor shares, however, depends on (1) whether the technical change is neutral or non-neutral, (2) whether the sum of production elasticities varies under technical changes, and (3) whether the labour/capital ratio varies. To analyse these possibilities, we distinguish between five classes of inputs: (a) land, (b) human labour, (c) bullock labour, (d) capital inputs including irrigation charges and all farm machinery (C_1) and (e) such non-mechanical inputs as new biological inputs (hybrid seeds) fertilisers, pesticides, new cultivation techniques (C_2). With the Green Revolution, C_2 has been the major expanding factor, complemented by a more modest increase in C_1. Comparing the gross production function for agriculture, before and after a growth in C_2 and C_1, we expect that, when $\Delta C_1 > 0$ and $\Delta C_2 > 0$, output increases, and the partial elasticities of production of all factors change. We illustrate this point in the framework of the following Cobb-Douglas production function (which satisfies neoclassical notions of a 'well-behaved function').

$$X = A L^{\alpha} B_1^{\beta} B_2^{\gamma} C_1^{\delta} C_2^{\rho}$$

Where A, α, β, γ, δ and ρ are constants, X = output, L = land, B_1 = human labour B_2 = bullock labour, C_1 = mechanical capital inputs, and C_2 = non-mechanical inputs. The constants α, β, γ, δ and ρ, numerically quantify the partial elasticities of production. The ratios of the partial elasticities indicate the relative factor shares between inputs, and, as Brown shows [6, 7] for the Cobb-Douglas production function, the elasticity of substitution between the factors is unity, regardless of scale-returns. This condition implies that, changes in factor ratios (substitution between factors) leaves relative factor shares unchanged. Factor shares change only when the addition of a new input (replacing or complementing existing input) embodies a technical change.

In essence, the embodiment quality implies that the technological change is non-neutral. Let the growth in C_2 and C_1 embody a technical change (the Green Revolution). A new production function then results (the technical change revealing itself in changed parameters) as follows:

$$X' = A' L^{\alpha'} B_1^{\beta'} B_2^{\gamma'} C_1^{\delta'} C_2^{\rho'}$$

Empirical studies suggest that, an expansion in C_2 is labour-using and that an expansion in C_1 is labour-saving [2, 3, 4, 5]: hence countervailing forces prevail. The net impact of the embodied technical change will depend,

Figure 1: Change in Net Revenue, (TC — TR), with Technological Change:

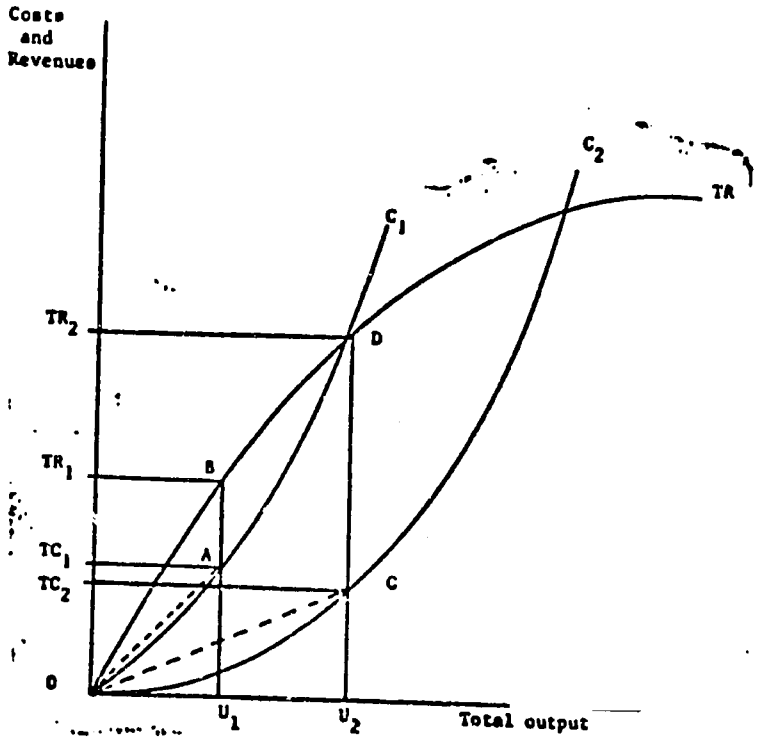

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TABLE 2: CHANGES IN TOTAL COST AND TOTAL REVENUES IN WHEAT PRODUCTION OF MAJOR PRODUCING STATES IN INDIA

States	Total Cost I / Total Cost II	Total Revenue I / Total Revenue II
Uttar Pradesh	1.73	2.49
Punjab	2.93	5.79
Maharashtra	−0.66	4.54
Rajasthan	1.98	8.51

Notes: Cost I stands for the cost of production of hybrid wheat with new array of inputs made available by new technology.

Cost II stands for the cost of production of indigenous wheat with irrigation and old array of inputs.

Total Revenue I and II stands for the same as the costs respectively.

Source: [15, 16, 17, 18, 20].

therefore, on the outcome of a statistical experiment. However, a theoretical explanation of expected outcomes can be given. For example, if C_1 is a labour-saving input, [2, 3, 4, 5], we expect that $\frac{\beta'}{\delta'} < \frac{\beta}{\delta}$, and that labour's share with respect to C_1 declines. Further, if C_2 complements labour, we expect that

$$\frac{\beta}{\rho} \lessgtr \frac{\beta'}{\rho'}.$$

If the net effect of the Green Revolution is, in fact, to reduce labour's share in total, the net change has to be as follows:

$$\left[\frac{\beta}{\delta} + \frac{\beta}{\rho}\right] > \left[\frac{\beta'}{\delta'} + \frac{\beta'}{\rho'}\right]$$

INCOME DISTRIBUTION EFFECTS BY FARM SIZE

A non-neutral technical change may be sufficient to change the distribution of income over factors, but it is only a necessary condition for a change in the distribution of income by farm size. On the other hand, embodied technological change and differences in adoption rates among the different farm size groups, are sufficiency conditions for a change in the distribution of income by farm size.

For this analysis, we depart from the usual macro-economic definitions and distinguish between embodied and disembodied technological change for a specific farm firm. Technical change is disembodied when the farmer is constrained from using it only by his personal and non-economic characteristics, or through his ignorance. In contrast, an embodied technical change is one that cannot be adopted by a farmer because of economic constraints. The farmer's current income and asset position is the most likely economic constraint, since 'embodiment' implies purchase of inputs to employ the technology. The economic status of the farm is binding because the farmer cannot finance[3] new purchases and/or the basic production structure cannot profitably incorporate the new input.

Because of past decisions, a predetermined distribution of wealth, and so on, a wide disparity prevails in farm income levels. Thus farmers face a technological change, such as the Green Revolution, on unequal footing. Farmers in different income groups might be expected to exhibit diversity in behaviour, since: (a) the marginal propensity to consume could decline at higher incomes, (b) the marginal propensity to invest in new productive inputs might rise with higher incomes, and (c) the items for which the investments are made could differ among income classes, and so on.

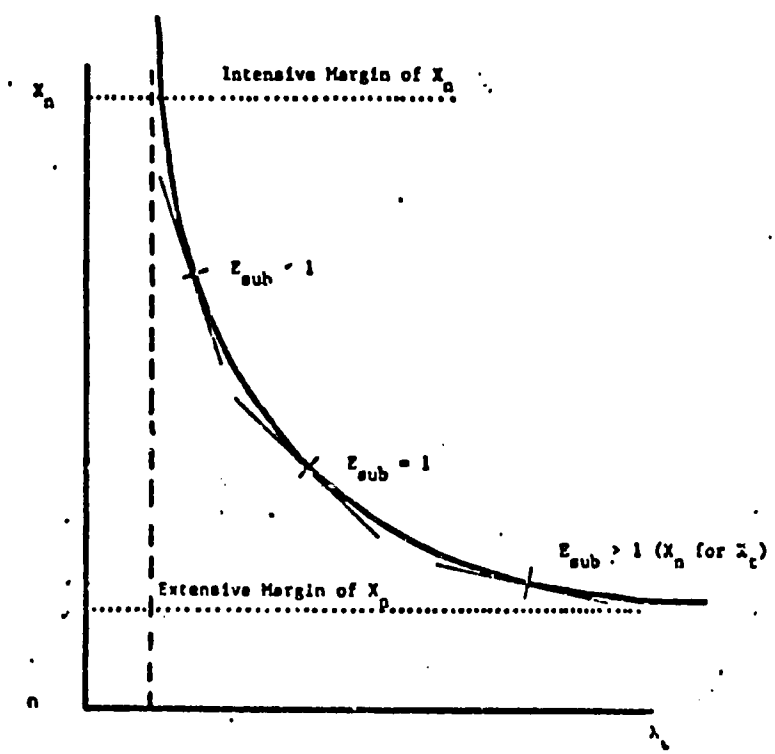
Basic economic grounds to explain variance in adoption rates of Green Revolution technology are thus implied by the fact of embodiment, the initial diversity of incomes in the farm community, and variance of absolute and marginal spending behaviour at different income levels. Further, as we will now demonstrate, variance in adoption rates ensures that the initial income spread in the farm sector will widen.

First, we assume the absence of government programmes to make credit available at non-commercial rates for low-income farmers. The allocation of loans, then, will be based on risk-aversion and potential profit motives of lenders. If government credit programmes require collateral or a demonstration of near-term profitability before loans are made, the programme is commercially based. As will be discussed later, credit programmes of non-commercial nature are necessary to reduce the extent to which technical change is embodied for the firm. We now use a generalised algebraic example to prove that the income gap will widen under these postulates and assumptions. An illustrative numerical example will follow.

Increase in output vis-a-vis farm size groups:

Let P_y, P_x, Y, and X be the output price, the input price, the level of output, and the level of inputs used, respectively, expressed in index form. Let R be the ratio of output to input prices, P_y/P_x, so that R portrays the real

FIGURE 2: ISOQUANT, SHOWING RELATIVE MAGNITUDES OF THE ELASTICITY OF SUBSTITUTION (E_{sub}) X_n FOR X_t.



profitability of production; R is a proxy for net revenue. R is also in index form.

The elasticity of supply with respect to the profitability of production can be written in the following identity:

$$\frac{dY}{dR} \cdot \frac{R}{Y} = \left[\frac{dY}{dX} \cdot \frac{X}{Y}\right] \times \left[\frac{dX}{dR} \cdot \frac{R}{X}\right]$$

In this expression, $\left[\frac{dY}{dX} \cdot \frac{X}{Y}\right]$ is the elasticity of production, and $\left[\frac{dX}{dR} \cdot \frac{R}{X}\right]$ is the elasticity of demand for inputs with respect to the profitability of using them. When a production function for a specific farm is derived, the elasticity of production will be uniquely determined as will the elasticity of demand for inputs. The elasticity of demand for inputs, as given here, incorporates both the income effect and the price effects with qualitative signs as recognised in consumer behaviour. A change in productivity of inputs can be reflected in the decline in real price per unit of input.

Now we subdivide total inputs (X) into two classes, traditional, X_t, and new, X_n. The profitability of employing these classes of inputs are R_t and R_n, respectively. Therefore, $X = X_t + X_n$, $R = P_y / E(P_{x_t} + P_{x_n})$, (where the denominator is the average cost of inputs) and $R_t = P_y/P_{x_t}$, $R_n = P_y/P_{x_n}$.

The elasticity of supply can be given as:

$$\frac{\partial Y}{\partial R} \cdot \frac{R}{Y} = \left\{\frac{\partial Y_t}{\partial X_t} \cdot \frac{X_t}{Y} + \frac{\partial Y}{\partial X_n} \cdot \frac{X_n}{Y}\right\} \cdot \left\{\frac{\partial X}{\partial R_t} \cdot \frac{R_t}{X} + \frac{\partial X}{\partial R_n} \cdot \frac{R_n}{X}\right\}$$

which is reduced to the following expression after dividing by R/Y.

$$\frac{\partial Y}{\partial R} = \left\{\frac{\partial Y}{\partial X_t} \cdot \frac{X_t}{X} + \frac{\partial Y}{\partial X_n} \cdot \frac{X_n}{X}\right\} \cdot \left\{\frac{\partial X}{\partial R_t} \cdot \frac{R_t}{R} + \frac{\partial X}{\partial R_n} \cdot \frac{R_n}{R}\right\}$$

To take an extreme case where the small farmer (a low-income farmer) does not purchase the new inputs,

$X_n = 0$; hence $\frac{\partial X_n}{\partial R_n} = 0$, $\frac{\partial X_t}{\partial R_n} = 0$, and $\frac{\partial X_n}{\partial R_t} = 0$. His change in supply is then given by:

$$\frac{\partial Y}{\partial R} = \left(\frac{\partial Y}{\partial X_t} \cdot \frac{X_t}{X}\right) \cdot \left(\frac{\partial X_t}{\partial R_t} \cdot \frac{R_t}{R}\right) = \frac{\partial Y}{\partial X_t} \cdot \frac{\partial X_t}{\partial R_t} \quad (X_t = X, R = R_t)$$

If, in addition, productivity of traditional input is not affected by the Green Revolution (another extreme assumption since it excludes in-farm economies of scale, but is totally consistent with the embodiment postulate),[3] and input and output prices do not vary significantly, the profitability of traditional inputs remains constant and thus $\frac{\partial X_t}{\partial R_t} = 0$. Hence the small farmer's level of production, before and after the technological change, should be the same.

By contrast, the larger farmer (a high-income farmer) is not financially constrained from buying the new inputs if their purchase is profitable. If he uses them, the following relations hold in general:

$$1 > \frac{X_t}{X} > 0 \qquad \frac{\partial X_n}{\partial R_n} > 0$$

$$1 > \frac{X_n}{X} > 0 \qquad \frac{\partial X_t}{\partial R_t} > 0$$

The new inputs can be either complements, or substitutes, for traditional inputs. In the situation where the farmer views the new inputs as strict supplements to traditional inputs (i.e, cross-effects with respect to the profitability of other inputs is zero), the expression for his addition to gross output will be:

$$\frac{\partial Y}{\partial R} = \left\{\frac{X_t}{X} \cdot \frac{\partial Y}{\partial X_t} \cdot \frac{\partial X_t}{\partial R_t} \cdot \frac{R_t}{R}\right\} + \left\{\frac{X_n}{X} \cdot \frac{\partial Y}{\partial X_n} \cdot \frac{\partial X_n}{\partial R_n} \cdot \frac{R_n}{R}\right\} + \left\{\frac{X_t}{X} \cdot \frac{\partial Y}{\partial X_t} \cdot \frac{\partial X_n}{\partial R_n} \cdot \frac{R_n}{R}\right\} + \left\{\frac{X_n}{X} \cdot \frac{\partial Y}{\partial X_n} \cdot \frac{\partial X_t}{\partial R_t} \cdot \frac{R_t}{R}\right\}$$

This expression for the growth of output is clearly greater than that of the small farmers, because the individual terms on the right-hand side are all positive. Where there are no externalities, so that the traditional inputs do not gain greater productivity and when prices remain constant, $\frac{\partial X_t}{\partial R_t} = 0$. Thus, the output of the large farmer grows. This is in contrast to the small farmer's output which remains constant.

In the more likely event, however, the new inputs substitute in part the traditional inputs. The outcome, then, is less clearly defined. The existence of substitution is *prima facie* evidence that $R_n > R_t$, where P_y is constant. The signs of the cross-effects will be $\frac{\partial X_n}{\partial R_t} < 0$ and $\frac{\partial X_t}{\partial R_n} < 0$.

For output to increase, (that is for $\frac{\partial Y}{\partial R} > 0$), the following inequalities would have to be true.[4]

TABLE 3: QUALITATIVE SUMMARY OF LOGIC OF NET INCOME DISPARITY GROWTH

Demand Elasticity to Product Price		Change in Total Revenue	Change in Total Cost	Change in Net Revenue
$\infty > \left\lvert\frac{\partial Y}{\partial P_y} \cdot \frac{P_y}{Y}\right\rvert > 1.0$	Large	> 0	> 0	≥ 0
	Small	< 0	< 0	< 0
$0 < \left\lvert\frac{\partial Y}{\partial P_y} \cdot \frac{P_y}{Y}\right\rvert < 1.0$	Large	< 0	> 0	≥ 0
	Small	< 0	< 0	< 0

TABLE 4: MARKET SOLUTION FOR SMALL, MEDIUM AND LARGE FARMS, PRE-TECHNOLOGICAL CHANGE, ON PER FARM BASIS

	Small	Medium	Large
Price P_y	6.52	6.52	6.52
Quantity q_{si}	0.516	0.723	1.042
Q_{si}	1.291	5.426	13.022
Total revenue	8.416	35.378	84.901
Input use	.0026	0.012	0.034
Total cost	0.125	0.574	1.700
Net revenue	8.291	34.804	83.200

TABLE 5: MARKET SOLUTION FOR SMALL, MEDIUM AND LARGE FARMS, POST-TECHNOLOGICAL CHANGE, FIRST APPROXIMATION ON PER-FARM BASIS

	Small	Medium	Large
Price P_y	6.59	6.59	6.59
Quantity			
q_{si}	0.516	0.740	1.069
Q_{si}	1.291	5.547	13.357
Total revenue	8.508	36.552	88.020
Input use	.0027	0.013	0.037
Total cost	0.136	0.652	1.835
Net revenue	8.373	35.900	86.185

$$\left|\frac{\partial X_n}{\partial R_n}\right| > \left|\frac{\partial X_t}{\partial R_n}\right| \text{ and } \left|\frac{\partial X_t}{\partial R_t}\right| > \left|\frac{\partial X_n}{\partial R_t}\right|$$

Given a constant P_y, the inequalities state that high-income (large) farmers would increase output if the growth in the demand for one type of input (say new inputs in this situation), resulting from a growth in its own profitability, exceeded the desire to reduce the use of a competing input when the profitability of the farmer input grows. These two forces tend to work against each other; the profitability of employing X_n leads to its greater use at the expense of X_t, but the marginal profitability of employing an additional unit of X_n will decrease (we suppose that the producer is in the economic range of declining elasticity for X_n). The decrease in productivity of X_n implies increasing relative profitability of marginal units of X_t. Hence a growing resistance to further substitution of X_n for X_t will prevail. The economic restraints in employing more X_n intensify because of its declining relative profitability *vis-a-vis* X_t.

The relative strengths of the conflicting forces can be observed in part by considering the elasticity of substitution of X_n for X_t. Being newly employed, it is likely that X_n is used more closely to its extensive margin than X_t is to its (Figure 2). That is, $\frac{X_t}{X} > \frac{X_n}{X}$, or traditional inputs still dominate the input mix even though both types are used. But this implies that the elasticity of substitution, X_n for X_t, exceeds unity. Under these conditions, it is expected that:[5]

$$\left|\frac{\partial X_n}{\partial R_n}\right| > \left|\frac{\partial X_t}{\partial R_t}\right|$$

Further, if we maintain the hypothesis that traditional inputs are virtually fixed in the farm sector; i.e. labour will not be easily retired from agriculture, land will not be quickly withdrawn, and traditional capital will still be largely employed, then traditional input employment will at least be constant. Thus,

$$\left|\frac{\partial X_t}{\partial R_t}\right| \geq \left|\frac{\partial X_t}{\partial R_n}\right|.$$

Lastly, it seems intuitively true that, the potential of a rise in new input productivity to negatively influence the use of traditional inputs would quantitatively exceed (in absolute terms) the potential of changes in traditional input productivity to negatively influence the use of new inputs. Institutional pressure to expand new input use, say through government programmes, not easily solved or reversed once started, might in itself be enough to make this true. Thus,

$$\left|\frac{\partial X_t}{\partial R_n}\right| > \left|\frac{\partial X_n}{\partial R_t}\right|.$$

Under these conditions, therefore, output would expand even when X_t and X_n were partial substitutes. What is more, the expansion of output would be due to the activity of the adoption of technology who, in the situation now discussed, would be the large farmer.

Net income effect of increased output by farm-size groups:

We now consider the income distribution effects of the relative increases in output on low and high-income farms when consumer demand is elastic,

$$\left|\frac{\partial Y}{\partial P_y} \cdot \frac{P_y}{Y}\right| > 1.0, \text{ and price inelastic,}$$

$$\left(0 < \left|\frac{\partial Y}{\partial P_y} \cdot \frac{P_y}{Y}\right| < 1\right).$$

Under the price elastic conditions, an increase in output will increase the total revenue depending on the degree of demand elasticity. The increase, however, will reduce the price per unit of output. For the small farmer who does not increase output, total revenue will fall. Also, if the small farmer does not alter the input of traditional resources, $\frac{\partial X_t}{\partial R_t} = 0$, total cost (imputed as well as incurred) will not decline, an realised net income will decline. Initially the same income effect will prevail for the small farmer when consumer demand is inelastic with respect to price.

Yet, even the lower product price can lead to higher total revenues for the large farmers. Although his total cost will increase as more inputs are used, the rational producer will restrain input purchases so that the marginal revenue is not exceeded by marginal cost. His net income will rise (or at worst stay constant). Thus, income disparity between large and small farmers, will widen. These qualitative relationships are shown in Table 3.

When consumer demands are price inelastic, an increased offering lowers both price and total market revenue for the farm sector. If we maintain the claim that the small producer does not contribute to the expanded offering or reduce his input use, his total and net income position worsens. But the large producer does not necessarily lose total revenue in this case (although he might, if sectoral total revenue falls faster than the total revenue of small producers). Indeed, it is also possible for large farmers to experience rising total revenue in spite of a deterioration in sectoral revenue. In either case, the economically rational producer will only spend on new inputs and so add to total costs, to the point at which changes in net revenue are equal to or exceed zero. Again, the income gap will widen.[6]

ILLUSTRATIVE NUMERICAL MODEL

We now use a heuristic model to better illustrate the mechanics of the preceding economic reasoning. Although simplifying assumptions are used, the quantities employed are numerical approximations of current magnitudes in India. This illustrative model is applied to three stages: Stage I depicts the market solution before the technological breakthrough, State II portrays the changes resulting from the Green Revolution, and Stage III envisages the changes in income in successive production cycles. Our discussion of stages is merely for convenience and has no con-

section with Rostowian stages of economic growth.

Stage I

Suppose that equations (1), (2) and (3) represent per-acre production functions of small, medium, and large farms, respectively:

(1) $q_1 = 5 + 0.5X_1^{.5}$ (small)

(2) $q_2 = .7 + 0.6X_2^{.5}$ (medium)

(3) $q_3 = 1.0 + 0.8X_3^{.5}$ (large)

where, now q_i $(i=1, 2, 3)$ is physical output per acre on farm size coded i and X_i is all inputs viewed as homogeneous mass.

Equation (3) supposes that the high-income farmer has the necessary capital, knowledge, and other fixed assets, to progress over the preceding production period; hence he will exhaust more of the potential scale economies than will the low income farmer.[9] We are, of course, aware of the long and somewhat inconclusive debate that surrounds the question of the relative efficiency of small farmers in India [1, 23]. For the time being, however, our model abstracts from the hypothesis based on previous empirical results and rests on standard theoretical logic.

A square-root form of the production function is selected for demonstration purposes, because its properties give 'easily added' supply functions (we suppose that the farmer is operating in a range of the production function, with production elasticities of less than unity) [12]. Equations (1a), (2a) and (3a) express the level of inputs used for the respective production functions:

(1a) $X_1 = (q_1 - 0.5)^2/(0.5)^2$

(2a) $X_2 = (q_2 - 0.7)^2/(0.6)^2$

(3a) $X_3 = (q_3 - 1.0)^2/(0.8)^2$

From (1a), (2a) and (3a), and the assumption of profit maximisation, the per-acre supply functions and the per-farm supply functions are derived. These are presented as equations (4), (5), (6), (4a), (5a) and (6a), respectively. In the formulation, P_x is the input price per unit of input, P_y is output price, q_{si} $(i = 1, 2, 3)$ is per-acre supply and Q_{si} is per-farm supply. We assume that small farms $(i=1)$ have an average acreage of 2.5 acres, medium farms have 7.5 acres, and large farms have 12.5 acres [14]. We assume, further, that intra-farm economies of scale do not exist, but that there are possible inter-farm scale economies.

(4) $q_{s1} = 0.5 + 0.125\ P_y P_x^{-1}$
(per-acre supply of small farm)

(5) $q_{s2} = 0.7 + 0.18\ P_y P_x^{-1}$
(per-acre supply of medium farm)

(6) $q_{s3} = 1.0 + 0.32\ P_y P_x^{-1}$
(per-acre supply of large farm)

(4a) $Q_{s1} = 1.25 + 0.3125\ P_y P_x^{-1}$
(per-farm supply of small farm)

(5a) $Q_{s2} = 5.25 + 1.35\ P_y P_x^{-1}$
(per-farm supply of medium farm)

(6a) $Q_{s3} = 12.5 + 4.00\ P_y P_x^{-1}$
(per-farm supply of large farm)

We suppose an agriculture composed of 60 per cent of small, 20 per cent of medium, and 20 per cent of large farms. Hence the aggregate supply function is

$$Q_m = 2150 + 628.75\ P_y P_x^{-1} \quad ..(7)$$

where Q_m is market supply (physical), P_y is output price, and P_x is input price.

Let the sector be essentially closed with respect to the trade in agricultural products, and let the regional demand function be

$$Q_d = 8100 - 900\ P_y \quad ..(8)$$

The demand function is inelastic with respect to product price[8] (but just so) over the range $9 > P_y > 0$.

The market is cleared when $Q_m = Q_d$, and the product price has the value:

$$P_y = 5950\ P_x / (900\ P_x + 628.75) \quad ..(9)$$

We assume $P_x = 50$ monetary units per purchased unit, given the current situation in India, especially in the use of high-yielding varieties. Where perfect competition exists in both input and output markets, P_y and P_x are the same for all farmers.

Prices, quantities sold per farm, total farm revenue, total farm cost, and per farm net revenue under market equilibrium are given in Table 4. Profit per large farm is 10.035 times that for small farms, and 2.391 times that of medium farms (Table 7). In turn, profit of medium farms is 4.198 times larger than that of small farms. These ratios indicate the extent of the initial income disparity.

TABLE 6: MARKET SOLUTION FOR SMALL, MEDIUM AND LARGE FARMS, POST-TECHNOLOGICAL CHANGE, SECOND APPROXIMATION, ON PER-FARM BASIS

	Small	Medium	Large
Price P_y	6.39	6.39	6.39
Quantity			
q_{si}	0.521	0.784	1.190
Q_{si}	1.303	5.878	14.878
Total revenue	8.325	37.560	95.073
Input use	.0036	0.027	0.101
Total cost	0.180	1.338	5.066
Net revenue	8.145	36.223	89.997

Stage II

As a result of the Green Revolution, we suppose three exogenous shocks that can be reflected through the model. First, the price of output from farms adopting the technology, (P_{y_n}), will decline since they will produce a red-coloured grain (which consumers treat as inferior to the traditional white wheat). So we assume that

$P_{y_n} = 0.8\ P_{y_t}$.[9] Secondly, the price per unit of the new input, (P_{y_n}), will exceed that of traditional inputs (P_{y_t}) (actual or imputed), thus $P_{x_n} = 1.2\ P_{x_t}$.[10] Third, the productivity of new inputs, X_n, greatly exceeds that of traditional inputs, X so that one unit of new input conceptually produces the same volume of output as a multiple number of traditional input units. Therefore, $X_n = 2.5\ X_t$.[11] These equations, when substituted into the originally defined production functions, permit a comparison of pre- with post-technological change (since both situations are reduced to common terms).

The production, per-acre supply, and per-farm supply functions, for the small, medium, and large farmers, will be those given in (10), (11), (12), (13), (14), (15), (13a), (14a) and (15a).

(10) $q_1 = 0.5 + 0.5\ X^{.5}$
(per-acre production, small farm)

(11) $q_2 = 0.7 + 0.9492\ X^{.5}$
(per-acre production, medium farm)

(12) $q_3 = 1.0 + 1.2656\ X^{.5}$
(per-acre production, large farm)

(13) $q_{s1} = 0.5 + 0.125\ P_y P_x^{-1}$
(per-acre supply function, small farm)

(14) $q_{s2} = 0.7 + 0.300\ P_y P_x^{-1}$
(per-acre supply function, medium farm)

7

TABLE 7: RATIOS OF LARGE AND MEDIUM FARM NET REVENUES WITH RESPECT TO SMALL FARM NET REVENUE, ORIGINAL, AND FIRST AND SECOND APPROXIMATIONS

	Original (Table 4)	First Approximation (Table 5)	Second Approximation (Table 5)
NR_l/NR_s*	10.035	10.293	11.035
NR_l/NR_m	2.391	2.401	2.485
NR_m/NR_s	4.198	4.289	4.447

* NR_l : net revenue, large farm.
NR_s : net revenue, small farm.
NR_m : net revenue, medium farm.

(15) $q_{sl} = 1.0 + 0.520\ P_y P_x^{-1}$
(per-acre supply function, large farm)

(13a) $Q_{sl} = 1.25 + 0.3125\ P_y P_x^{-1}$
(per-farm supply function, small farm)

(14a) $Q_{sm} = 5.25 + 2.250\ P_y P_x^{-1}$
(per-farm supply function, medium farm)

(15a) $Q_{sl} = 12.5 + 6.504\ P_y P_x^{-1}$
(per-farm supply function, large farm)

(16) $Q'_m = 2150 + 969.436\ P_y\ P_x^{-1}$
(aggregate supply function)

Here we assume that, on the planning horizon at least, no farmer will plan to leave agriculture. Thus, the post-technological market supply function, (16), is the weighted sum of the farm supply functions, with original weights. The new supply function is expressed in terms of the original prices. It incorporates the supply-increasing influences of rising input productivity, dampened by the supply-depressing influence of falling product prices and rising input prices.

If population grows by 2.5 per cent and disposable income per capita increases by a similar percentage, total demand shifts upwards to

$$Q_d = 8505 - 945\ P_y \qquad ..(17)$$

In equilibrium, the product price is expressed in the form

$$P_y + 6355\ P_x/(945\ P_x + 969.436)$$

again in terms of the pre-technology prices.

The full market solution, given the input price $P_x = 50$, is given in Table 5. The ratios of net revenue for large to small farms, medium to small farms, have increased (see Table 7), but the ratio of net revenue between large and medium farms has not changed. Thus, it is demonstrated that, the first-round impact of the technological change is to widen the income gap between adopters and non-adopters.

As a side note, we observe that the model shows that even the small farmer could realise or anticipate a slight rise in net income, possibly owing to an improvement in traditional white wheat prices resulting from the cessation of large and medium farm production of traditional grains (Table 8). But this good fortune would be short-lived even if it were actually realised. More generally, we would expect the smaller farmer to lose welfare, even relative to his former position.

Stage III

We suggested in the theoretical discussion that, farm spending behaviour was related to the farm's net income position. We now formalise those previously stated behavioural relationships and hypothesise that, the change in farm expenditure is linearly related to the change in net farm income over the preceding period.[12] When subscripts (t+1) and t indicate the present and past time periods.

$$P_{x(t+1)} X_{(t+1)} - P_{x(t)} X_t = \alpha_i (NR_t - NR_{t-1}) \qquad ..(19)$$

We assume that the market price for input does not change over time; hence $P_{x(t+1)} = P_{xt}$. Dividing by P_x, and transposing,

$$X_{(t+1)} = X_t + \alpha \frac{i(NR_t - NR_{t-1})}{P_x}$$

$$(\text{When } NR_t - NR_{t-1} > 0) \qquad ..(20)$$

The factor α_i (i=1, for small, 2 for medium and 3 for large farms, respectively) is the product of the marginal propensity to invest out of net income and the marginal propensity to purchase non-land inputs (traditional for small farms, new for large and medium) out of investment funds. In the example, $\alpha_1 = 0.04$, $\alpha_2 = 0.07$, and $\alpha_3 = 0.11$. These magnitudes reflect the current behavioural situation in India, [15, 16, 17].

We emphasise that the numerical quantities used are for the post-technological change period. They reflect a set of economic relationships different from those that existed before the new technology made investment profitable for large farmers.

It is well documented that, before the Green Revolution, the average propensity to invest in non-land inputs decreased as farm size increased [20]. The reasons for this might be as follows. Under traditional technology, large farms could have come close to exhausting the potential for profitable new investment in traditional inputs well in advance of small, economically constrained farmers. Hence, large farmers' new net revenue might be spent, either on consumption goods or land, to increase absolute income in direct proportion to the number of new acres bought. Small farmers, on the other hand, could still find it profitable to invest (out of new income) in the non-land inputs which they had previously been constrained from purchasing. After the Green Revolution, it would again become profitable for large farmers to invest in new inputs, and, because of the lower marginal utility of consumption vis-a-vis small farmers, large farmers would demonstrate larger marginal and average propensities to invest in non-land inputs.

Because the net revenue of all producers increased in the first period, the use of non-land inputs will increase for all farmers. The solution to equation (20) shows that, small farmers should increase input use (traditional inputs) by 24.2 per cent, the medium farmers by 218.1 per cent, and the large farmers by 278.9 per cent (both on new inputs).

The resultant production functions, per-acre supply functions, and per-farm supply functions, are given in equations (21), (22), (23), (24), (25), (26), (24a), (25a), and (26a), respectively.

(21) $q_l = 0.5 + 0.557\ X^{.5}$
(production function, small farm)

TABLE 8: RATIOS OF FARM NET REVENUES, POST-TECHNOLOGICAL CHANGE WITH RESPECT TO PRE-TECHNOLOGICAL CHANGE, BY FARM SIZE

	NR (First Approximation)*	NR (Second Approximation)
	Original	Original
Small farm	1.01	0.982
Medium farm	1.032	1.041
Large farm	1.036	1.082

* NR = net revenue

8

(22) $q_2 = 0.7 + 1.402\ X^{.6}$
(producing function, medium farm)

(23) $q_3 = 1.0 + 2.113\ X^{.6}$
(production function, large farm)

(24) $q_{s_1} = 0.5 + 0.165\ P_y P_x^{-1}$
(per-acre supply, small farm)

(25) $q_{s_2} = 0.7 + 0.655\ P_y P_x^{-1}$
(per-acre supply, medium farm)

(26) $q_{s_3} = 1.0 + 1.469\ P_y P_x^{-1}$
(per-acre supply, large farm)

(24a) $Q_{s_1} = 1.25 + 0.413\ P_y P_x^{-1}$
(per-farm supply, small farm)

(25a) $Q_{s_2} = 5.25 + 4.914\ P_y P_x^{-1}$
(per-farm supply, medium farm)

(26a) $Q_{s_3} = 12.5 + 1.861\ P_y P_x^{-1}$
(per-farm supply, large farm)

Again, assuming no net entry or exit from agriculture, the aggregate supply function becomes

$$Q_{s_y} = 2150 + 2476.305\ P_y P_x^{-1} \quad (27)$$

The demand function remains as given in (17). In equilibrium the market price of output would be given by

$$y = 6355\ P_x / (945\ P_x + 2476.305) \quad (28)$$

Again, with all quantities expressed in terms of the initial product and input prices and assuming that $P_x = 50$, the full market solution is presented in Table 6.

The model now shows that the income disparity, even among adopters, will grow over time. The ratio of large-to-medium farms' net income has grown from 2.39 to 2.48, or by about 4 per cent (Table 7). An even more dramatic growth in disparity is seen between the large and small farms. The ratio of net incomes grew from 10.03 to 11.05, or by about 10 per cent. Further, the small farmer is worse off relative to his own former position (net income falls by about 2 per cent) (Table 8), so that one can conclude that the small farmer will be even less able (than he was formerly) to employ the new technology in an attempt to catch up. The income gap, therefore, will continue to widen in successive production cycles.

Thus, we have demonstrated, both theoretically and quasi-empirically that, embodied technical change, like that of the Green Revolution, will exaggerate existing inter-farm income disparities. The gap will grow because the initial pre-technological change income distribution means an unequal opportunity for farmers to attempt to adopt the technology. Further, the economic behaviour of farmers in different income classes differs, and differs in a way that reinforces the tendency for incomes to diverge.

Some Policy Implications

The analysis presented has some policy implications for India and other developing countries. These are not dwelt on here, but are suggested as a target towards which more inquiry should be directed.

Since mechanization may dampen the increase in labour demand, resulting from the expanding factor of seed-fertilisers, the policies that encourage premature mechanisation in surplus-labour economies, such as India's, do not seem conducive to solving the problem of growing unemployment. The policies we question on these grounds are the indiscreet subsidisation of farm machinery and credit availability for the same. In addition, the import and foreign aid policies that encourage and facilitate the use of huge labour-displacing farm machinery also requires re-examination.

As we have demonstrated, the embodied technological innovation marked by the Green Revolution, left to itself, has an inherent tendency to widen the disparities between small, medium, and large farmers, not only in the initial stages but also in successive production cycles. This tendency can only be counteracted by Government's policy measures. Alternatives that might be studied could include:

(1) A policy measure aimed at raising the production levels of small farmers, e.g. cheaper credit facilities for these farmers, subsidisation of seed/fertilisers and so on. Caution would be needed, however, for many ills have resulted in other countries which have embarked on this course (particularly the United States).

(2) A progressive system of taxation on rural incomes that are growing with the Green Revolution. There is hardly any effective measure of agricultural income tax now, although laws are on the books in several states.

(3) A comprehensive scheme of income transfers or welfare payments for the small farmers, possibly financed out of tax revenues from large farms.

(4) An effective implementation of laws pertaining to land ceilings to reduce the basic disparity in income. But again, caution is needed, for to close off the possibilities of added economies of scale by setting too low a ceiling would be counter-developmental.

These suggestions can only be placed in operational perspective, and discussed with wisdom, if the magnitudes assumed in this paper are empirically verified. Furthermore, many behavioural relationships assumed here require statistical grounding. The real evidence demanded cannot be adequately supplied by surveys, and studies based on the surveys, that were conducted a decade-and-a-half ago — however good these surveys and studies might have been. Hopefully, new statistical light will now be shed on these policy matters soon.

Notes

1 These are: (a) all marginal products exceed zero, (b) diminished marginal product exists, (c) homogeneity is guaranteed, but not specified *a priori* and (d) there is a finite limit to output as inputs increase to infinity. [6].

2 We do not wish to limit our use of the word 'finance' to the procurement of funds in the loan market or to the securing of credit from distributors of production inputs. There also could be a strong relation between the level of net income in real terms and the amount that a farmer would be willing to reinvest to finance his own enterprise. That is, the average propensity to consume may be smaller for a large farmer than a small farmer. Attitudes towards risk-taking might also be expected to vary directly with net income.

3 The present form of analysis could also be used to evaluate the situation in which disembodied technical change occurs, since in this case, the technological change could be interpreted as increasing the productivity of traditional inputs as well as adding new inputs.

Thus, $\dfrac{\partial X_t}{\partial R_t} > 0.$

In this case growth in output would be partially due to the output of small farmers as well as large. Even so, the large farmer would add proportionally more to output than would the smaller.

4
$$\frac{\partial Y}{\partial R} > 0, \text{ if } \left\{\frac{X_t}{X}\right\} \cdot \left\{\frac{\partial Y}{\partial X_t}\right\} \cdot \left\{\frac{\partial X_t}{\partial R_t} + \frac{\partial X_n}{\partial R_t}\right\} \cdot \left\{\frac{R_t}{R}\right\} + \left\{\frac{X_n}{X}\right\} \cdot \left\{\frac{\partial Y_n}{\partial X_n}\right\} \cdot \left\{\frac{\partial X_t}{\partial R_n} + \frac{\partial X_n}{\partial R_n}\right\} \cdot \left\{\frac{R_n}{R}\right\} + \left\{\frac{X_t}{X}\right\} \cdot \left\{\frac{\partial Y}{\partial X_t}\right\} \cdot \left\{\frac{\partial X_t}{\partial R_n} + \frac{\partial X_n}{\partial R_n}\right\} \cdot \left\{\frac{R_n}{R}\right\} + \left\{\frac{X_n}{X}\right\} \cdot \left\{\frac{\partial Y}{\partial X_n}\right\} \cdot \left\{\frac{\partial X_t}{\partial R_t} + \frac{\partial X_n}{\partial R_t}\right\} \cdot \left\{\frac{R_t}{R}\right\} > 0.$$

But this is true if,

$$\left\{\frac{\partial X_t}{\partial R_t} + \frac{\partial X_n}{\partial R_t}\right\} > 0 \text{ and}$$

$$\left\{\frac{\partial X_n}{\partial R_n} + \frac{\partial X_t}{\partial R_n}\right\} > 0 \text{ or if}$$

$$\left|\frac{\partial X_t}{\partial R_t}\right| > \left|\frac{\partial X_n}{\partial R_t}\right| \text{ and}$$

$$\left|\frac{\partial X_n}{\partial R_n}\right| > \left|\frac{\partial X_t}{\partial R_n}\right|$$

5

$$\Gamma_n = \frac{\Delta\left\{\frac{X_n}{X_t}\right\}}{\left\{\frac{X_n}{X_t}\right\}} \cdot \frac{\left\{\frac{P_{Xt}}{P_{Xn}}\right\}}{\Delta\left\{\frac{P_{Xt}}{P_{Xn}}\right\}} > 1.$$

$$\therefore \left|\frac{\Delta\left\{\frac{X_n}{X_t}\right\}}{\left\{\frac{X_n}{X_t}\right\}}\right| \cdot \left|\frac{\left\{\frac{P_{Xt}}{P_{Xn}}\right\}}{\Delta\left\{\frac{P_{Xt}}{P_{Xn}}\right\}}\right| > 1.$$

But $\frac{P_{Xt}}{P_{Xn}} = \frac{R_n}{R_t}$. Substituting gives

$$\left|\frac{\frac{\Delta X_n}{X_n}}{\frac{\Delta X_t}{X_t}}\right| \cdot \left|\frac{\frac{R_n}{R_t}}{\frac{\Delta R_n}{\Delta R_t}}\right| > 1$$

$$\therefore \left|\frac{\Delta X_n}{\Delta X_t}\right| \cdot \left|\frac{R_n}{R_t}\right| > \left|\frac{X_n}{X_t}\right| \cdot \left|\frac{\Delta R_n}{\Delta R_t}\right|$$

$$\therefore \left|\frac{\Delta X_n}{\Delta R_n}\right| \cdot \left|\frac{R_n}{X_n}\right| > \left|\frac{\Delta X_t}{\Delta R_t}\right|$$

$$\cdot \left|\frac{R_t}{X_t}\right| \text{ (if } X_n, X_t, R_n, R_t$$

all change)

In the limit $\frac{\Delta X_n}{\Delta R_n} = \frac{\partial X_n}{\partial R_n}$ and

$\frac{\Delta X_t}{\Delta R_t} = \frac{\partial X_t}{\partial R_t}$. Further, since $R_n > R_t$

and $X_t > X_n$. $\left|\frac{R_n}{X_n}\right| > \left|\frac{R_t}{X_t}\right|$.

$$\therefore \left|\frac{\partial X_n}{\partial R_n}\right| > \left|\frac{\partial X_t}{\partial R_t}\right|$$

6 The implicit assumption made in this analysis is that the output of the non-adopter is indistinguishable from that of the adopter of the new inputs. In this case, consumers cannot discriminate and create a price differential for the outputs of different farms. If consumers make this distinction, as in India where the output of adopters is *red*, existence of a price differential becomes possible [10]. A higher price for the output of low-income farmers would dampen the widening of the income disparity. This aspect will not be treated theoretically, but will be built into the heuristic example that follows.

7 In essence, we are suggesting that, what we observe in data is the *ex-post* production function, while there is conceptually an *ex-ante* production function that incorporates all the 'latest' technology that could be attained. The degree to which any farmer can approach the *ex-ante* production function is determined by the number and severity of the constraints placed upon him by nature, his past decisions and his own personality.

8 The monetary units in this section are not to be strictly interpreted as referring to rupees or dollars.

9 Estimated from [10].

10 Estimated from [17].

11 *Ibid.*

12 It is quite likely that, in practice, these steps occur simultaneously with those given in Stage II, with decisions and responses based on anticipation, rather than on experienced fact. For the sake of exposition, however, we evaluate the stages separately in the same manner, as the analysis of consumer demand behaviour separates the price and income effects.

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