HUCAER

WP 8504

המרכז למחקר בכלכלה חקלאית

THE CENTER FOR AGRICULTURAL ECONOMIC RESEARCH

[Hebrew University. Center for agricultural economic research]

WORKING PAPER NO. 8504

CAPITAL ACCUMULATION
THE CHOICE OF TECHNIQUES
AND AGRICULTURAL OUTPUT

By

Yair Mundlak

Rehovoth, Israel, P.O.B. 12

רחובות, ת.ד. 12

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First Draft : April 1984
Revised Draft : October 1984

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INTRODUCTION[1]

Economic growth is achieved largely through capital accumulation and technical change. However, these two processes are not independent. The generation of technical change requires resources and, in this sense, it can be considered to be an investment activity. This in fact is recognized by naming cumulative investment in nonphysical capital "human capital". The implication of this is that the rate of growth of the economy depends, to a large degree, on the rate of capital accumulation. This paper deals with some aspects of the structure of this interdependence between capital accumulation and technical change. The emphasis will be on agriculture but many of the propositions are of general nature.

The green revolution provides a good example of technical change which implementation has required capital accumulation in agriculture. A recent study by Bhalla, Alagh, Thind and Sharma (BATS) of foodgrains growth in India based on district data provides empirical evidence for some of the propositions developed in this paper. In comparing production changes from the period 1962-65 (pre-green revolution) to 1970-73, a period "when the new technology in Indian agriculture was well established",[2] the authors state that "our study shows that the introduction of new technology after the mid-sixties is gradually but surely changing the production structure of Indian agriculture".[3] It is clear that if the transformation to the HYV requires capital, it can only be gradually implemented. This is well consistent with the other findings characterizing the nature of the changes brought about by the green revolution.

"To sum up, the differences in yield levels of high and low growth districts are adequately explained by the increasing efficiency of factor inputs, like fertilizers, male workers, and intensity of cultivation. In this regard, for the high growth districts the role of capital (like fertilizers) tends to become increasingly more important as compared with that of labor."[4]

This statement is based on the fact that "whereas in traditional slow-growing agricultural regions, labor continues to be the main factor of production, the new technological inputs are gradually emerging as predominant contributors to increase in yield levels particularly in the high-growth districts. Significantly, the elasticities of yield with respect to most of these technological inputs are much higher during the seventies as compared with the sixties. In all the regions formed through growth of output or growth of yield classification, male workers emerge as a significant explanatory variable with a positive and high elasticity coefficient. This is a significant result and refutes the hypothesis that because of existence of excessive labor, the marginal productivity of labor is zero in Indian agriculture. In fact, with the introduction of new technology, even the traditional factors of production in combination with modern inputs have tended to become more productive in the high yield growth area. In most of the high and medium growth districts (by output or yield), the marginal productivity of labor by itself and when taken with intensity and or fertilizers has recorded a notable increase.

However, it is notable that with the introduction of new technological inputs like fertilizers, tractors and tubewells, and with increase in intensity of cultivation, the elasticity of labor declines quite perceptibly and it ceases to be the predominant factor of production. The contribution made by new technological inputs is the greatest among the high growth districts, but keeps on declining relatively as growth rates of districts decline".[5]

To summarize, the introduction of HYV has required capital inputs, it is capital intensive in the sense that it increases the share of capital inputs in total output and it represents technical change in that it increases yields and increases the productivities of all inputs including labor whose factor share declines. Most important, it has taken a long time and after twenty years it is far from being completed. There is no comprehensive framework that can produce all these results. The reason is that most of the work on the production side of the economy is based on the concept of a production function. As such, some of the empirical evidence quoted above is dealt with under the title labor-saving technical change. That is, the production function changes by factor augmentation to yield under given prices higher capital-labor ratios. Under such an analysis, the production function changes but at any time, there is only one production function. Thus, coexistence of production functions, such as those associated with the traditional and modern varieties, is not accomodated by the theory. In part, coexistence can be considered as a transitional phenomenon resulting from imperfect knowledge but this explanation cannot account for the length of time that it has required to introduce the modern techniques and for the geographical variations in such a pattern. The green revolution is considered here as an example, indeed a very important one. Another example is the motorization of agriculture. Motorized agriculture represents a different technology from non-motorized. It has also taken a long time to be implemented.

The point of departure is the recognition that at any time, there are numerous production functions. Basically, a production function is a micro-concept and it describes the input-out relationship of what is referred to here as a technique. Thus, the traditional and the HYV are two distinct techniques described by two distinct production functions. The production function that describes a technique relates changes in output to some changes in the inputs, holding some of the variables -- such as plant variety or soil type -- constant. The variables that are held constant are discrete.

The collection of all the techniques is referred to as technology. A change in the collection is referred to as technical change. Not all the techniques that are available are actually implemented at any time. It is, therefore, useful to distinguish between the available and the implemented technology. The foregoing comments on the relationships between technical change and capital accumulation refer to the effect of capital accumulation on the determination of the implemented technology.

This paper gives a very simplified view of the world. Yet is is sufficient to capture the empirical evidence as quoted above. Other implications of this approach are discussed elsewhere.[6]

The discussion begins by adopting the framework of Danin and Mundlak for the choice of technique, starting with the supply side of the economy, followed by the discussion of the choice under equilibrium of supply and demand. The change in the composition of the implemented techniques is related to investment in the discussion of the rate of implementation of new techniques. It is shown that the introduction of a new technique may generate a disequilibrium situation and that the rate of its alleviation depends on <u>gross</u> investment. Once this disequilibrium is eliminated, the further intensification of the use of this technique depends on <u>net</u> investment, that is, on capital accumulation.

It is then argued that in an economy that accumulates capital, it is expected that, on the whole, the new techniques will be more capital intensive than the existing ones. This is then followed by a discussion of some empirical implications. Particularly, the role of prices and the scope for price and other policies is considered.

THE PRODUCTION STRUCTURE AND COEXISTENCE OF TECHNIQUES[7]

For simplicity of exposition assume that agricultural technology consists of two techniques, "traditional" and "modern", denoted as 1 and 2 respectively. They are represented by well-behaved production functions, displaying constant returns to scale in labor (L) and capital (K). The unit isoquants of the two techniques are shown in Figure 1. The curve denoted by $Y_1 = 1$ represents the various combinations of labor and capital that result in a unit output generated by the traditional technique. A similar interpretation applies for the modern technique, as represented by $Y_2 = 1$. Note that the curves are drawn in such a way that the modern technique is considered to be more capital intensive.

The choice of techniques by an individual farmer in the situation described in Fig. 1 depends on the ratio of wage rate (w) to rental rate on capital (r). At a low wage-rental ratio, $\omega = w/r$, the labor-intensive traditional technique has a lower cost of production, and therefore the modern technique will not be employed. Conversely, for a relatively high wage-rental ratio, only the modern technique is used. Under a weak assumption with respect to the behaviour of the isoquants, there exists a value $\tilde{\omega}$ for the wage rental ratio, at which the cost of production of the two techniques is the same. This is shown in Fig. 1 by the isocost line with slope $\tilde{\omega}$ tangent to the two isoquants. Thus, at $\tilde{\omega}$ the two techniques are equally efficient. Consequently, the farmer is indifferent to the choice of technique. He can use the traditional technique with capital labor ratio $\tilde{k}_1 = k_1(\tilde{\omega})$ or the modern technique with a capital-labor ratio $\tilde{k}_2 = k_2(\tilde{\omega})$ or a combination of the two techniques. The values $\tilde{k}_1$ and $\tilde{k}_2$ are the input ratios that correspond to $\tilde{\omega}$ of the traditional and modern techniques, respectively.

Turning from an individual farmer to agriculture at large, let Fig. 2 represent the agricultural technology. The factor endowment is summarized by the capital-labor ratio, $k_A = K/L$, which is shown as the slope of the ray through A. The wage-rental ratio is now determined as the slope of the isoquant for the given k. The question is which is the relevant isoquant. For a sufficiently low capital-labor ratio, specifically for $k \leq \tilde{k}_1$ only the traditional technique will be employed. In this case ω will be determined by the slope of the isoquant of the traditional technique evaluated at k, and by construction for $k < \tilde{k}_1$ we have $\omega(k) < \tilde{\omega}_1$. Conversely, for $k \geq \tilde{k}_2$, $\omega(k) \geq \tilde{\omega}$ In those two cases agriculture specializes in one of the two techniques. Consequently, the two techniques coexist when $\tilde{k}_1 \leq k \leq \tilde{k}_2$. In this sense, $\tilde{k}_1$ and $\tilde{k}_2$ can be viewed as treshold values.

Under the assumption of full employment, the intensity of utilization of the individual techniques is determined by k, $\tilde{k}_1$ and $\tilde{k}_2$. This can be shown graphically by drawing a parallelogram. Thus, in terms of Fig. 2', when the economy produces at A, m represents the proportion of output generated by the modern technique, and the complement, t = 1 - m, comes from the traditional technique.[8/]

While the treshold values, $(\tilde{k}_1, \tilde{k}_2)$, are determined solely by the technology, k reflects capital accumulation. Thus, as the choice of techniques depends on k, it will change with capital accumulation. Given full employment in agriculture, the intensity of utilization of the modern technique increases with k at the expense of the traditional technique. That is the proportions of labor and capital employed in the modern technique increase or, alternatively, the proportion of agricultural output generated by the modern technique increases. This can be shown graphically by moving point A to the left along the cost line and drawing a new parallelogram.[9]

This simple minded analysis has a very important repercussion: Capital accumulation leads to the employment of capital intensive techniques. In general we view the modern techniques to be capital intensive, consequently, their relative importance increases with capital accumulation. The converse is also true. It is impossible to increase the relative importance of the modern techniques without capital accumulation. This result is established here in a partial analysis of agriculture, considering only the supply side. We turn now to show that this is also true when the whole economy is considered and demand is taken into consideration.

THE ECONOMY

The extension of the analysis to the economy as a whole requires to show how techniques are selected along the equilibrium path of the economy. This is the path of points at which supply and demand are equated. A point on the equilibrium path is represented here by the intersection of the transformation curve and properly defined demand curve. To simplify the analysis, non-agriculture is aggregated into one sector and it is assumed that it uses only one technique. Also, without a loss in generality, it is assumed that non-agriculture is more capital intensive, so that its capital-labor ratio (k_I) is larger than that of agriculture (k_A); specifically it is assumed that $k_I(\omega) > k_2(\omega)$ $k_1(\omega)$

The resulting transformation curve is shown in Figure 2, with points T, A, M marked on it. The curve is divided into segments identified by the utilized techniques. At low levels of agricultural production, only the traditional technique is used whereas, at a high level of agricultural output, only the modern technique is used. In between there is the region where the two agricultural techniques are used. This segment of the transformation curve is a straight line. The slope of the transformation curve is the price of the agricultural product in terms of the non-agricultural product (p). Therefore, the segment representing coexistence of techniques corresponds to a constant price, $\tilde{p}$. To show the relationship between agricultural output and the price p, the supply function is drawn in the left hand panel of the figure. When the two techniques coexist, it is possible to increase agricultural output without increasing prices. This, however, requires a shift of resources from non-agriculture to agriculture and therefore, a decline in non-agriculture ouput (Y_I).

Also in the same figure a transformation curve is drawn for the same economy if it were deprived of the modern technology. Obviously, this is an inferior situation to an economy whose output plan is to the left of T.

. The next step is to introduce demand functions. When tbere are only two products, the income consumption curve contains all the information on the demand in the economy. This curve is drawn in Figure 3 for price $\tilde{p}$ in such a way that the demand for the agricultural product x_1 is expressed as a function of the demand for the nonagricultural product, x_2. When the two products are normal, the curve is ever increasing with respect to the two axes. The economy is initially at point A where the two techniques coexist. With capital accumulation, the transformation curve shifts outward and the equilibrium point moves from A to E, where the price remains unchanged. Consequently, capital accumulation produces only income effect and no price effect and, therefore, the increase in sectoral outputs is proportional to the income elasticities. When the two products are normal, they both increase with capital accumulation. Such a joint increase in production requires a decline in the relative importance of the traditional technique. To see this, we note that the price at A and E is the same, so must be the capital labor ratios $\tilde{k}_1$, $\tilde{k}_2$, and $\tilde{k}_I$ Then the only way to increase the non-agricultural output with prices held constant is to shift resources from agriculture to non-agriculture. But at the same time, it is required that the agricultural ouput increases as well. This can happen only if in agriculture the traditional technique is replaced by the modern technique. Such a shift will cause an increase in the agricultural capital-labor ratio. It can thus be concluded that capital accumulation which takes place under a state of coexistence of the two techniques in agriculture generates a shift of resources away from the traditional technique. It should be noted that this result is now achieved for the economy that it is always in a short-run equilibrium.[10]

THE RATE OF IMPLEMENTATION OF NEW TECHNIQUES

The main point of the foregoing discussion was that an introduction of new capital intensive techniques is subject to capital constraint and therefore the rate of adoption of the technique depends on the rate of capital accumulation. As such, it is clear that when dealing with an important sector of the economy, the introduction of a new technique may take time to accomplish.

To relate this finding to other treatments of the adoption of new techniques, reference is made to Fig. 1. assume that when the modern technique is introduced, the capital labor ratio is k and the economy is initially located at point N. Obviously, after the introduction of the modern technique, the efficient production plan is changed from N to A. The question that is generally asked is what determines the pace of movement from A to N whereas our concern so far has been the movement from T to A. In other words, we have dealt with movements <u>along</u> a newly formed efficiency frontier whereas the movements from N to A can be interpreted as a movement <u>toward</u> a newly formed efficiency frontier. The determinants of the pace of such a movement often given in the literature can be classified into two groups, those related to heterogeneity of capital and those related to uncertainty and imperfect knowledge.

In the foregoing discussion, it was implicitly assumed that capital goods are homogenous so that horses and tractors are the same thing. This indeed is a simplification of reality. Eliminating this assumption and recognizing that capital goods are heterogenous introduces another dimension into the discussion. If the two techniques in question require different forms of capital, then the pace of moving from N to A will be determined by the ease of changing the composition of the capital stock. In general, the disappearance of the capital good associated with the traditional technique is determined by obsolescense or discard and the introduction of the capital good associated with the new technique is determined by gross investment. Consequently, the rate of implementation of the new technique will be determined by the rate of gross investment, whereas the decline in the traditional technique will depend on the rate of disappearance of the capital good associated with it. Thus, the movement from N to A would imply a gradual reduction of the capital-labor ratio in the traditional technique from k to $\tilde{k}_1$. In this process ω will gradually decline from its level at N, as determined by the traditional technique, to $\tilde{\omega}$.

The essence of the argument on heterogeneity of capital is that the two techniques may require different compositions of the various capital goods, not necessarily two. If this is the case, then a change in the composition of the two techniques will require a change in the composition of the various capital goods. If this process takes the economy off the efficiency frontier, then the return to the frontier will depend on gross investment.

So far we have treated the modern technique as a new entity completely unrelated to the traditional technique. In subsequent discussion, we comment on the economics of generating techniques. However, from a strictly formal point of view, once the new technique is available, it can be expressed as if it were obtained by some change of the traditional production function. Doing so may help us to utilize known results related to various forms of technical change. This, however, is of only limited value as it does not explain the coexistence of techniques and the determinants of their implementation.

However, incorporating some known forms of technical change helps to isolate the importance of the various determinants. Start by assuming that the modern technique is obtained simply by a Hicks neutral technical change (NTC) in the traditional technique. In this case, there is no difference in the threshold values, $\tilde{k}_1 = \tilde{k}_2$, and the new technique dominates completely the old technique and it is therefore disadvantageous to employ the two techniques simultaneously. Yet if capital is heterogenous in the sense that the two techniques use different capital goods, there will be a transition period during which the two techniques will still be used simultaneously. A special case of this is in the embodiment hypothesis developed by Solow. Under this hypothesis, the new technique is embodied in a new capital good, say machine, and it cannot be applied with the old machine. Consequently, the rate of introduction of the new technique will depend on the rate of <u>gross</u> investment rather than net investment. Thus, the traditional technique will disappear eventually, even if net investment is nil.

The situation is somewhat different when the modern technique is generated by a factor augmenting technical change in the traditional technique. In contrast to the previous case, factor augmenting technical change generates a difference in the threshold value so that $\tilde{k}_2 > \tilde{k}_1$. In this case, if $\tilde{k}_2$ exceeds the available capital-labor ratio, the rate of implementation will eventually depend on net investment. Thus, if the economy does not accumulate capital, it will not discard the traditional technique.

Another reason for coexistence of techniques is uncertainty or lack of knowledge (Griliches). The new technique may be superior but firms do not know it and may require time to sample it. During this period of search, the various techniques will coexist. The search process requires resources. At the farm level, the amount of resources devoted to the search depend on their cost (Kislev and Shchori-Bachrach, Feder and Slade). At the industry level, such cost depends on the availability of such resources. The result of a search by a farmer depends on the time that he allocates to the search and to his ability to digest it. The latter, as Schultz postulated, depends on the level of education. Hence the speed of implementation which reflects imperfect knowledge is also positively related to capital, in the form of human capital.

ON THE GENERATION OF NEW TECHNIQUES

New techniques are generated by firms, private or public, which spend resources on research and development. Given the state of science there is generally a choice to be made in determining the research strategy. For the purpose of our discussion, the key variable is the capital intensity of the new techniques. The foregoing discussions indicated that capital accumulation generates demand for capital intensive techniques. Thus, the producers of techniques should aim at the development of capital intensive rather than labor intensive techniques. However, overshooting is counterproductive. Since the rate of implementation depends on the rate of capital accumulation, the threshold level of the new techniques should not be too high. Otherwise, the market for such techniques will be very limited.

This story can be told by looking at the firm level. In the absence of a new capital intensive technique, capital accumulation increases the capital-labor ratios, thus increasing real wages and decreasing the real rental rate on capital. Thus, the owners of capital will be interested to invest their capital in techniques that prevent the rate of return from falling. This generates the demand for the capital intensive techniques.

By its very nature this process leads to a decline in the labor share (S_L) and as such can be considered as labor saving. For a constant return to scale production function in K and L we can define the following function of labor share:

$$\theta = \omega / k = \frac{wL}{rK} = S_L / 1 - S_L$$

θ is monotonically increasing with S_L. Referring to Figure 1, the movement from T to A increases k with ω held constant. Consequently θ, and therefore S_L decline. The transition from N to A implies a decline in ω under a constant k which again results in a decline of the labor share.

For the purpose of simplification, we have dealt with two techniques: traditional and modern. The appearance of additional techniques can be handled in a very similar fashion. One case, however, is worthy of examination for its own interest and for future reference: the case of NTC in the modern technique. We select the modern technique to be the subject of the NTC for a purpose. As it has been argued that the process of capital accumulation causes a shift in the direction of capital intensive techniques, then -- other things being equal -- the demand will call for development of the NTC to be implemented on the modern techniques. In a more detailed framework, the cost of producing and changing techniques, as well as the required research time, should be introduced. If the required time is significant, by the time the research is completed, the traditional technique may not be of any importance. Therefore, effort will be directed at increasing the productivity of the modern techniques. This consideration has a dynamic aspect. With time, the modern techniques become traditional and, therefore, they have already been worked on so that the easy gains might have already been made and additional gains may be subject to increasing cost. Thus, both from the demand side and the supply side, it is likely that the effort of improving an existing technique will be aimed at the modern techniques.

An improvement in the productivity of a technique should increase the degree of its utilization. In part, this can be illustrated graphically in Figure 4. The initial techniques are represented by $Y_1(0)$ and $Y_2(0)$ with threshold values $\tilde{k}_1$ and $\tilde{k}_2$. Neutral technical change in the modern technique shifts its unit isoquant to $Y_2(t) = 1$. The threshold values decline accordingly to $\tilde{k}_2(t)$ and $\tilde{k}_1(t)$. For any value of k, the importance of the traditional variety declines.[11] The net effect of this change is again labor saving. Thus we have a situation where the net effect of a Hicks neutral technical change is labor saving.

The foregoing discussion describes the changes in technology that are called for by the process of capital accumulation. They apply to all sectors of the economy. The references to the work of BATS made earlier in the paper illustrates their relevance to understand the changes brought about by the green revolution.

EMPIRICAL IMPLICATIONS

The present framework has a variety of empirical implications. In discussing those it is helpful to represent the two techniques in terms of their input-output relationships rather than isoquants. Assuming constant returns to scale in terms of capital and labor, the average labor productivities are functions of the capital labor ratios and as such they are drawn in Fig. 5. The points on this figure correspond to points with the same designations as in Fig. 1. Corresponding to Fig. 1, the envelope is identical with $f_1(k_1)$ for $k \leq \tilde{k}_1$, it moves along the segment TM for $\tilde{k}_1 \leq k \leq \tilde{k}_2$ and thereafter, for $k \geq k_2$ it becomes identical with $f_2(k_2)$.[12/]

The scope for increasing average labor productivity in agriculture for such an economy consists of capital accumulation in agriculture and the introduction of new techniques which are not excessively demanding in terms of their capital requirements. What is then the role of prices in such a process? In answering this question, it is necessary to distinguish between equilibrium and disequilibrium analysis. The foregoing discussion was largely within the framework of equilibrium analysis. Thus subsequent discussion is kept within this framework. Introducing disequilibrium in the factor market will introduce additional complications but will not change the nature of the results.

The real factor prices (prices in terms of the product) are determined by the production function, and are shown in Fig. 5. Consequently, for agricultural technology which consists only of the traditional technique, the movement from T to N will imply an increase in the real wage w/p and a decline in the real rate of return on capital, r/p. The introduction of the modern technique into agriculture facilitates the movement from N to A and thereby simultaneously increase average labor productivity, rental on capital and decrease the wage rate and the labor share. All this is basically a restatement of our previous isoquant analysis and it is consistent with the empirical evidence quoted from BATs.

Once point A, or any other point on the segment TM, is reached, average productivity increases only with capital accumulation, with constant factor prices. This process continues until the traditional technique is completely abandoned, as indicated by point M.

Capital accumulation in the economy at large, reflects saving behavior and as such may be responsive to the rate of return on capital. In this paper, the interest is in sectoral analysis and for that matter overall capital accumulation is taken as given. The intersectoral allocation of the capital stock is done mainly through new investment. It is assumed that the share of agriculture in total investment is positively related to the ratio of the rate of return in agriculture to that in the rest of the economy. Empirical support for this assumption can be found in the analysis of the Argentinian experience by Cavallo and Mundlak. Similar results are obtained by yet unpublished work of Coeymans and Mundlak for Chile, and by Mundlak and Strauss (Mundlak 1979) for Japan, through the use of the flow of funds equation.

The introduction of the modern technique and the movement from point N to the segment TM increases the rate of return in agriculture and agricultural investment should increase accordingly. This then increases the rate of capital accumulation in agriculture and speeds up the implementation of the new technique.

This indeed is substantiated by the data for the Punjab as demonstrated in Figures 6-8 which show the number of private tubewells, the electricity and fertilizer consumption. It can be seen that these variables have increased very rapidly from the mid-sixties once the opportunities of the high yielding varieties were recognized.

The increase in the capital-labor rate in agriculture is achieved not only by capital accumulation but also by the drain of labor force from agriculture. The drain should be interpreted as a growth of agricultural labor force at a rate lower than the increase in the total labor force. Thus, if the economy were in steady state where the overall capital-labor ratio remains constant, such a drain of labor from agriculture would increase the agricultural capital-labor ratio.

So far, the analysis has dealt only with the supply side of the economy. To complete the analysis, demand is now brought in. Again reference is made to Fig. 3 for an illutration of equilibrium determination in a closed economy. Prior to the introduction of the modern technique, the economy is located at N. After the introduction the economy moves in the direction of A merely by reallocating the existing capital. Such a move involves an increase in agricultural and non-agricultural outputs and a decline in agricultural price. The decline in price is shown in two steps, first $P_N > P_T$, since they are both on the same transformation curve, and second,

$P_T = P_A$ by construction. Therefore, $P_N > P_A$. Thus, under P_A the demand for agricultural output will increase and the new equilibrium will be to the left of A, say A*. Is this result strange? May be, but it conforms to the data. For instance, taking the ratio of prices received by farmers to that of prices paid by farmers as an approximation of the agricultural price relative to the non-agricultural price, we find that in the United States the ratio in 1977 was 66 percent of the 1910-14 average and in Australia the 1977 level was at 56 per cent of the 1961-63 average.[13] Similar trend is observed for most countries.[14]

Obviously a single equation empirical analysis of supply of such data would show negative supply elasticities. This is a misleading result in the sense that the movement from N to A is the net result of changes in supply and demand. The movement is initiated by the technical change which has a direct effect on the agricultural supply. If the demand remained constant, such a change would have identified a demand rather than a supply function. However, the technical change increases income and as such, causes also a shift in the demand curve. Consequently, the curve connecting output and price is neither a supply nor a demand curve. There is an identification problem which requires a more detailed framework for empirical analysis.

The move from N to A was considered under the assumption of no capital accumulation. With capital accumulation the transformation curve moves and as indicated above point E represents an equilibrium point achieved with the augmented capital. Note that the price of E is the same as in A. Consequently, a situation is generated where an increase in output is obtained with price held constant. This represents a perfectly elastic supply. This indeed is what Fig. 2

indicates. But such a situation is contrary to all the empirical evidence on supply response. Yet there is no inconsistency between this framework and the known empirical results.

To dramatize the situation, suppose that the economy in question is an open rather than a close economy and the economy is at point T where the Price is $p_T = \tilde{p}$. Suppose that the international price increase to $p > \tilde{p}$. Under the new price, the economy should adjust to a new equilibrium point to the left of M. Such an adjustment requires a substantial shift of resources from non-agriculture to agriculture. Such a high mobilization of resource does not occur for the following reasons. As already discussed above, the intersectoral allocation of capital is done largely through gross investment. Thus, a dramatic change in the share of agriculture in the capital stock may require many years to accomplish. Similarly, as the empirical analysis of off-farm migration indicates, this process is also time-consuming (Mundlak 1979). Thus, it may take a long time for the response to materialize. However, it will materialize provided the price will remain at the new level. But would it? The movement from T to M indicates a major change in supply. That could only be absorbed by a corresponding decline in price, therefore, the new price is not sustainable. In a narrow sense, this argument does not apply to a small open economy. However, agricultural technology is, in general a public good and other countries having a similar technology, are expected to respond in the same way. The best example is the HYV of grains which are used all over. The world is a closed economy and therefore prices decline as argued above. By this argument, point M will not be reached unless the demand justified production at M. The mechanism of stopping short of M can either be rational expectation on the part of farmers or simply trial and error. Since the resource adjustment consistent with the movement from T to M is time consuming, somewhere in the adjustment process prices will start falling and the process will terminate. Be it what it may, it is clear that the response of agricultural output to annual variations in prices is going to be weak. This is postulated to be a reason for weak supply response often obtained in empirical analyses. Yet, this framework suggests that when techniques coexist the response to expected long-run prices is rather strong.

The whole discussion was conducted under the simplifying assumption of a single agricultural product. In a reality, any region can grow a variety of products. Some of these products utilize the same resources and therefore the adjustment in such cases is easier and faster. Consequently, a stronger response is expected to price variations of short duration. This is consistent with empirical analyses which report stronger response for individual crops than for aggregate outputs.

Another simplifying assumption made above is that there are no intermediate products or raw materials. The introduction of such inputs into the analysis have several dimensions. In the case of a closed economy, an increase in the demand for such inputs require adjustment in the non-agricultural sector which are of the very same nature of the adjustment discussed above. For instance, the increase in the demand for fertilizers brought about by the green revolution required a shift of resources to augment the production capacity of the fertilizer industry. During such a process, fertilizer availability becomes a constraint to the increase of agricultural output. This point was explicitly discussed by Desai. For an open economy, the adjustment may be faster if there are no foreign exchange constraints. But again, if the same technology is spreading all over the world and there is no excess capacity then a similar delay is expected.

The case of energy is somewhat different in that there is no availability problem, only a price problem. Thus, when the price of energy increases, it affects more strongly the price of the techniques which are energy intensive. In terms of our graphical analysis, this can be considered as a technical decline, opposite to technical progress. In this case, instead of output, the figures should report value added. An increase in the price of energy (or any other raw material) decreases the value added. Thus applying the results stated above with respect to NTC, the intensity of the use of the energy intensive technique will decline.

If we allow for the fact that agricultural production does utilize raw materials, and that those can be changed faster than capital and labor, then we could expect some price response.

To conclude the argument on supply response to prices for aggregate output subject to demand constraints, we have distinguished three major cases (1) Technical change in the form of appearance of a new technique generate an increase in output and a decline in price. (2) An increase in capital with constant technology of coexiting techniques generates an increase in output under constant prices, (3) An increase in the price ratio of output to raw materials will generate a positive supply response. However, this response reflects the importance of the raw materials in total cost and as such will not be very strong. Empirical analyses which do not differentiate between these effects will result in some mixture. This mixture will also reflect the fact that the response is largely to expected rather than observed prices.

Yet it has been suggested that with the technology under consideration, a strong supply response can be expected to permanent price changes and that such a response may require a long time. Can this claim be substantiated? As indicated above, empirical analysis of the process of intersectoral resource allocation does indeed indicate that the rate of allocation is price responsive in the anticipated direction. Integrating labor migration and investment allocation with the production structure will produce the output response.

There is, however, another way which can provide some evidence on the supply response as well as on some of the forementioned considerations. It is noted that technical change affects farm income in a similar way to prices. Consequently, a one percent increase in yield affects income almost the same as a one percent change in price. It is said almost because an increase in yield increases harvest and handling cost. Thus, the variable that farmers respond to should be $AR = p \times \text{yield} \times c$ where c is a fraction to adjust for the extra harvest cost (cf. Mundlak and McCorkle).

AR increases with technical change and as such it has a permanent component which should guide farmers decision. This is illustrated with data for wheat in the Punjab. The following table presents two regressions where the dependent variables are the proportion of the cultivated land planted in wheat. The explanatory variables are alternatively prices or average revenues of rice, wheat, maize, American cotton, Desi cotton and sugarcane. Also included are the percentage of land irrigated and the total fertilizer consumption.

There is a strong multicollinearity in the data. To overcome this, the regression was estimated by using the principal component approach as explained in Mundlak (1981). The degree of multicollinearity is reflected by the statistical rank. For the price equation the statistical rank is 2, whereas the number of independent variables is 8. That means that there are 6 linear combinations of the variables that are jointly not significantly different from zero. The statistical rank for the average revenue equation is 3, indicating somewhat weaker multicollinearity.

The fit of the average revenue regression is higher than that of the price regression. More importantly, the coefficient of wheat changes from significantly negative in the price equation to significantly positive in revenue equation. In both equations there is a considerable indication of response to prices or average revenues, as the case may be, of competing or complementary crops. This study is only at an early stage and therefore we will save comments on the multiproduct structure of Punjab agriculture to a later stage. However the empirical results are in line with the foregoing discussion.

PUNJAB: WHEAT ACREAGE RESPONSE

	Price	Average Revenue
R^2	.877	.946
Statistical Rank	2	3
Constant	.45256	.2404
P - Rice	-.01351	.0003
	(5.6)	(1.0)
P - Wheat	-.00157	.0047
	(1.8)	(11.4)
P - Maize	-.00025	.0015
	(.2)	(1.9)
P - American Cotton	-.00128	-.0018
	(7.8)	(1.4)
P - Desi cotton	-.00056	-.0092
	(2.2)	(6.3)
P - Sugarcane	.00014	-.0005
	(.4)	(2.7)
Fertilizer	.00006	.0001
	(6.5)	(10.2)
Percent irrig. land	.12259	.1469
	(7.8)	(15.6)

The dependent variable is the proportion of total area planted in wheat.

The variables p-rice, ..., p-sugarcane are 3-year moving averages of prices of the respective crops deflated harvest wage rate for the price regression. In average revenue regression these variables are replaced by moving averages of average revenues deflated by the harvest wage. The moving average for year t is of the variables at t-1, t-2, and t-3. For the first observation only t-1 was used. For the second observation the log is of t-1 and t-2.

Fertilizer is total consumption.

Irrigated land - the proportion of cultivated land in irrigation.

The first line reports the proportion and total variance explained by the regression (R^2).

The second line reports the measure of statistical rank.

The numbers in parenthesis are the absolute values of the t-ratios under the null hypothesis.

Some Conclusions, Policy Implications and Scope

The discussion has centered on the role of capital accumulation in the introduction and implementation of technical change. It has been argued that in the event of capital accumulation there will be a tendency for technical change to take the form of capital intensive techniques. A major outcome of the analysis is that such technical change cannot be implemented without capital accumulation.

Capital is broadly interpreted. It represents the resources that the economy divert at any period from present consumption in order to increase its production in future periods. The capital goods produced by such diverted resources include physical as well as non-physical components such as education, research, extension, or briefly human capital. The conclusion then is that an increase in the rate of capital accumulation should foster growth.

The rate of capital accumulation depends on private saving behavior, on the behavior of the public sector (government saving) and foreign saving (borrowing from abroad). A detailed discussion of these components is beyond the scope of the paper. However, it is important to note the foreign borrowing may be helpful if it is properly used. Recent experiences of some countries indicate that it can be misused. Thus, there are additional considerations. In what follows, it is assumed that resources are used efficiently.

Taking the overall capital constraint of the country as given, agricultural growth will depend on the generation of new techniques and on the available resources for their implementation. Policies that extract resources from agriculture are expected to have a negative effect on agricultural growth and the opposite is true for policies which facilitate the flow of resources into agriculture. That, of course, assumes that agriculture continues to have a flow of new techniques that can be implemented efficiently. We have used the HYV as an example for growth constrained by capital availability. In this case, capital takes the form of irrigation facilities, fertilizers, insecticides, roads as well as non-physical items such as domestic research, extension and general level of schooling.

Some of the investment necessary for the expansion of agricultural output is generally performed by the public sector. This is mainly directed at investment in infrastructure. The investment on farms are largely private although in part might benefit from subsidized finance. Assuming rational behavior, the higher is the profitability of new investment, the larger the investment will be. Therefore, the price system has an important role in influencing the rate of accumulation and therefore on technical change in agriculture. The response may be slow but it is there. Thus, policies directed at the taxation of agriculture are likely to have a serious cost in terms of agricultural growth, as was the case in Argentina (Cavallo and Mundlak). Sometime it is claimed that taxing rent, such as was the case in Japan for instance, is neutral in the sense that it should not affect agricultural growth. This is no more a clear case if it is recognized that the new techniques increase the rent on land and at the same time require investment. Elimination of rent, or part of it, reduces the incentive to fully utilize the available technology. This result cannot be obtained under technology which consists of one technique only.

The foregoing conclusions assume that farmers are rational and do utilize the changing opportunities. Sometimes this assumption is questioned as a result of failure of empirical analyses to detect supply response to prices. The possible reasons for such empirical results are analyzed. It is indicated that the response should be observed at the level of intersectoral resource flow, and here the empirical evidence shows that such flows are indeed price responsive.

The reason that it is not easily observed by direct measurements is that the resource adjustment is slow whereas the prices vary and that such variations reflect mainly transitory components. To overcome this problem, it is argued that supply response should be measured with respect to changes in average revenue. An empirical illustration substantiates this argument.

The discussion was conducted largely within the framework of equilibrium analysis. It also assumes implicitly that the relevant markets exist and function. The analysis is aggregate and deal with a simple world and as such it is not conducive to answer specific micro questions. That, however, should not dilute the conclusions.

A possible extension of the analysis that was not included is related to disequilibrium in the factor markets. Such an extension would require some changes in the analytic framework but again would not change the nature of the conclusions.

From the analytic point of view, the special feature of the analysis is in the structure of production where the technology is allowed to consist of more than one technique. The concept of a technique is very general indeed and can be used opportunistically according to needs. It was indicated above that different products are identified with different techniques. Thus capital accumulation leads to an increase in output of the capital intensive techniques and thus the process of product cycle known in the literature of international trade is produced.

Alternatively, each firm can be considered as a different technique. Each firm has embodied in it some specific factors which are summarized by the term entrepreneurial capacity. Entrepreneurs that have low level of human capital can be identified or represented by capital extensive techniques. As such they will be losing ground in the process of capital accumulation. Consequently, the industry will realize a concentration of entrepreneurs with higher level of human capital. If such entrepreneurs are also more productive, then the exit of firms will increase the productivity of the industry as a whole. Applying it to agriculture, such a process is postulated to have contributed to increase in agricultural productivity in the developed economies.[15/]

In the analysis land was suppressed by assuming the agricultural production function to be constant returns to scale in capital and labor. Again, the introduction of land would complicate the analysis without changing the main conclusion. However, such conclusion can now be extended. It is possible, by analogy to the situation where capital accumulation generates a decline in the labor share, to show that with land held fixed, capital accumultion and growth in the labor force will lead to land saving technical change. Such an approach can explain the puzzle where sometimes on small farms the factor share of land is rather small.[16/]

Figure 1.

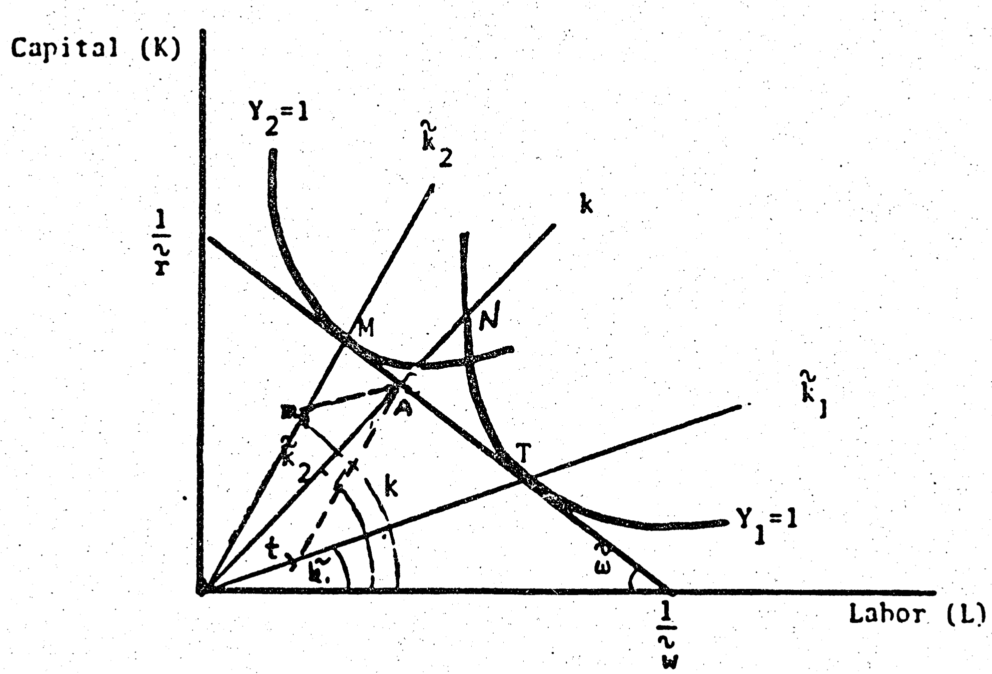


Figure 2.

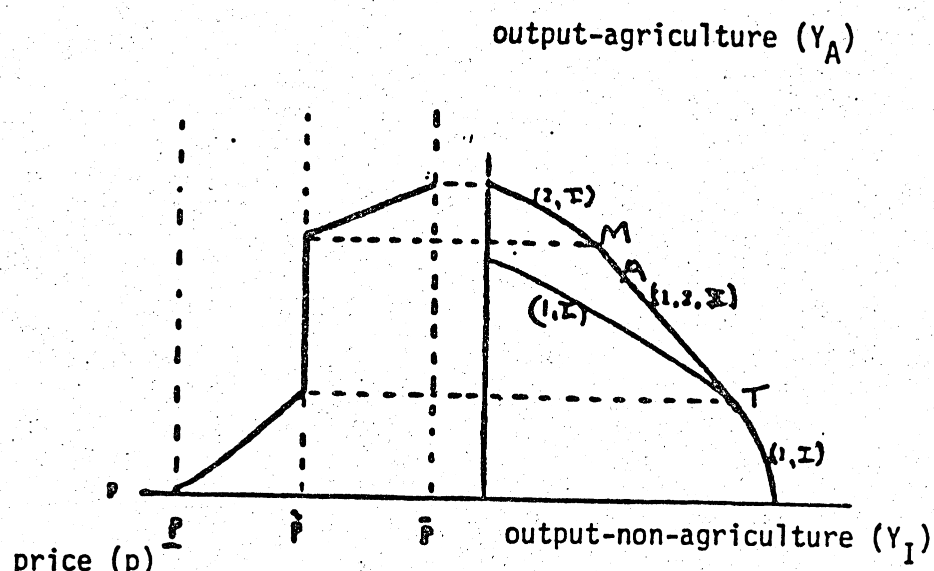
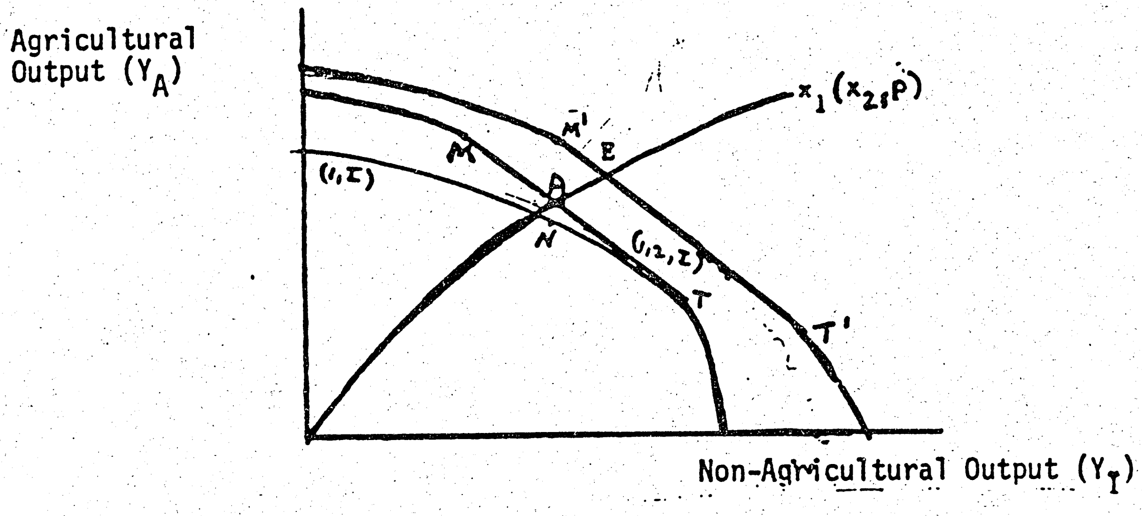


Figure 3.



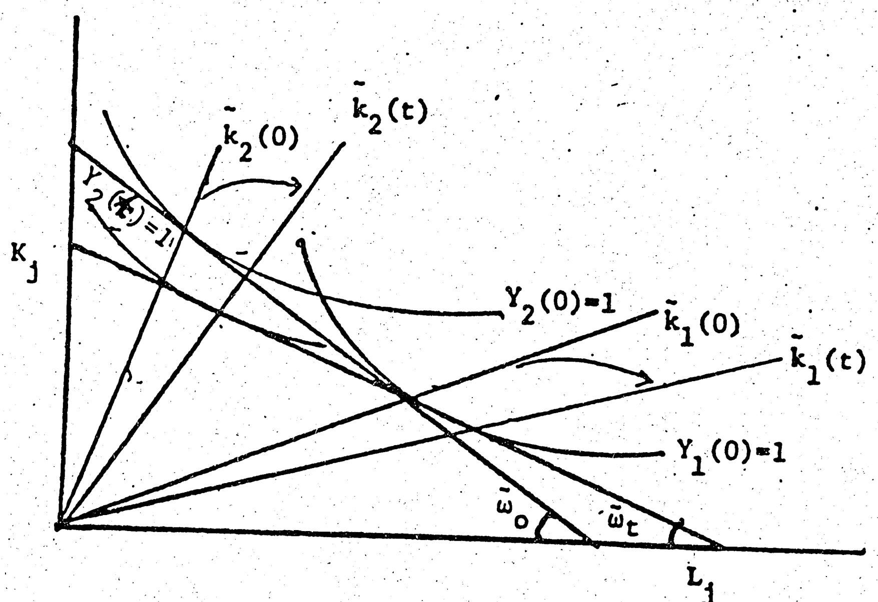


Figure 4

Figure 5

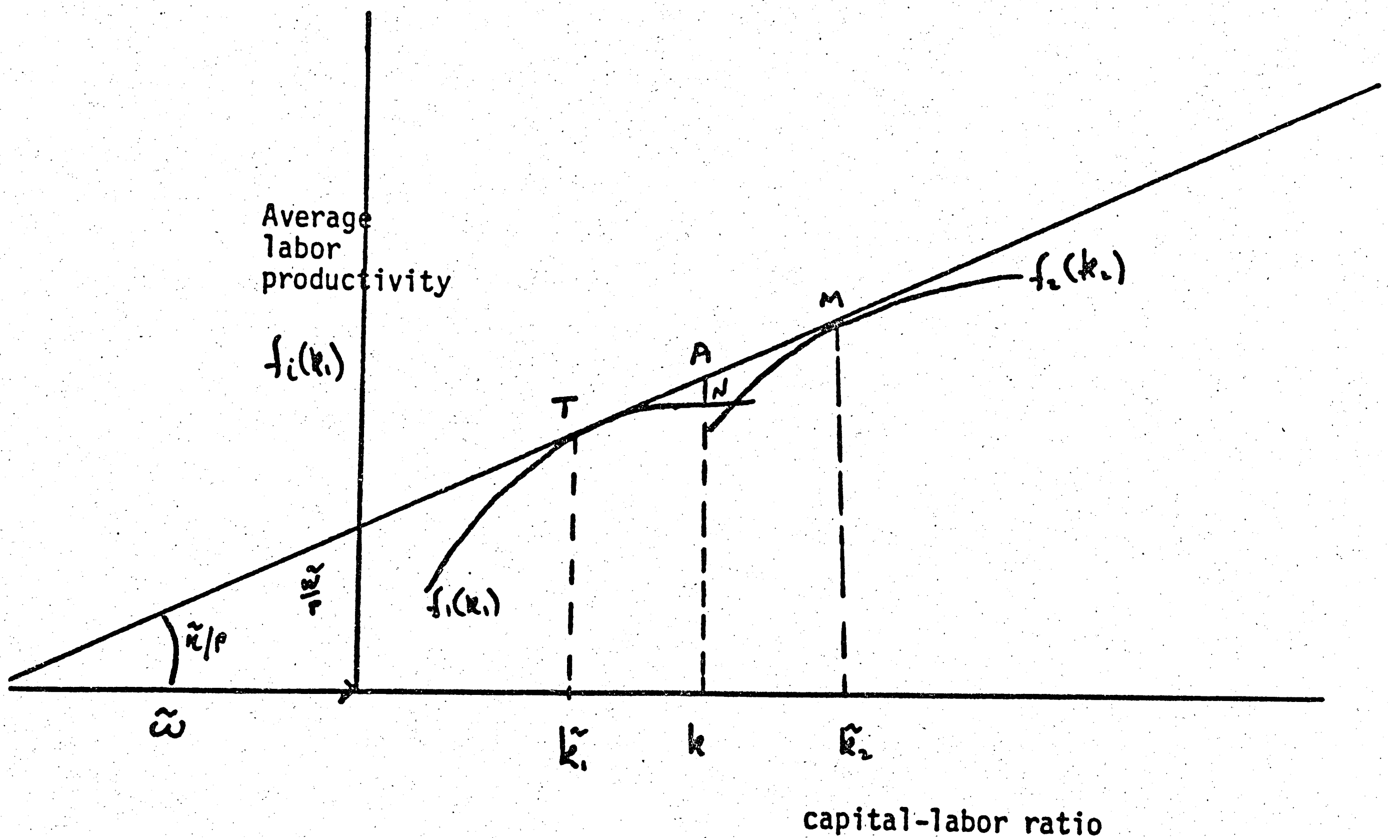


Fig. 6. Punjab: Private Tubewells

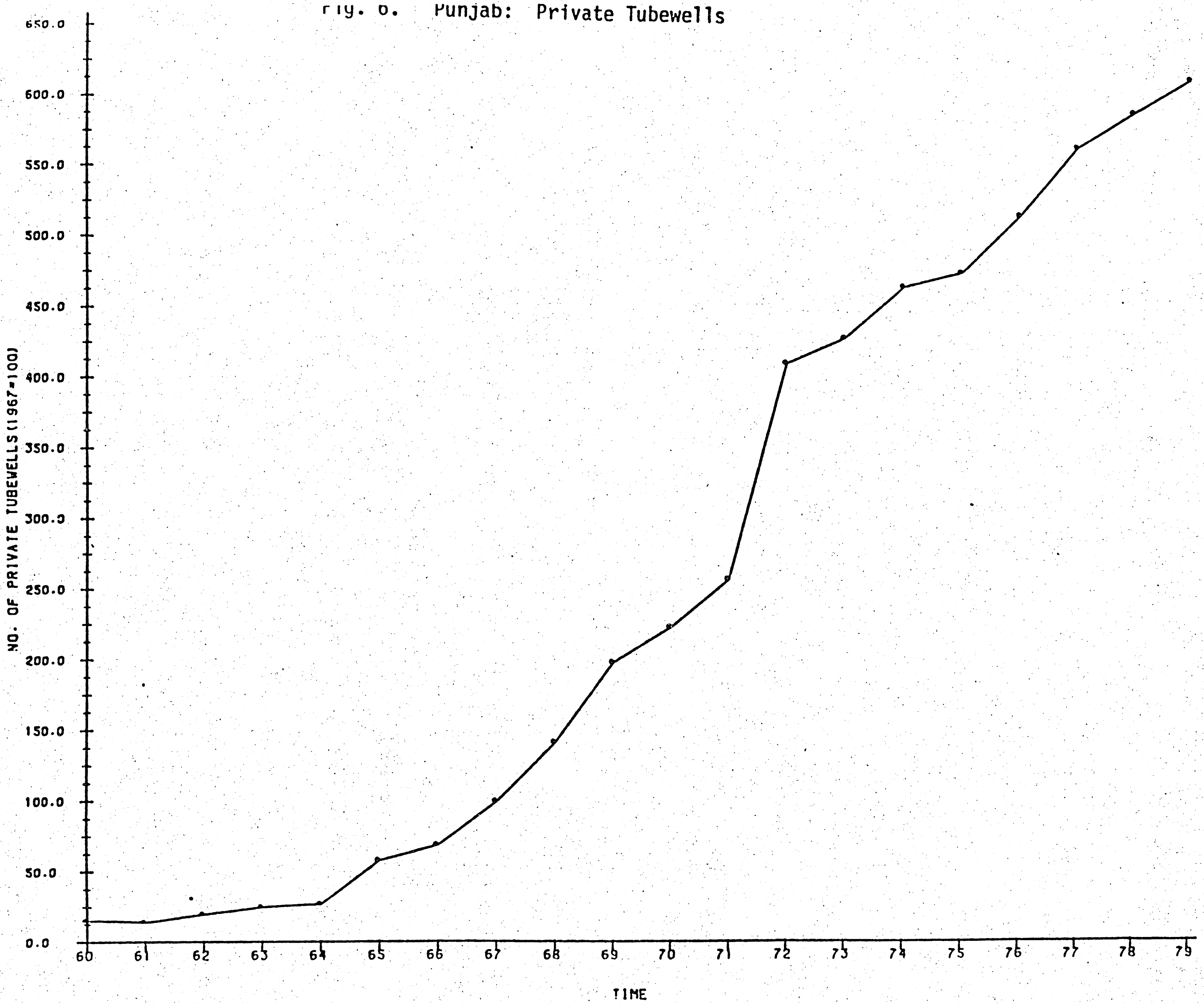


Fig. 7. Punjab: Fertilizer Usage

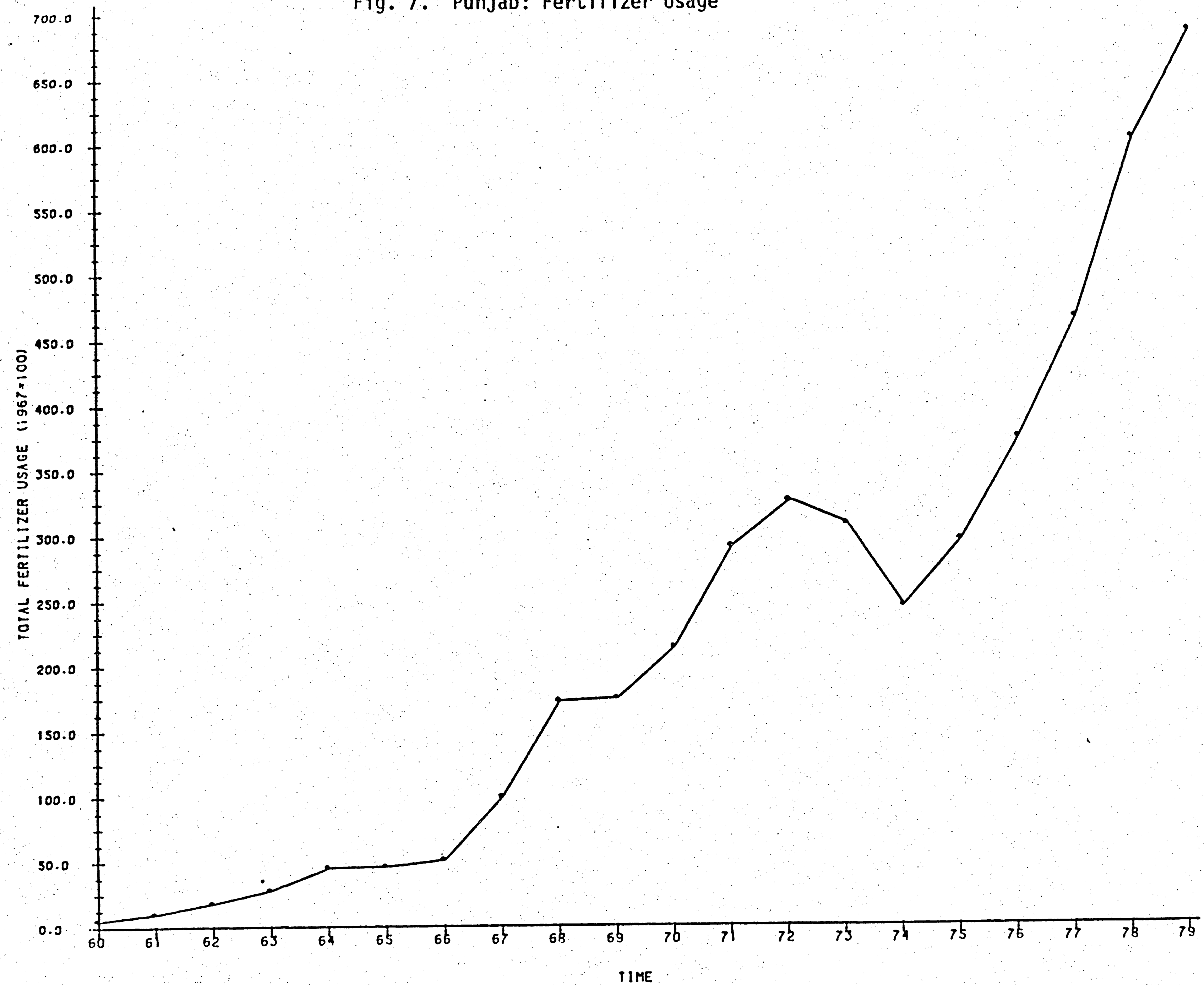
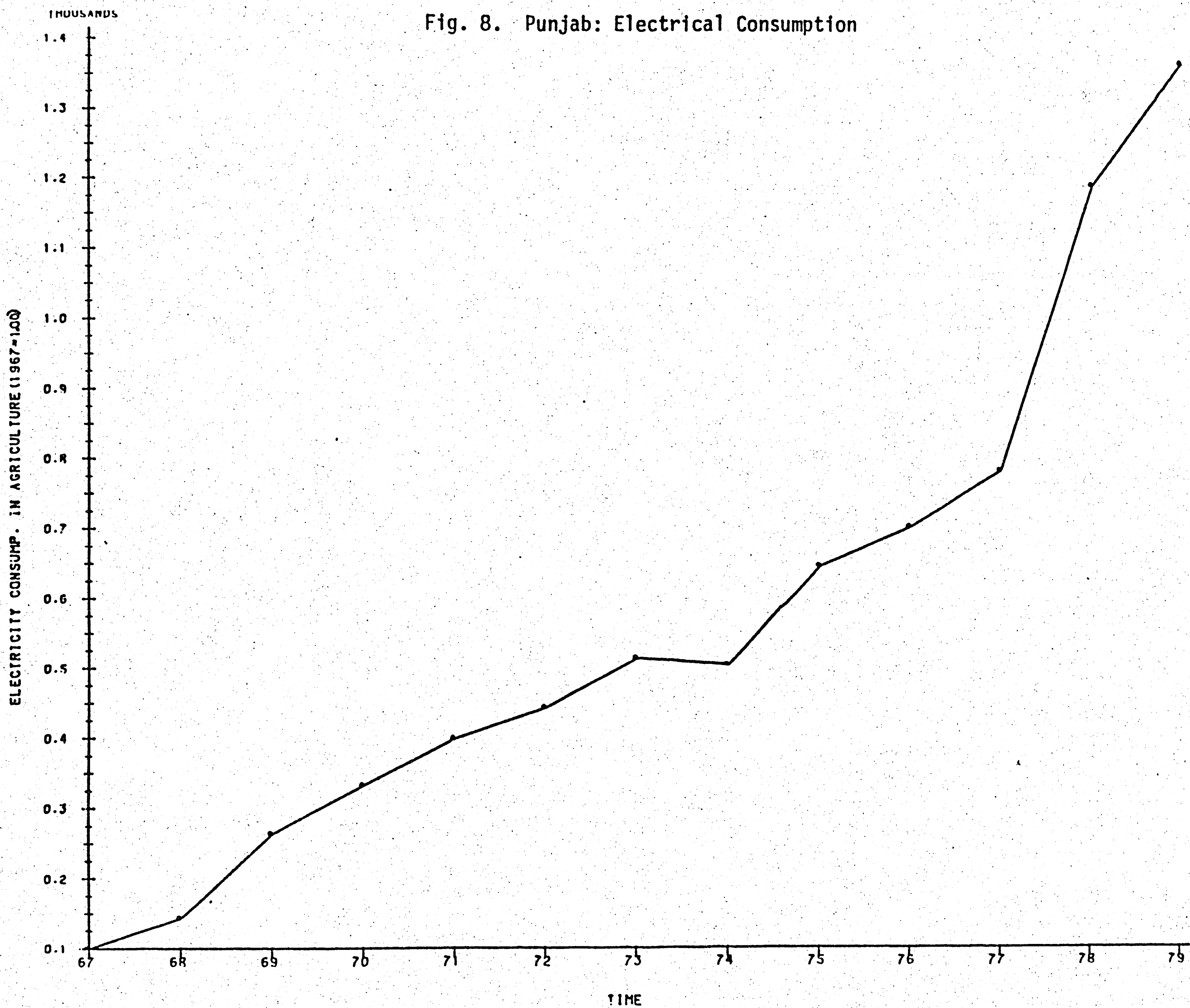


Fig. 8. Punjab: Electrical Consumption



FOOTNOTES

[1]This paper draws on Mundlak (1983).

[2]BATS, p. 5.

[3]Ibid, p. 148.

[4]Ibid, p. 50. The qualification of capital to fertilizer is attributed to the multicollinearity that exists between the various capital inputs. "However, when one starts analyzing aggregate crop data, it is discovered that irrigation gets inter-correlated with other factors like fertilizers, tractors..." (Ibid, p. 3).

[5]Ibid, pp. 148-149.

[6]Of particular importance is the implication of this approach for the econometrics of production function. This is discussed in Mundlak (1984).

[7]For more details, see Danin and Mundlak.

[8]The assumption of full employment of K and L can be expressed as $k = lk_1 + (1 - l)\, k_2$, where $l = L_1/L$ is the proportion of the agricultural labor force allocated to the traditional technique.

[9]Analytically, solve for l from the full employment conditions given in footnote 8 and note that we deal with the case of coexistence so that $k_i = \tilde{k}_i$, i - 1, 2, $l = (\tilde{k}_2 - k) / \tilde{k}_2 - \tilde{k}_1)$. Consequently, $dl / dk < o$.

[10]There are other possibilities where, at the initial or the end equilibrium point, there is a specialization in a single technique. These are not interesting cases from the point of view of applications and therefore are not discussed here.

[11]This can be shown analytically by writing the ratio of labor employed in the modern to that of traditional technique $\frac{1 - l}{l} = \frac{k - \tilde{k}_1}{\tilde{k}_2 - k}$

This ratio is increased when both threshold values decline, as should be expected. In fact, it can be shown that, for a given k, this is the only way that 1 - 1 can increase.

[12]In the literature on agricultural development, following Hayami and Ruttan, the envelope production function is referred to as a meta production function.

[13]Food and Agricultural Organization of the United Nations, FAO Production Yearbook for 1977, Table 116.

[14]Ibid.

[15]For an evaluation of the concentration of forms on productivity see Kislev and Rabiner.

[16]This question was discussed in Mundlak (1964) with respect to the low factor share of land in family farms in Israel. Such farms are very small in size (mostly less than 4 hectares). The explanation given was that in order to overcome the area limitation, farmers moved to products which require little land but are capital intensive.

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