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CHOICE OF TECHNOLOGY: A CRITICAL SURVEY OF A CLASS OF DEBATES

by

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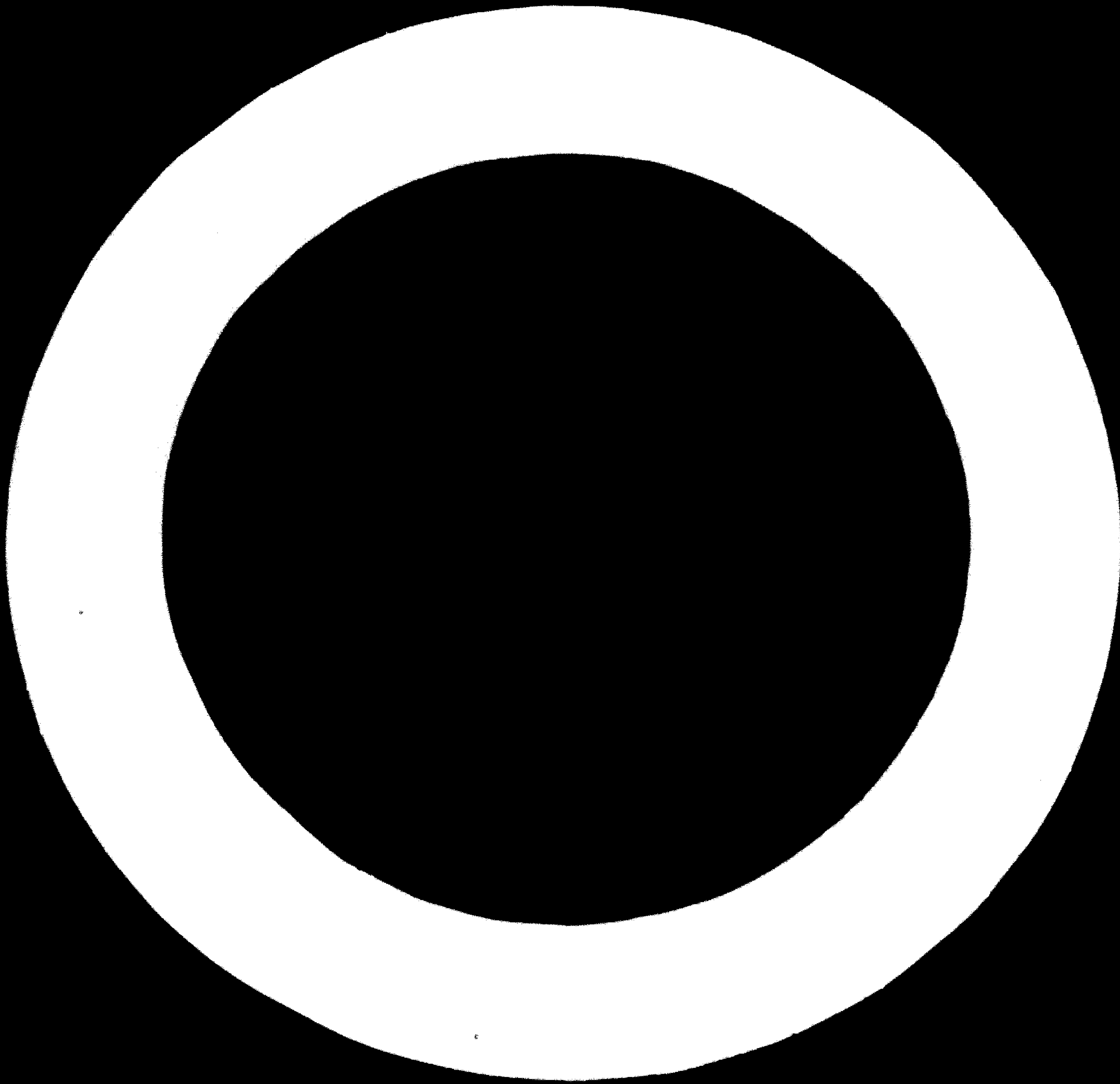

1. Efficiency and Optimality

Before entering into the debate that took place over the complex question of choice of technology in the context of development planning, certain preliminary issues have to be cleared up. This includes the concept of technical efficiency, which is one of the dominant ones in the field of policy-oriented economics.

Suppose we are considering some technical choice i which permits the production of an output combination (x) using an input combination (y). If it is possible to produce the same bundle of commodities (x) with less of at least one of the inputs and no more of any of the inputs, then the technical choice i is not efficient. This is simply because efficiency implies producing a given quantity of output with as little inputs as possible. Similarly, if with that collection of inputs (y), an output combination can be produced which exceeds (x) in terms of some output and is no less in terms of any of the outputs, then again the technical choice i must be regarded as inefficient. This is because efficiency also implies that for any given collection of inputs we should try to get the maximum of outputs.

In fact we can combine the two criteria together by treating inputs as negative outputs.1/ Thus defined, what efficiency requires is that no more of any "output" can be obtained given the amount of the others.

This criterion takes us a certain distance, but not a great deal. If a certain technical choice leads to greater output of a certain commodity and less output of some other commodity in comparison with another technical choice, the criterion of technical efficiency does not help us at all. Both these technical choices may satisfy the test of efficiency and we would be left with a problem still to be resolved.

Often the concept of technical efficiency is applied to a given point of time, but there is no difficulty in extending it over time. All we need to do is

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1/ See Debreu (1959). A good introduction to the problems of efficiency can be found also in Koopmans (1957).

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to treat a certain commodity today to be different from the same commodity tomorrow. In other respects the definitions, concepts and the criteria need not be altered. The same problem of incompleteness persists, naturally, even in the extended version of technical efficiency, embracing more than one point of time. In fact now we might face a choice whereby we have more of a certain commodity at point of time t and less of some commodity at a point of time (t + 1) in comparing two alternative technological possibilities, and once again the criterion of technical efficiency cannot resolve this feud.

The main usefulness of the criterion of efficiency is in terms of permitting a preliminary sorting out. A number of technological possibilities may be eliminated on grounds of inefficiency and then we shall be left with a set of efficient technological possibilities the choice between which must be made on the basis of some criterion. Efficiency is like a test that applies to the "qualifying round", and it needs supplementation by some other criterion to determine the winner amongst those alternatives which have qualified.

This is where the notion of optimality is to be brought in which is also one of the basic concepts used in economics. An optimum choice represents the best that we can get among the alternatives that are feasible. Naturally, in order to choose the optimum combination, we must have some criteria which can discriminate between the different alternatives.

A preliminary logical point may be cleared up at this stage. We can distinguish between two conditions for rational choice, viz. (i) the existence of a "complete ordering", and (ii) the existence of a "choice set". The former requires that any two alternatives should be consistently comparable with each other in terms of some ordering relation, e.g., "being at least as good as". This property is sometimes called "connectedness". Another required condition is "transitivity" which demands that if x is regarded as being at least as good as y, and y is regarded as being at least as good as z, then x should be

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regarded as at least as good as x[2]. When these conditions are satisfied then a complete ordering exists over the relevant conditions.

The condition of the existence of a choice set is somewhat different. This requires that there should exist some alternative which is regarded as at least as good as every alternative in the available set. This simply means that a "best" alternative exists. For the purpose of choosing an optimal policy the existence of a choice set may be regarded as sufficient. It is important to note that the existence of a complete ordering is neither a sufficient nor a necessary condition for the existence of a choice set.

It is not <u>sufficient</u> because we may be able to order alternatives in a certain fashion, but if there are an infinite number of alternatives, it is possible that no best alternative may exist. For example, alternative 2 may be preferred to 1, alternative 3 to 2, alternative 4 to 3, and so on, <u>ad infinitum</u>. It is not a <u>necessary</u> condition because we might be able to compare some alternative with all the others and find it to be at least as good as all the other alternatives, but nevertheless there may be intransitivities, or a lack of connectedness. For example x may be regarded better than y and also better than z, but we may not be able to compare y and z using whatever criterion we might be using. Even then we might feel safe in choosing x, since it is the best alternative, even though we cannot compare the two inferior alternatives, viz, y and z.

Inspite of this difference between the conditions for the existence of a "choice set" and the condition for the existence of a "complete ordering", it

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2/ On the logic of ordering, see Arrow (1951), and Debreu (1959). It may be noted that the way we have defined any two alternatives being comparable guarantees not only "connectedness", but also yields "reflexivity", which requires that every alternative be regarded as "at least as good as" itself. When the alternatives considered are the same, what was defined as "connectedness" is in fact a condition of "reflexivity". By and large in optimal policy decisions, reflexivity is not a major source of worry; in fact, a minimal degree of sanity seems to be sufficient to guarantee this. The real problem arises with connectedness and transitivity. On this, see in particular Arrow (1951).

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is nevertheless clear that there is an intimate relationship between these two aspects of rational choice. In fact, most of the discussions on optimality have been concerned with getting a criterion for a complete ordering, and it has been supposed that this will, in itself, guarantee the identification of a best alternative. This presupposition makes eminent sense when the number of alternatives is finite, when a consequence of the existence of a complete ordering is the existence of a choice set. When, however, the number of alternatives is infinite this may or may not be so. Furthermore, even when a complete ordering does not exist we might still be able to find the best thing to do. While we shall not be concerned very much in this paper with this contrast, it is important for us to bear in mind the difference between these two requirements of rational selection. Indeed, in some problems the distinction can be extremely important.

No matter whether we concentrate on a "choice set", or a "complete ordering", we need some method of ordering, i.e., a criterion to tell whether a certain alternative x is better than, or worse than, or indifferent to, another alternative y. The concept of technical efficiency can be used partly for this purpose, and we might find that x is more efficient than y and simply eliminate y. However, as we noted before, this does not help when x and y are both efficient. Much of the debate on the choice of techniques is concerned with the supplementation of the criterion of technical efficiency by some other criterion that will permit us to tell between the efficient alternatives. In the discussion that follows, we shall be concerned with a choice among a set of efficient alternatives, and shall assume that the inefficient ones have already been pruned out.

Thus, we shall have no further use for the concept of efficiency as such, which (it will be assumed) has done its job, and the discussion will concentrate on some supplementary criteria which takes us beyond efficiency. The lively debate on technological choice which has taken place over the last two decades has been concerned with methods of supplementing the relatively uncontroversial criterion of technical efficiency. To this range of problems, we now turn.

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2. Sub-Optimality of Savings Rate and Choice of Technology as a Problem of "Second Best"

Investment decisions can be classified into various types, e.g., the optimum size of investment, the optimum capital-intensity, and the optimum sectoral allocation. While it is important that we recognise these investment decisions to be different, we cannot regard them to be independent. Indeed much of the controversy on the choice of technology concerns the dependence of the amount of savings on the factor proportions selected.

A simple illustration may bring out the difference between some of the schools of thought. It may be argued that wage earners tend to have a higher propensity to consume than those who earn the profits. This is likely to be spectacularly so in a socialist economy where the profits are earned by the State, but it may hold even in the case of a privately owned enterprise. Given this assumption, it will appear that the proportion that is saved out of the additional income will depend on the distribution of the additional income between the wage earners and the profit earners. And this distribution, in its turn, depends on the choice of technology, since a more labour-intensive technique will (given other things) tend to lead to a higher share of wages.

A special case of this has been much discussed in the literature, viz., the assumption that the wage earners have a propensity to consume of 1 and profit earners have a propensity to consume of 0. This is, however, a rather limited case, and the problem with which we are concerned holds under much more general conditions, viz., whenever the propensity to save of profit earners is systematically higher than the propensity to save of wage earners. Given this assumption there would be a direct link established between the degree of labour-intensity chosen and the proportion of the additional income that will be saved.

It is easy to describe situations where one technique will lead to a higher amount of total output and another technique will generate a higher amount of total savings. If we wish to attach an additional weight on the savings generated,

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over and above the weight that is attached to all output (be it saved or consumed), then clearly this will affect our decisions regarding which techniques to choose.

For the purpose of this discussion total output and total savings may be regarded as two separate commodities, even when they are assumed to be physically homogeneous, as in some simple models. The question of economic efficiency discussed in the last section may be applied to such a case. Any technique which generates less of either total savings or total output and no more of the other, may be simply rejected as inefficient. But after this preliminary pruning operation has been carried out, we would be left with a set of techniques that cannot be compared on pure efficiency grounds. We shall then have cases with a higher amount of total savings going with a lower amount of total output. Which do we choose, in such a situation, will depend crucially on the additional weights to be attached to savings vis-a-vis output.

At this stage we might ask "Why must we attach any additional weight on savings as such?" After all savings involve a certain sacrifice of present consumption in favour of future consumption, and what reason is there for us to believe that it is always better to sacrifice present consumption for the corresponding amount of future consumption? Indeed there is no such compelling reason, in general. What the debate on choice of technology did was to assume (often implicitly) a sub-optimal rate of savings whereby some outside constraint prevented the savings rate from rising to the optimal level. As a consequence, there was a persistent reason for looking kindly towards any policy which led to a higher proportion of savings.

Why this sub-optimality should arise is itself a complex question. In the case of a private enterprise economy it can certainly be argued that the rate of savings may be considerably below optimal.3/ In particular, it has been argued that people might be willing to sign a contract forcing everyone to save a certain amount for the future, even when they may not do it individually under

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3/ See Pigou (1932), Ramsey (1928), Baumol (1952), Dobb (1960), Sen (1961), (1967b), Marglin (1963a), (1963b), Feldstein (1964), and others.

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the market mechanism, and a situation of this kind has been christened as the "Isolation Paradox."4/

There seems to be considerable agreement at a practical level regarding the need for raising the rate of saving for many under-developed countries. Indeed one has only to look through the planning documents of a variety of countries to see how one of the persistent themes is the need for a higher rate of saving and a higher rate of growth.5/ These clearly are based on some assumptions, usually implicit, about the objectives to be achieved by the economy, in terms of which the existing rates of saving appear to be below optimal. Sometimes the arguments are fairly sophisticated,6/ sometimes not.

Whatever the reasons for the sub-optimality of the savings rate, that this is a persistent diagnosis for most under-developed economies seems to be clear. In the presence of such sub-optimality it is not difficult to see why an additional weight has to be attached to the part of the additional income that is saved and invested compared with the part that is consumed. It is in this context that much of the controversy on the problem of choice of technology in the recent years can be fully understood.

Essentially the problem as stated is that of choice of technology in a world of sub-optimal savings. It can also be viewed as a problem in the theory of "Second Best."7/ Since there is misallocation at the margin of choice between savings and consumption, thanks to some specific constraint, this will reflect itself on the choice of the degree of labour-intensity implicit in

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4/ Sen (1961). See also Baumol (1952), Marglin (1963a), Harberger (1964), Lind (1964), Phelps (1965) and Sen (1967b).

5/ See R. F. Kahn (1958) for a review of some of the planning documents in this context.

6/ Optimum savings models have tended to yield extremely high rates of savings as the general rule. These are very much in excess of the usual rates of savings observed anywhere in the world. See in this context Tinbergen (1956), (1960), Goodwin (1961), Chakravarty (1962), Sen (1967a), among others.

7/ See Lancaster and Lipsey (1956).

technological selection. The problem would have been totally different if it had been a case of allocating an optimal amount of savings between techniques with varying degrees of labour-intensity.

A distinction should in this context be made between (i) a general equilibrium formulation where the amounts of saving, the degrees of labour intensity, and the pattern of investment are to be simultaneously selected, and (ii) a partial equilibrium picture where the technical choice is confined to finding an optimal labour-intensity for a marginal project. In the former case the inoptimality of the savings rate may not be assumed, but may result from the allocational exercise. In the latter case, an over-all sub-optimality of savings may be taken as given, since the project in question is too small to affect the overall inoptimality of savings.

One may be given some kind of an objective function which depends on technical choice and the proportion of savings. In the absence of any constraint on savings our choices should lead to an optimal situation with the usual marginal equalities, if the exercise is of the former kind. That is, in the absence of a specific constraint on the rate of savings, the rate of transformation between consumption at time t and consumption at time (t + 1) will equal the rate at which we are ready to substitute one for the other.8/ There would then be no need for a marginal preference in favour of future consumption, implying an additional weight on the savings generated. On the other hand, even in the general equilibrium framework, if some outside constraint is imposed which prevents the rate of saving from rising above a certain level, a sub-optimality of savings could result. Then it will be appropriate to attach an additional weight on savings vis-a-vis the part of the income immediately consumed.

8/ This is with the assumption of smooth differentiability. When there are only a limited number of basic alternatives, resulting in "kinks" in the transformation surfaces, the corresponding rule will take the form of a set of inequalities. See Dorfman, Samuelson and Solow (1958), Chapter 12.

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Such constraints can arise for a variety of reasons, including political difficulties in taxation. The planners may want a higher rate of saving in terms of the objectives assumed by them, but fail to achieve this for fear of political reactions.[9] Given this political constraint, the sub-optimality of the savings rate that may be generated will tend to influence the optimal technical choice in the direction of choosing relatively more capital-intensive techniques, implying a relatively higher rate of savings.

This is precisely where a different school of thought can be found, who may argue that such political constraints do not in fact hold. It has been argued that the total amount of income to be saved can be determined by the planner in any way he likes, and he can then see that this decision is executed through such machinery as are in his disposal, e.g., wages and incomes policy, taxation policy, and monetary policies. If this is assumed then the link between the choice of techniques and the proportion of income saved goes. Then technical choice may be made with the aim mainly of maximising the amount of output,[10] and the proportion of the output to be invested could be left to a decision to be made at a separate stage.

In the context of such an assumption it will be right to argue that in a surplus labour econmomy people should try to maximise the amount of income generated, forgetting all about savings. This argument could spring either from assuming that there is no sub-optimality of savings, or from assuming that the proportion of income that can be saved, even if constrained, is not dependent on the distribution of income. Various strains of these arguments can be seen in the literature.

9/ Whether this range of problems can arise in a fully socialist economy is a matter for discussion. For some indications that they do, see Pajestka (1962), and Marglin (1966).

10/ The implicit framework here is that of a one-commodity model, but the corresponding conditions for a multi-commodity model are easy to obtain.

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Having commented on what appears to be some of the major issues that divide the different schools of thought in the debate on technical choice, we may now proceed to discuss the controversy in some greater detail. We develop a general framework in the next section and then express the various criteria in terms of that for comparison and contrast. This general framework will use a highly simple model with one homogeneous commodity, which nevertheless captures almost the entire controversy on choice of techniques for an under-developed economy, which took place in the recent years. At a later stage in the context of a model on concave programming, we shall release this assumption, and discuss the problem in a multi-commodity context.

3. A General Framework

Let there be a production function relating output (Q) to labour (L) and capital (K).

$$Q = Q(L, K) \qquad \ldots (1)$$

We assume this to be homogeneous of the first degree, i.e., with constant returns to a scale. Let the wage rate be given by w, the propensity to consume of wage earners by c_1 and the propensity to consume of the profit earners by c_2. The amount of the income that is saved is represented as S, which is given by the following relationship:

$$S = L.w(1 - c_1) + (Q - L.w)(1 - c_2) \qquad \ldots (2)$$

We assume that the supply of labour is unlimited.[11/] The object of the exercise is to maximise a certain weighted sum of output and savings.[12/] It is to be

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11/ For a contrast of views on the empirical acceptability of this assumption, see Nurkse (1953), Lewis (1954), (1955), (1958), Eckaus (1955), Meller (1956), Rosenstein-Rodan (1957), Leibenstein (1957), Viner (1957), Haberler (1957), Oshima (1958), Fei and Ranis (1964), Schultz (1964), (1967), Jorgenson (1966), (1967), Marglin (1966b), Sen (1966c), (1967b), Mehra (1966), among others.

12/ In a general equilibrium framework, the weights should vary with the choice of techniques, and the objective function should be "Non-linear" (see Sen (1962), Appendix E). However, in the case of a small project, the total savings and consumption for the economy as a whole, may not be much affected by the marginal choice. There the weights can be taken as given, much like the perfectly competitive firm taking the prices as given.

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remembered that savings S is a part of output Q, so that the weight attached to S is in the nature of "a premium", i.e., it is an <u>additional</u> weight over and above the weight that S receives as a part of Q. Let this premium on savings be given by λ, which we have taken to be positive, since we have assumed the savings rate to be sub-optimal.[13/] The object, therefore, is to maximise the following welfare function

$$V = Q + \lambda \cdot S \qquad \ldots (3)$$

Given the amount of capital, the problem of choice of techniques is simply to find the right amount L, which will determine the appropriate degree of capital intensity (K/L). Thanks to the assumption of constant return to scale it does not matter how we choose K, for the discussion is all in terms of ratios per unit of capital. It is clear that the first order condition of maximisation of the objective function is given by

$$\frac{\partial V}{\partial L} = 0 \qquad \ldots (4)$$

Given the equations (1), (2) and (3), it can be seen that the condition of maximisation given by (4), requires the following:

$$\frac{\partial Q}{\partial L} + \lambda \left[w(c_2 - c_1) + \frac{\partial Q}{\partial L} (1 - c_2) \right] = 0 \qquad \ldots . (5)$$

As a condition on the marginal productivity of labour we can re-write relationship (5) as follows, defining that magnitude to which the marginal product of labour is to be equated as "the real cost of labour" (w^*).

$$w^* = \frac{\partial Q}{\partial L} = \left[\frac{(c_1 - c_2)\lambda}{1 + (1 - c_2)\lambda} \right] w \qquad \ldots (6)$$

Much of the controversy on the choice of technology for an underdeveloped economy with surplus labour can be seen to be variations on the theme represented by (6). With this general framework, we can sort out the different contributions in this controversial field.

13/ The choice discussed here is for a marginal project. A more wide exercise should take λ as a variable. The optimality conditions, however, will remain the same for appropriate values of λ.

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One clarificatory remark should be made before we proceed further. The evaluation of alternative techniques depends crucially on the value of λ, i.e., on the additional weight to be attached to investment vis-a-vis consumption. The value of λ in its turn depends on the relative weights to be attached to consumption today vis-a-vis that in the future. What we are really trying to do, therefore, is to provide a one-period model which tries to catch the essence of comparison of the relevant sets of time series of consumption representing alternative technological possibilities.

That the problem of choice of techniques cannot but be solved except in terms of making explicit value judgments about alternative sets of time series was discussed in Sen (1957), where it was also shown that the different criteria proposed in the literature really boil down to doing this very thing in a highly implicit manner. Explicit attempts at making these comparisons can be found in Sen (1957), (1960), Eckstein (1957), Bagchi (1962), and others. This problem has been penetratingly studied by Marglin (1966a), in an approach that we are going to comment on later.

4. Contributions of Lewis, Polak, Buchanan and Kahn

In his classic study of the theory of economic growth, Lewis (1955) analysed the problem of choice of techniques for economies with surplus labour. He argued:

> "Special care is to be taken in those countries which have a large surplus of unskilled labour, for in such circumstances money wages will not reflect the real social cost of using labour. In these circumstances capital is not productive if it is used to do what labour could do equally well; given the level of wages such investments may be highly profitable to capitalists, but they are unprofitable to the community as a whole since they add to unemployment but not to output." 14/

> "It is then arguable that the real cost of using labour in cottage industry is zero, whereas factory production uses scarce capital and supervisory skills." 15/

It is clear that there is some assumption under which the "real cost of labour" will in fact be zero, as argued by Lewis. Looking at equation (6) the question that arises is this: what is it that Lewis is assuming which leads to

14/ Lewis (1955), p. 386.

15/ Lewis (1955), p. 140.

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this result? It should be one of two things: either (i) he is assuming that $c_1 = c_2$, that is both the classes have the same propensity to consume, or (ii) that $\lambda = 0$, i.e., there need be no premium on savings. The first does not seem to be the assumption that Lewis is making. The second assumption, however, fits in very well with Lewis' presentation. While Lewis is concerned with inadequate rates of growth in underdeveloped countries, his analysis is not based on an explicit identification of "optimal" rates of saving. This is partly because Lewis focuses attention on factors other than capital accumulation influencing the rate of growth. But this is also due to the fact that he does not discuss growth in terms of optimisation, so that no concept of sub-optimal growth (or sub-optimal savings) can emerge. Assuming, therefore, that no special weight is to be attached on savings vis-a-vis consumption, it would appear that Lewis' deduction that the real cost of labour is nil would follow.

$$w^* = 0 \qquad \text{... (6.1)}$$

Polak (1943) had suggested in a pioneering discussion of the balance-of-payments problems of countries reconstructing after the war that there was a special virtue in maximising output per unit of capital. Buchanan (1945) made a similar suggestion: "If investment funds are limited, the wise policy, in the absence of special considerations, would be to undertake first those investments having a high value of annual product relative to the investment necessary to bring them into existence."16/

This criterion has sometimes been referred to as the "Rate of Turn-over Criteria". It was strongly criticised by Kahn (1951) because it assumed that capital was the only scarce factor. He argued that the social opportunity cost of employing labour to produce the output has to be deducted from the figure of the "value added". So what one should try to achieve is the maximization of output taking into account all the relevant opportunity costs. This criterion has sometimes been known as "Social Marginal Productivity Criterion."

Even in this context, however, it may be argued that the real cost of labour could be taken to be zero when dealing with a surplus labour economy. In fact

16/ Buchanan (1945), p. 24.

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Kahn himself found the Polak-Buchanan criteria to be "particularly desirable" in such an economy.17/

This too can be seen to be a case of deriving a zero shadow price of labour by taking λ equal to zero. There is indeed no discussion here about any sub-optimality of savings requiring an additional weight to be put on savings vis-a-vis consumption. In the absence of such sub-optimality, it does indeed make sense to assume the real cost of labour to be nil. It would thus appear that the contribution of Lewis, Polak, Buchanan and Kahn concentrate on a situation where λ is taken to be nil and savings are not assumed to be sub-optimal.

5. Contributions of Dobb, Galenson and Leibenstein

One of the most penetrating analysis of the problem of choice of techniques for a planned economy in the context of surplus labour was provided by Maurice Dobb. Indeed Dobb (1960) must be regarded as a classic in the field of development planning. It is a little unfair to identify Dobb only with a criterion that he formally proposed, since much of the ground-clearing in this intricate branch of economics was also done by him, in a series of contributions.18/

Maurice Dobb has emphasized the crucial link between choice of techniques on the one hand and the rate of saving and the rate of growth on the other. His own emphasis is very much towards the maximisation of the rate of growth. It is clear that if this is our only objective, the weight that is attached to savings vis-a-vis consumption today is infinitely large, since it is the savings rate and not immediate consumption that affects the rate of growth.19/

It can be checked that more the relative weight to be attached to savings vis-a-vis consumption higher the value of λ. As we move towards the extreme

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17/ Kahn (1951), p. 51.

18/ Dobb (1954), (1956) and (1960)

19/ In all these discussions the impact of consumption on productivity through such things as nutrition is being assumed away. Dobb himself touches on this question a little bit in the context of discussing the higher productivity of labour in the advanced economies given the complementary equipment; see Dobb (1956), p. 37-38. See also in this context Galenson and Pyatt (1964).

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cases of trying to maximise only the rate of growth, becomes "very large". And (6) reduces to the following formula:

$$w^{*} = \frac{\partial Q}{\partial L} = \left[\frac{(c_1 - c_2)}{(1 - c_2)}\right] w \qquad \ldots (6.2)$$

In Dobb's calculation the real cost of labour was identified with the wage rate itself and this will indeed be the case with his assumptions. Since it is assumed that workers consume everything i.e., $c_1 = 1$, from (6) we get:[20]

$$w^{*} = w \qquad \ldots (6.3)$$

The criterion put forward by Galenson and Leibenstein has been the hub of much controversy. While much misunderstood, it had a phenomenal impact. It has a number of different aspects, including an important emphasis on the effect of increased income on the rate of growth of population, which was a somewhat special element in their criterion. However, concerning the controversy in question, the Galenson-Leibenstein criterion is very similar to that of Dobb. The emphasis on maximising the rate of growth which makes it appropriate to consider (6.2). Further with the assumption of $c_1 = 1$, (6.3) gives the relevant labour cost.

A formula that Galenson and Leibenstein use, is:

$$r = \frac{p - e.w}{c} \qquad \ldots (7)$$

where

p = output per machine,

e = number of workers per machine,

w = wage rate, and

c = cost of machine.[21]

It is clear that maximisation of r amounts to maximising the rate of profit

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20/ Dobb also assumes that $c_2 = 0$, i.e., all profits are saved. This assumption is optional for (6.3).

21/ Note, however, that capital here is identified with fixed capital only. This, under certain circumstances, may be very misleading because of the quantitative importance of working capital. On this see Sen (1960), pp. 110-113.

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per unit of capital.[22] If the choice of techniques is aimed at maximising r, then labour is to be valued at the market wage rate. This corresponds to (6.3).

Galenson and Leibenstein, like Dobb, concentrate on the case where $c_1 = 1$, and $c_2 = 0$. The latter assumption is quite redundant for the specific allocational rule recommended, i.e., even for (6.3). That $c_2 = 0$ is not a necessary assumption has not been widely recognised. Ranis (1962) argues that the "Galenson-Leibenstein case is based on two rather extreme assumptions", including the marginal propensity to save out of profits being "one"[23] Hirschman and Sirkin (1958) in their critique of the Galenson-Leibenstein criteria recommend that "we must discard the assumption that all profits are reinvested," since it is "particularly unrealistic."[24] However, in fact, this assumption is quite redundant for the "Galenson-Leibenstein rule", since (6.3) follows from (6.2) whenever $c_1 = 1$, no matter whether c_2 is zero or positive, as long as it is less than unity. In fact the precise value of c_2 makes no difference to the allocation rule for growth maximisation, given $c_1 = 1$.

6. Contributions of Chenery

Professor Chenery has made a number of penetrating contributions to the discussion of choice of techniques. He has consistently emphasised, beginning with his earliest contribution,[25] the need for a programming framework, and has explicitly considered trade balance considerations and income distribution as parts of the welfare function. Since both these elements have been relatively neglected in the literature,[26] Chenery's contributions have been particularly apt.

22/ Galenson and Leibenstein are much concerned with the case represented by (7) but they treated it really as an "illustration". While this case corresponds to the allocational rule given by (6.3), i.e., $w^* = w$, they really aimed at a more general case, as explained by Leibenstein (1963) and Galenson and Pyatt (1964).

23/ Ranis (1962), p. 300.

24/ Hirschman and Sirkin (1958), pp. 469-70.

25/ Chenery (1953)

26/ See, however, Polak (1943).

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However, in the context of the specific debate on the degree of labour-intensity to be chosen in a labour-surplus economy, Chenery fell into a trap. He identified the cost of labour as the "increase in consumption",27/ which would make it identical with the criterion proposed by Dobb, Galenson and Leibenstein, i.e., corresponding to (6.3). It is not clear, however, whether this was what he intended, viz., to put all emphasis on growth and none on immediate consumption. As he explained: "The effect on national income, $\triangle$ Y, can be approximated by applying a set of corrections to the businessmen's calculation of the annual rate of profit."28/

There is a strong ambiguity here since this way of measuring the "national income" amounts to attaching a weight of zero to immediate consumption and putting all weight on investment, which is not the standard practice in national income calculations. This would make sense in the context of the extreme assumptions of growth maximisation, where the price of immediate consumption in terms of saving is taken to be nil, but this does not seem to be the intention of Chenery. Perhaps what is intended is to get a weighted sum of consumption and investment, and it may be surmised that Chenery was moving towards the same type of problem as we have been concerned with in the determination of λ.

In his later explorations of the problem Chenery has clarified the picture very substantially. In Chenery (1955), Chenery (1959), and Chenery (1961), we find a series of discussions based on an explicit presentation of an objective function involving a variety of considerations, with a programming exercise leading to the choice of an optimum technological pattern, along with an optimum investment allocation in general. The emphasis is very much on the inter-dependence of the different sectors and on the possibility of using accounting prices. The ambiguity referred to above about the cost of labour does not occur in these later contributions, and the general framework of discussion is broad enough to take into account most of the alternative criteria proposed in the literature.

27/ Chenery (1953), pp. 82-83.

28/ Chenery (1953), p. 82.

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7. Contributions of Bator, Fei and Ranis

Francis Bator in a provocative paper argued that there was "no conflict" between maximising present output and maximising the growth rate. 29/ Since the controversy at that stage was very much concentrated around this particular problem, this was a startling statement. However this result followed simply from his assumption that "the rate of saving is independent of the (as if) market imputed distribution of income."30/

In terms of our model this would correspond to the assumption that $c_1 = c_2$.31/ If the rate of savings is to be independent of the rate of distribution of income, there cannot be any difference in the effective propensity to consume of the two classes. This immediately yields the result $w^* = 0$, as in (6.1). Given this assumption about savings, the extra weight to be attached to savings makes no difference whatever to our choice of techniques. A choice of technique that maximised the immediate income would then also maximise the amount of savings, and therefore irrespective of the weights to be attached to the two, the optimum policy should be to maximise immediate output. With a surplus labour economy this involves choosing a technique of production as labour-intensive as efficiently possible.

In this context we might make a contrast between the result of the "real cost of labour" being nil as discussed by Polak (1943), Buchanan (1945), Lewis (1955) and Kahn (1953), and that by Bator (1957). While the former group of people are not concerned with sub-optimality of savings as such, and therefore implicitly assume $\lambda = 0$, Bator is concerned with it. He does not, however, have to link up the problem of generation of savings to choice of techniques because of his assumption of $c_1 = c_2$. Either assumption is sufficient to yield the result: $w^* = 0$.

29/ Bator (1957), p. 99.

30/ Bator (1957), p. 98.

31/ This does not necessarily happen automatically, and Bator assumes an efficient fiscal machinery which yields this result through deliberate policy.

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The models of Fei and Ranis are not by and large optimality models. They are essentially concerned with what happens rather than what should happen. However, in Fei and Ranis (1964) we find an assumed relation between income distribution and savings. While critical of Galensen and Leibenstein formulation, Ranis (1962) is also much concerned with growth. He is, however, relatively optimistic about the possibility of taxation bringing about a change in the savings rate from that determined by the market. This is not surprising because of Ranis' concern with possibilities of taxation in the financing of economic development, and his study of the rather successful Japanese case.[32/]

However, we cannot attribute any specific criterion to Ranis and Fei since they do not state explicitly any optimality conditions from which an optimal choice of technique can be derived. Nevertheless, their works provide some insight into the problem in question.

8. Contributions of Eckstein

Eckstein (1957) put forward a synthesis of the different criteria proposed. His discussion can be translated into the framework of (6). In effect Eckstein's procedure amounts to obtaining a value of λ by the explicit use of a discounting operation of future consumption possibilities. The discount rates are related to the utility functions of the individuals and their chances of survival over time.

Eckstein defends the use of the individuals' "pure time discount" in social choices by appealing to "consumers' sovereignty", which is somewhat dubious, since (a) the consumers involved are not only the present ones but also those yet to be born, and (b) even for the present generation "consumers' sovereignty" may not get adequate expression in their individual time preferences thanks to various types of inter-dependencies discussed by Baumol (1952), Sen (1961), (1967B), and Marglin (1963a).

32/ See Ranis (1959).

/...

But aside from this question, Eckstein did achieve a synthesis which sorted out many of the outstanding issues. If the cases discussed by Polak (1943), Buchanan (1948), Kahn (1951), Lewis (1955) and Bator (1957) correspond to the allocational rule (6.1) and those discussed by Dobb (1954), (1956), (1960), and Galensen and Leibenstein (1955) correspond to (6.2), or (6.3), Eckstein (1957) aimed at the general formula (6).

9. Contributions of Marglin: Savings and Technical Choice as Variational Problems

Marglin's main contribution has been to provide an integrated framework of analysis for problems of optimum accumulation and those of technological choice. The usual variational studies of optimum accumulation have tended to ignore problems of technical choice, or have (alternatively) denied any special link between savings and technical choice via the distribution of income.33/ Marglin (1966a) has provided a framework for a successful integration of these two facets of investment allocation. We cannot do justice to Marglin's many-sided contributions here, but we present below some comments on his main approach.

We use the following symbols: C = total consumption, K = total capital stock Q = total output, l = employment per unit of capital, q = output per unit of capital, and U = utility at a given point of time. U is assumed to be a function of C of that period, i.e., $U = U(C)$.34/ The function to be maximised is the aggregate of U over time, W.35/ $\dot{K}$ stands for investment, i.e., $\dot{K} = \frac{dK}{dt}$. The exercise consists in maximising W, given the following relations between output, savings, and consumption for the economy as a whole:

33/ See Ramsey (1928), Goodwin (1961), Samuelson (1960), Chakravarty (1962), Sen (1967a).

34/ This assumption of the independence of one period's utility from the value of consumption in other periods is not a very satisfactory assumption (see Hicks (1965), pp. 256-8). This is, however, not crucial in the problem being discussed here.

35/ Since Marglin deals with an infinite horizon, he follows Ramsey (1928) in assuming a utility function bounded from above. The maximisation of total utility is posed as equivalent to the minimization of the integral of the difference between "bliss" and total utility in each period. Marglin takes $U(0) = -\infty$, and $\lim_{C \to \infty} U(C) = 0$, with diminishing utility throughout.

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$$Q = K.q(l)$$

$$S = \dot{K} = K \left[q(l) - w.l \right] (1 - c_2) + K.l.w(1 - c_1) \quad \ldots (8) \ldots (9)$$

$$C = K.q(l).c_2 + K.l.w(c_1 - c_2) \quad \ldots (10)$$

Alternative tools of variational analysis can be used in the exercise. Marglin poses the problem in terms of Pontryagin's "Maximum Principle,"[36] even though the proves the optimality of his conditions independently. We first follow his poser and then relate it to the preceding discussion.

Taking K as the "phase variable" and l (representing the technological choice) as the "control variable", the following "Hamiltonian" expression can be formulated:

$$H = U(C) + \psi.\dot{K}$$
$$= U(K.q(l).c_2 + K.l.w(c_1 - c_2))$$
$$+ \psi.K.\left[q(l) - w.l \right] (1 - c_2) + \psi.K.l.w(c_1 - c_2) \quad \ldots (11)$$

ψ is the utility price of capital investment and H the total value of output in terms of utility in a given period. When Ω represents the control region, the optimal time sequence of technological choice will have to satisfy the following necessary condition given by Pontryagin's "Maximum Principle" for non-terminal points of time.[37]

$$H(\psi, K, l) = \sup_{l \in \Omega} H(\psi, K) \quad \ldots (13)$$

We may restrict l within the closed interval $(\underline{l}, \bar{l})$, where $\underline{l}$ is the value for which the marginal product of labour equals the wage rate, i.e., $q'(\underline{l}) = w$, and $\bar{l}$ is the value for which the wage bill just exhausts the total product, i.e., $q(l) = \bar{l}.w$. These two limits correspond respectively to the Dobb-Galenson-Leibenstein solution and the Lewis-Polak-Buchanan-Kahn solution.[38] If l lies

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36/ Pontryagin (1962)

37/ Theorem 1 in Pontryagin (1962), see pp. 19-21, 189-91. The other necessary condition given by Pontryagin concerns the value of ψ, which yields:

$$\dot{\psi} = -\frac{\partial H}{\partial K} \quad \ldots. (12)$$

38/ The latter is not strictly correct, since they wish to maximize q, i.e., choose $q'(l) = 0$. Marglin assumes that $q'(l)$ is positive throughout, so this solution is not possible in his case. Therefore, he puts the limit where the wage bill exhausts the output. On the contrast between these two cases, see Sen (1960), pp. 29-31.

/...

in the interior of the region Ω, we should then require:[39]

$$\frac{\partial H}{\partial l} = 0 \qquad \ldots (14)$$

From (11) and (14) we obtain:

$$\frac{U'(C)}{\Psi} = \frac{w(c_1 - c_2) - q'(l)(1 - c)}{q'(l).c_2 + w(c_1 - c_2)} \qquad \ldots (15)$$

Since Ψ is the price of investment in terms of utility and $U'(C)$ is the value of consumption in the same terms, the left hand side of (15) corresponds to the society's marginal rate of indifferent substitution between consumption and investment. Since λ is the _extra_ weight to be attached on investment vis-a-vis consumption, we can write:

$$1 + \lambda = \frac{\Psi}{U'(C)} \qquad \ldots (16)$$

It is easy to check that from (15) and (16) we can obtain the following value of the "real cost of labour", w^*.

$$w^* = q'(l) = \left[\frac{(c_1 - c_2)\lambda}{1 + (1 - c_2)\lambda}\right] w.$$

This is precisely the same as that given by (6).[40] The relationship between the two ways of posing the problem is indeed a close one, and our earlier formulation can be seen to fit well into the picture of finding an optimum path of technique choice over time. There λ is simply taken as given; here it is assigned its proper value derived from the variational exercise. The two exercises, therefore, fit well into each other.

It is to be noted, however, that Marglin's definition of the "shadow price" of labour differs from our definition of w^*. He defines it as that expression with which we should equate the marginal product of labour, in terms of the _true_

39/ Marglin shows that a set of assumptions of non-satiation and of continuity suffice to guarantee this. See Marglin (1966a), pp. 40-41.

40/ Note that $q'(l) = \frac{\partial Q}{\partial L}$, thanks to the assumption of constant returns to scale.

/...

value of the output, including a higher weight on that part of it which will be reinvested (taking the whole of the marginal output as going to the enterprise). Our "real cost of labour" was equated to the market value of the marginal product. Because of this definitional difference, Marglin's "shadow price" of labour can exceed the market wage w in some cases, whereas our w^* is contained in the interval $(0, w)$. Analytically, however, the two rules are exactly equivalent. Defining w^{**} as Marglin's shadow price of labour, we obtain his allocation rule as:

$$w^{**} = \frac{\partial Q}{\partial L} \left[1 + (1 - c_2) \lambda \right] = (c_1 - c_2) \lambda . w \qquad \ldots (17)$$

It is clear that (6) and (17) are exactly equivalent rules. Which particular definition we use is entirely a matter of convenience.

The main contribution of Marglin lies in the explicit link-up of λ in the one-period model with optimisation over time involving variational methods. It differs from the usual optimum accumulation models in having an explicit constraint on savings, based on the distributional assumptions, and it differs from the usual discussions on choice of techniques in doing an optimum accumulation exercise over time with variational methods, using an explicit utility function.

10. Programming and the Shadow Price of Labour

The whole question of choice of techniques is seen to turn on the relative weights to be attached to investment and consumption i.e., on λ, and this depends on the extent of sub-optimality (if any) of the savings rate, which in its turn depends on our utility function. We have examined how "the difference between the schools of thought regarding the valuation of labour really boils down to a difference in objectives."41/ The "real cost of labour" w^* given by (6) has varied from the one extreme of 0, as given by (6.1), to the other extreme of w, as given by (6.3) depending on the weights to be attached to consumption and savings in the objective function (3).

41/ Sen (1960), Chapter V, p. 62.

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An alternative way of defining the cost of labour is to identify it as the "shadow price" of labour in the sense of programming. This is obtainable from formulating the problem of resource allocation in this economy, including that of choice of techniques, as an exercise in programming. The objective function V is some concave function of the process selection vector p representing the intensity of each activity. The "slack" (or excess supply) of each resource j is taken to be a concave function of p, viz. $f_j(p)$, given the total supply of resource j. With m types of resources, the set of $f_j(p)$ can be represented by F(p).

Also, with each choice of process intensities p, some purchasing power is created, depending on the level of employment, wages, etc., and given the demand functions we can trace the minimum amounts of consumer goods that must be produced to meet these demands. Let E(p) represent the "excess production vector", standing for the difference between the actual production and these minimum output requirements.

The choice variables consist of the elements of the vector p, which includes technological choice. The problem is:

$$\text{Maximise } V = V(p) \qquad \dots (18)$$

subject to

$$p \geq 0, \qquad \dots (19)$$

$$F(p) \geq 0, \qquad \dots (20)$$

$$\text{and } E(p) \geq 0 \qquad \dots (21)$$

If V(p), E(p) and F(p) are linear, this will be a problem of linear programming. Further, with the framework of linear activity analysis, we can get an output vector q linearly related to the activity vector p, and then can make V some function of q. We take, for this analysis, a very general interpretation, and assume no more than that V(p), E(p) and F(p) are all concave, but not necessarily strictly concave. This makes the problem one of concave programming, covering also the special case of linear programming.

/...

Let p^* be an optimal solution to the problem, and let r^* and s^* be the optimal dual variables related respectively, to the resource constraints and the demand constraints. They have the usual saddle-point properties.[42] In the case of linear programming, r^* is interpretable simply as the set of shadow prices of the respective resources. Even in the more general case of concave programming, the dual variables specify the limits of marginal returns to the respective resources.

It can be demonstrated that the inner product of E(p) cum F(p), and s^* cum r^*, must be zero in the optimal solution.[43]

$$(s^*, E(p^*)) + (r^*, F(p^*)) = 0 \qquad \ldots (22)$$

Every r_j, s_i, f_j and E_i, must be non-negative, so that a strictly positive f_j must imply a zero r_j^*. However, a strictly positive f_j implies that there is some excess ("slack") of resource j. So either a resource has no "slack", or its dual variable (corresponding to the shadow price) is nil.

There is nothing startling in this result, which is a standard one in concave programming, including the special case of linear programming. But it might look as if it contradicts our analysis of the "real cost of labour". It appears that irrespective of the objectives, either there is full employment of labour, or its shadow price must be nil. Since we are concerned with a surplus labour economy, it looks as if labour must be taken to be costless, no matter what objective function we choose. This seems to contradict what we said earlier.

There is, however, no real contradiction. If there is surplus labour even under optimal allocation, the marginal return to an additional unit of labour must be zero. In this sense the shadow price of labour has to be nil. This does not mean that the marginal product of labour is nil (i) in the sense that no more output can be physically produced by using more labour, or (ii) in the sense that it is zero in terms of its market value. We may be able to produce more of V, given the resource requirement constraints, but not the demand constraints. In this problem, where the constraints (21) are ignored, the marginal return to a

42/ See Karlin (1959), Theorem 7.1.1.

43/ See the proof of the Kuhn-Tucker Theorem in Karlin (1959), pp. 200-203.

/...

unit of resource j may not be zero even when r_j^* as previously defined is nil. Second, $V(p)$ involves some valuation of the output, but it may not coincide with the market valuation of it. Taking q to the output vector associated with the technological choice vector p, and y to be the vector of market prices, it is entirely possible that the inner product of q and y may respond positively to an additional unit of resource j, even though $V(p)$ does not respond to it.

In our simple model, $(\frac{\partial V}{\partial L})$ gives the marginal product of labour in the sense of programming, and that was indeed nil, as in (4). This does not, however, mean that $(\frac{\partial Q}{\partial L})$ should be made equal to zero by appropriate allocation, and w^* as the value with which $(\frac{\partial Q}{\partial L})$ is to be equated is given by (6). But (4) and (6) are exactly equivalent to each other. There is no difference on what to do, but only on the definition of the "cost" or the "price" of labour. Rule (17), corresponding to Marglin's analysis, and our rule (6) are exactly identical with rule (4).

11. Concluding Remarks

We have concentrated in this critical survey on the broad currents of controversy. There are numerous other themes within these general trends of thought, which we have not been able to present fully.

Our basic framework was developed in terms of some very general assumptions. By making more specific assumptions, we have tried to present the different criteria as special cases of that general framework. Thus our emphasis has been on the common analytical structure in these various theories. Differences in policies recommended have been systematically traced to the differences in empirical or value assumptions, so that a common core of analysis has emerged.

This study of analytical unity in the diversity of policy recommendations is aimed mainly at clarifying the issues in dispute. Issues not very prominent in the controversy, including problems of "efficiency" (see Section I), have not received as much attention as they could, perhaps, have had. Our main focus has been on things controversial. Since this is a bias, even if justifiable, I would like to draw the attention of the reader to this fact before I end.

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