

Productive Transformations and Economic Theory

Only recently have economists concentrated their attention on the revolutionary technological changes in progress and on the associated transformations of the structures of the economy. This has resulted in a proliferation of theoretical attempts which, taking the analysis of particular innovations as their starting point, have proposed ambitious refoundations of the dynamic theory in the most varied directions. It seems it would be a good idea, therefore, to stop a moment and consider where economic theory stands with regard to this problem, and how it is equipped to deal with the analysis of these processes.

The first question we must ask ourselves in this respect is: "what is production today?" or, rather, "how is the process of production changing today?" The difference in formulation is not without relevance. It might in fact be the case that some "new" characteristics of the process of production — like, as we shall see, the increasing importance of the environment — only appear as such when the focus is on *change*; remaining in the shade when the attention is directed instead to the *unchanging* features of production. Thus, the real problem is represented not by the changes in technology in themselves — which do, of course, take place, but which, to a greater or lesser extent, have always taken place — but by a shift of focus to the process through which such changes are realized — one of those shifts of attention which represent the true revolutions of the economic discipline.¹

What is required then, rather than new analytical tools or more sophisticated models, is to define precisely the object of the analysis, bringing to light in particular the strict relation between the problems considered and the method of analysis adopted, and between the latter and the conceptual categories we are using.

¹ On this point see J.R. HICKS, "The Scope and Status of Welfare Economics", *Oxford Economic Papers*, 1975, Vol. 27, No. 3.

Quantitative Adjustment and Qualitative Change

The way changes in technology and the resulting productive transformations have been dealt with by the dominant theory² is by means of models which, for the most part, have been built to obtain (or to maintain) the equilibrium between the demand generated by an economic system and its supply capacity through a "quantitative adjustment".³

This is quite evident in explicitly or implicitly aggregate models — like one-commodity models or models where the production of a bundle of goods combined in fixed proportions is considered — or in models which behave in an aggregate way, as is the case when a change in the relative weight of the different compartments of the economy results from an expansion of supply and demand at the same pace within each sector but at a different pace between sectors.

In these models a given productive capacity, expression of a method of production in the sense of a given way of satisfying certain economic needs, can be operated at different levels of intensity (in the short run) or augmented/reduced (in the longer run), in order to meet an increasing or decreasing demand. The problem, whether the capacity is given or whether changes in its dimensions are considered, is to produce *more* or *less* in order to fill a gap between supply and demand appearing either at the level of final demand or in some intermediate stage of production.

The attempt to consider a "qualitative change" within this framework relies on the introduction of technical progress identified with a modification of given technical coefficients; but it is clearly a failure. A *superior* technique is defined as a technique which allows *more* of a given commodity (or of a given basket of commodities) to be obtained from given resources; the logic of a quantitative adjustment still prevails over a conceptualization of technical progress which retains only the definition of a change, but must actually fit the existing model without altering its structure and hence without modifying its analytical reach. The hypothesis underlying the model, in other words, is still that of a

² By "dominant" theory we mean not only the neoclassical analytical apparatus of production theory whose central concept is the production function, but also other approaches which, although different from the neoclassical one in many respects, share with the latter a given way of analyzing the problem of the "change".

³ Or to underline the effects of a failure of such an adjustment.

productive structure which is and remains the expression of a given way of working of the economy. Only changes in the dimensions of this structure (or slight modifications which do not affect its bulk) can be considered, by introducing laws of movement of the technical coefficients which affect the quantitative relation between the given inputs and the given output.⁴

The problem of a qualitative change implying an entirely different way of functioning (and of producing) of the system in response to different needs and different productive problems, can be perceived more easily in a multisector-model where the structure of supply does not (or does no longer) fit the structure of demand. In this case, too, it will necessarily result in a gap between supply and demand in some sector, and can therefore be mistakenly interpreted as a signal of a disequilibrium of a quantitative kind to be taken care of by adjusting upwards or downwards the production (or the demand) of the one commodity or of the other. We remain then in the logic of the (explicit or implicit) aggregate models.

The mismatch between the structure of supply and the structure of demand, however, can be interpreted in a different way: that is as a signal that what is required is not a simple change in the composition of the existing bundle of goods, but something completely different. This might mean some specific new goods, but it might also mean, more generally, something not yet well defined, as is usually the case when new needs appear, and new ways of satisfying these needs are considered.⁵

We are thus no longer confronted with the problem of operating at a different level of intensity or of simply modifying a given productive capacity, but with the problem of substituting a *different* productive structure, which, since it reflects a different way of matching (perhaps different) economic and social needs, is not comparable with the former in terms of *more* or *less*, referring to an input-output relation which no longer has any meaning.⁶

⁴ The adjustment in this case takes place through a shift of resources — immediate, or gradual as is the case in "vintage" models — from the production of capital goods (machines) of the old kind to machines of the new kind, given an *a priori* choice carried out in terms of a comparison of a quantitative kind (more or less output for given resources) between the techniques considered.

⁵ Such a phenomenon needs not necessarily originate from the demand side, but can also be the outcome of the appearance of different methods of production which entail a restructuring of consumption and demand according to different patterns.

⁶ The way this problem has been dealt with by the dominant theory amounts instead to cancelling it. The hypothesis that *old* machines can be used to produce the *new* ones means in fact

The problem appears clearly in Pasinetti's latest book,⁷ where changes in the preferences of the consumers at higher levels of real income result in rates of growth of demand which, in a multisector set-up, differ between commodities, so that the demand in some sectors cannot match the increases in productivity deriving from the "learning by doing" in production. The qualitative nature of the disequilibrium arising at the aggregate level is evident. As the demand for some of the goods produced in the system gradually becomes saturated, the appearance of new products does not take place at such a pace that the demand can grow at the same rate as average productivity: this is because learning is slower in consumption than in production.

The analytical implications of this qualitative aspect of the disequilibrium, however, are not pursued any further. Once the problem has been put in these terms, the author goes back to the analysis of the quantitative effects of the disequilibrium, that is to the recurring divergence between demand and supply capacity which causes the system to advance in fits and starts and prevents it from maintaining full employment all along.

The Analysis of Change by Means of Comparison

It is therefore not sufficient that the qualitative features of a problem be perceived, for the problem itself to be treated properly from an analytical point of view. The greater danger today, in fact, is not the fact that scarce attention is paid to the radical productive transformations which are going on, but that the problem is still dealt with as if it were a simple matter of quantitative adjustment. This appears both from theoretical questions and applied research which reflect clearly (explicitly or implicitly) the underlying analytical framework. Thus, just to make an example, much more time and effort is still devoted to the

that "no change in the process of production takes place in the relevant moment of the embodiment of the new technology, that is in the making of the machine" and thus allows us not to take into account the process through which productive capacity acquires a different specification corresponding to a new technique. See M. AMENDOLA, "The Path to a Dynamic Analysis of the Traverse: A. Lowe and J.R. Hicks", *Eastern Economic Journal*, July-Sept. 1984.

⁷ L.L. PASINETTI, *Structural Change and Economic Growth*. A theoretical essay on the dynamics of the wealth of nations. Cambridge University Press, 1981.

attempt to estimate employment associated with the productive capacity portrayed as coming out of a given process of innovation, rather than to the role that human resources will be called to play for the transformation of the productive structures to be realized as the process of innovation takes place.

Attention, therefore, must be directed to the analytical structure and to the explanatory power of the underlying model. What we would like to stress, in this respect, is that the inability of the models in use to treat technological change as a qualitative phenomenon — and hence to focus on the process through which such a phenomenon takes place rather than registering and measuring its presumed quantitative effects — depends in the first place on the method of analysis adopted; and that this method, in turn, implies a representation of the process of production and of the technology (and the use of concepts and definitions, like that of capital goods) which deprives the phenomenon itself of its true dynamic nature.

The method we are referring to in particular consists in comparing a given situation with what would have been if, everything else remaining constant, some element had been different. The effects of changes in conditions of the economy are thus analyzed by means of a comparison between positions corresponding to different conditions, labelled as *before* and *after* the change. The comparison permits us to deduce the effects of given events from models/theories built on reliable relations which represent a thorough reaction mechanism.

This is the method used by classical as well as by neoclassical economists, and, in part, by Keynes too; even if the content of the model (i.e. the terms of the comparison) is different in each case: a long-period position is not the same thing as a Marshallian equilibrium, and this, in turn, differs from a Keynesian equilibrium.⁸

The theory of technical progress developed within an analytical framework which is an expression of this method, focuses on the effects of changes in technology which can be deduced from the comparison of states of the economy characterized by the use of different techniques. The comparison, however, is possible only if we have the terms of the comparison, that is if we can consider states of the economy which are a) *defined*,⁹ and b) comparable. This implies, in

⁸ See chapters IV, V and VI of J.R. HICK'S *Causality in Economics*, Blackwell, Oxford, 1979, for a thorough examination of this method, although the general definition of "equilibrium method" used by the author might not please some *orthodox* followers of classical thought.

⁹ That is completed in some sense: which, in our case, means considering states of the economy characterized already by a (total or partial) adjustment to a given technique.

particular, that the *difference* between the techniques considered is only apparent. The productive structure of the economy, which is the expression of a given way of dealing with certain productive problems, cannot be radically changed (so as not to cancel the possibility of a comparison between the alternative situations considered); therefore, only innovations which have a quantitative effect — that is which bring about a modification of the ratio of the quantity of the given output to the amount of resources employed — can be considered.

Now, if it is certainly true that any modification of the process of production has a quantitative aspect which can be expressed in terms of a modification of an input-output relation,¹⁰ it is also true that this result tells us nothing about the processes which brought about the result itself nor about the new way of functioning of the economy. In short, it tells us nothing about how the existing technological alternatives and productive structures came into existence and what specific forces generated them.

To sum up, the method of analysis based on comparison takes for granted already realized and comparable productive structures, does not allow one to deal with substantial modifications of the working of the economy and considers only quantitative effects of minor technological improvements affecting given input-output relations.

The Process of Innovation as the Object of the Analysis

A qualitative change as an entirely different way of tackling and solving a productive problem implies dealing with something *different* which is not comparable in terms of *more* or *less*, *superior* or *inferior*, not only because of a difference in kind; but above all because it is not definable *ex ante* and it is not available for comparison.

¹⁰ This is particularly the case when the terms of the comparison are defined in such a way as to permit one not to take into account the specificity of the inputs, as is the case with the vertically integrated technical coefficients used by Pasinetti, which “do not correspond to labour and capital goods employed in any particular firm or industry... but represent all the labour and capital goods, in whatever remote corner of the economic system they may have been applied, which are necessary to produce the final commodity under consideration”, and which therefore “acquire a meaning of their own, independent of the origin of the single parts which compose them”. L.L. PASINETTI, *Structural Change, etc., op. cit.*, pp. 114-117.

Recent analytical work (for the most part, not undertaken by economists in the orthodox sense of the term) and applied research on patterns of technical change, diffusion of particular innovations and processes of industrial transformation, has shown that 1) technology is not something fully realized at its first appearance, on which firms can (more or less freely) draw whenever they feel like it,¹¹ and 2) that the process of innovation, rather than the absorption of given technological opportunities into the prevailing economic structure, is the process through which, given an initial impulse, a new technology is developed step by step as a particular answer to certain productive problems in a specific environment, and is at the same time the process through which the new productive structures of the economy acquire their specific features as the technology is building up.¹²

What is “different”, therefore, must be interpreted as the indication of a tendency which gets defined and realized through a process. The first step to make, then, is to define exactly the object of the analysis, that is to shift the focus onto that process of innovation until now left in the dark as the antecedent of an event considered only at the level of its quantitative effects on the economy. In this perspective the analysis of the time articulation of a process of transformation of the productive structures of the economy comes to the forefront. This may lead to different alternative developments, according to the particular path chosen out of the eligible ones at each successive moment, where the range of the feasible choices at each moment gets smaller or bigger because of the constraints or the endowments which accumulate while moving along the path(s) which brought the economy to its present state.

What we need, then, is not a comparison between already defined technological states of the economy, but a sequential analysis, focussing on the time articulation and on the irreversibility of the different phases of a process of innovation as defined above.

¹¹ Which implies, in particular, that it is no longer possible to represent a method of production by means of a “technique” defined *ex-ante*, in a general and abstract way, by given technical coefficients. See M. AMENDOLA, “A Change of Perspective in the Analysis of the Process of Innovation”, *Metroeconomica*, October 1983.

¹² See, among the others, J.S. METCALFE, “Impulse and Diffusion in the Study of Technological Change”, *Futures*, vol. 13, 1981; J.S. METCALFE and M. GIBBONS, “On the Economics of Structural Change and the Evolution of Technology”, paper contributed to the 7th Congress of the I.E.A., Madrid Sept. 1983; G. DOSI, “Technological Paradigms and Technological Trajectories” — A Suggested Interpretation of the Determinants and Directions of Technical Change, *Research Policy*, 1982, and *Technical Change and Industrial Transformation*, Macmillan 1984; K. PAVITT, “Patterns of Technical Change — Evidence, Theory and Policy Implications”, *Papers in Science, Technology and Public Policy*, No. 3., Imperial College, London, and the Science Policy Research Unit, University of Sussex.

The Analytical Features of a Sequential Approach

In order for a sequential analysis to be able to capture the building up of a new technology and of its own specific productive capacity, it must rely on a representation of the process of production which does not entail considering an already realized productive structure, whichever way the latter is represented.¹³ There is in fact a strict relation between the definitions we are using, which translate our interpretation of the phenomena considered, and the kind of analysis we can carry on; a different way of dealing with a certain problem must therefore necessarily move from a redefinition of the most relevant basic concepts, such as, in our case, the concepts of process of production, of capital goods, and of the technique.

E. Lundberg, one of the most interesting exponents of the Stockholm school which has given a fundamental contribution to the development of a sequential analysis, wrote in the thirties, "The consideration of the investment process itself, — in other words —, the capital increase, as an element in the determination of the total income-generation, makes it impossible to consider *simultaneously* the later use of the newly formed capital. Therefore, the formation of a capital product and its use must be treated separately".¹⁴

The first requirement of a representation of the process of production aimed at throwing light on the unilateral dependence of the successive events on the preceding ones — which is typical of the sequential character of economies undergoing a change — is to bring out the difference between the phase of construction and the phase of utilization of a new productive capacity, and to draw the analytical implications of their articulation in time.¹⁵

¹³ That is, whether we are confronted with the "machines" translating a given capital-labour ratio in an aggregate production function framework, with the input-output coefficients of a Leontief-type model, or with the coefficients which, given the levels of output, bring about the state of self-replacement of the system in a Sraffian model, where fixed capital is transformed into a flow by means of a joint production approach.

¹⁴ E. LUNDBERG, *Studies in the Theory of Economic Expansion*, Reprints of Economic Classics, A.M. Kelly, New York 1964, p. 31. This does not mean however introducing a simple gestation-lag to take into account the time for a given investment to mature, but carrying on the analysis of the process through which the new productive capacity of the economy comes into being.

¹⁵ The reference, of course, is to the Austrian theory of capital of Böhm-Bawerk and Hayek, and, in particular, to the Neo-Austrian theory recently proposed by J.R. Hicks in *Capital and Time*, Clarendon Press, Oxford, 1973, and in other writings. In this approach production is fully

This intertemporal complementarity resulting from the technical features of the process of production,¹⁶ however, is only one aspect — although an essential one — of the problem. "It is in fact not sufficient to state generally that a given change will be later followed by a certain reaction, whereupon still another reaction may be expected, etc. Such formulations are either drawn from an unmodified equilibrium theory, or they refer directly to an actual development. Instead, the consequences themselves of *defined* discrepancies of time have to be investigated in the sequence analysis. The special device used in a sequence analysis to bring out the succession of events in time consists in the introduction of the 'unit-period'. In every analysis of this kind the changes are of course referred to successive intervals of time... The division into periods is mostly supposed to serve only as a formal way of referring events to different points of time... but in fact it is closely related to the subject of investigation".¹⁷

This means that each unit-period is characterized in the first place by the fact that some decisions are taken within it: the "single-period theory" — one of the two parts of sequential analysis — is concerned in fact with the difference between what happens in that period and what is planned to happen at the beginning of the period.¹⁸

A sequence of periods results therefore in a related sequence of decisions; the *technical intertemporal complementarity* of the process of production is thus matched by the *intertemporal complementarity of the decision process*, which sets the way along which the process of production will actually take place.

integrated vertically: the capital goods used in each process are produced within it and the process of production, made up of a phase of construction and of a phase of utilization, must be taken as a whole over time. This allows one to distinguish between investment at cost and investment of output capacity, and, in particular, to give a proof of Ricardo's "machinery effect" on the unemployment brought about by the introduction of machinery.

¹⁶ We are referring to the technological irreversibility of the process of production which entails considering it as a whole over time.

¹⁷ E. LUNDBERG, *Studies in the Theory etc., op. cit.*, pp. 46-47.

¹⁸ "At the beginning of a given period certain plans are formed and certain decisions as to the production, payments, etc., are made. These plans contain the relations between the expected values of the variables, being defined *ex ante facto*. The interaction between the executed decisions determines certain results during the period. These *ex post* values of receipts, investments, savings, etc., will generally differ from the expected values, and after a certain time-lag, defined by the unit-period, cause new plans and decisions, which give rise to new results during the following unit-period, etc. The unit-period is therefore defined by our assumption about the tardiness of new plans and new decisions concerning the variables selected for the analysis". E. LUNDBERG, *Studies in the Theory etc., op. cit.*, pp. 48-49.

What is it that strings together the different periods — that is the different decision moments — so as to form a real sequence?¹⁹

The decisions taken at each given moment depend a) on the constraints which delimit the range of the economically feasible choices, and b) on the expectations of the values that the relevant variables of the analysis will take. In fact, it is the expectations which, in the uncertain context of a technology whose development cannot be defined *a priori*, serve as a link between successive periods, forming the sequence through which the analysis of the process of change can be carried out. But in order to do so, the expectations themselves must not be influenced by what happens in the current period; once we allow them to be based on current experience, in fact, the single periods become self-contained and the link between them tends to disappear.²⁰

The most common hypothesis in this sense is that the expectations which rule in the current period are based on past experience, that is on the result(s) of the previous period(s). The decisions taken at each given moment on the basis of the prevailing state of the economy as reflected by the existing constraints, on the other hand, will bring about a modification of the state itself (given the lags depending on the intertemporal complementarity of the process of production); so that new decisions on a different basis will be taken in the following period(s), in a decision-generating process which will set the stage for analyzing the process of innovation.

Qualitative Change as the Break in the Sequence

To turn to a sequential approach, however, does not automatically mean to treat changes in technology as qualitative changes.

This is the case, for instance, of the two and three-sector models recently proposed by Van Schaik and Lowe,²¹ which have a formal

¹⁹ This problem is the object of the "continuation theory" — the other part of the sequence analysis — which is concerned in particular with the effects of the events of a first period on the expectations and the plans that determine the events of the following periods.

²⁰ "It was because I did allow (expectations) to be influenced ... by current experience, that my model was moved in a 'quasi-static' direction" writes J.R. HICKS, referring to his *Value and Capital* temporary equilibrium model. See *Capital and Growth*, Clarendon Press, Oxford 1965, p. 66.

²¹ A. VAN SCHAİK, *Reproduction and Fixed Capital*, Tilburg University Press, 1976; A. LOWE, *The Path of Economic Growth*, Cambridge University Press 1976.

sequential structure, but keep reducing the transition between techniques to a mere shift of resources between sectors, thus abstracting once again from the process through which the change takes place.²²

But this is also true of Hicks's Neo-Austrian model which, although shifting the focus from the point of arrival to the path along which the productive capacity of the economy adjusts to a change in the technique, still portrays this "traverse" as a quantitative adjustment brought about by a diversion of resources from the production of the old to the production of the new machines, in the same way as in "vintage" models. The assumptions of a single homogeneous final product, of a barter economy and of "full performance" (implying that all output which is not consumed is invested, except a constant take-out), make the rate at which new processes start at each moment depend on the rate at which they started in the past, and reduce the decision process to a sequence of decisions of a quantitative kind which can be fully traced out *ex ante*²³ and where expectations play no role.²⁴

What has just been said brings out the essential analytical problem we must consider. Expectations matter when we are concerned with a *real* choice, that is with a choice which has to be made in an uncertain context: and a qualitative change is a real choice.

When the decision process which links the periods in a sequence reflects expectations which are formed, no matter how, on past experience, we are on the contrary bound to imply a substantially unchanged underlying structure, and hence a substantially certain context.²⁵ In this case there is no change in the model/theory we are referring to; that is we remain in equilibrium according to Hahn's definition "an economy is in equilibrium when it generates messages which do not cause agents to change the theories which they hold or the policies which they pursue".²⁶

²² What makes the trick is the old established assumption that old ways can produce new equipment as well as old. See note 6 above.

²³ In fact there is neither any real choice on *how much* to invest, nor on *how* to invest the preassigned amount, as the definition of a "superior" technique automatically implies its choice.

²⁴ The same obtains when expectations are explicitly reintegrated into the model, but made depend on past experience, as is the case, for instance, when we assume the current growth rate to keep ruling in the future. See M. AMENDOLA and J.L. GAFFARD, "A Sequential Approach to the Analysis of the Process of Innovation", paper contributed to the 7th Congress of the I.E.A., Madrid, September 1983.

²⁵ Expectations will therefore necessarily have a quantitative content, referring to modifications in size of the given structure.

²⁶ F. HAHN, "On the Notion of Equilibrium in Economics", An Inaugural Lecture, Cambridge University Press 1973, p. 25.

An innovative choice resulting in the development of a new technology and in the transformation of the existing productive structure implies instead that the messages generated — although necessarily translated into quantitative terms — call for a change of the model/theory adopted, and hence for a change of the way expectations are formed. In Hahn's words, we have a rupture of the equilibrium, and we need to *learn* new relations on which to rely.

This, however, does not mean a complete severing of the sequence, and does not leave us without analytical points of reference. If the link with the past is cut as far as the decision process is concerned, the link represented by the technical intertemporal complementarity of the process of production is still there: a link resulting at each given moment in the constraints set to the range of feasible choices by past investments and by the present phase of the production processes. And the relevance of the role played by these constraints in a sequential model is quite evident. "Expectation is necessarily, in the first place, imagination. But plainly it is not unconstrained figment. It is *critical* imagination limiting its creation of hypothetical sequels of any specified course of action, rendered feasible by the individual's possessed resources, to what is free from discernible obstruction. It is only sequels *deemed possible* that can bear upon the business of choice".²⁷

"Given the constraints, we are left with the building of the new model/theory, which would require "a 'higher level' theory of the learning process. But such a theory is not available at present".²⁸

This is the point where an inductive approach might help. Instead of using *a priori* assumptions to test through empirical investigation, we can turn to the observation of the relevant aspects of the phenomena considered to derive new reliable relations, and, in particular, new ways of forming expectations. The analytical frame of the sequential process sketched in the previous pages allows one to proceed in this direction in an organized way, sorting out the relevant elements of a process of transformation and bringing to light new routine behaviours and criteria for choice. The observations can thus be given a place and a meaning in a framework to which they, in turn, will give a realistic content.

²⁷ G.L.S. SHACKLE, "A Student's Pilgrimage", in this *Review*, June 1983.

²⁸ F. HAHN, "On the Notion of Equilibrium etc.", *op. cit.*, pp. 20-21.

The "New" Features of the Process of Production

It is a generally held view that changes in technology today are bringing about a substantial modification of the very nature of the phenomenon of production, whether this is called tertiarization, dematerialization, informatization or the like.

Looking at what is happening, in fact, one can have a glimpse of a process of production whose profile is rather different from that usually sketched by the dominant theory.

The first aspect to underline, in this respect, is a segmentation of the market which reflects not only the increasing diversification of demand in a world which is becoming ever richer and more complex, but also policies aimed at protecting and increasing the presence on the market. As production becomes less standardized and more personalized, to be able to meet a vastly articulated and differentiated demand and to react rapidly to changing market conditions acquires great importance. We thus have a first requirement of "flexibility" of the process of production.²⁹

But there is a different and deeper meaning of flexibility which is relevant today in relation to new emerging features of the process of production.

We have just mentioned the trend towards a personalization of production in response to a more and more specific and complex demand. What must be added, now, is that this demand tends to become a thorough *input* of the process of production, as is more and more frequently the case, when the customer takes part in the specification and the design of the product required and/or in the research of the solution to his productive problem.³⁰

The image of a process of production which consists in operating a preexisting productive capacity to meet the requirements of an external demand thus gives way to an activity of research and coordination of specific inputs which, assembled in different shapes and proportions, make up products with variable specifications corresponding to the particular needs of specific customers. The essence of production, then, becomes "the specialized research, upstream the strictly defined manu-

²⁹ The point of arrival in this perspective — which still refers to a process of production carried out in a plant by means of "machines" and fixed capital equipment — is the "flexible manufacturing system".

³⁰ See B. BRUSCO and C. SABEL, "Artisan Production and Economic Growth", F. Wilkinson (ed.), *The Dynamics of Labour Market Segmentation*, Academic Press 1981.

facturing phase, of the *ingredients* more suited for finding a *solution*, that is for giving an answer to the wide range of specific requirements downstream the same phase".³¹

Flexibility is thus required not only for market strategies, but in the very moment of the organization and hence of the specification of the process of production. The solution of a productive problem, as well as a clear definition of the problem itself, are in fact not ready there, to be taken off a shelf: they come out of a gradual process which calls for rapid changes of direction in the research and organization of the inputs, as new developments are continuously taking place.

This kind of flexibility clearly requires a deep knowledge of the environment and a great capacity to integrate it and to be integrated into it. And this integration — which, we have just seen, makes the canonic distinction between supply and demand fade away, and learning in production and learning in consumption appear as the two faces of the same process — implies in turn a reconsideration of the concept of "environment" and of the role the latter plays in the process of innovation. The environment, no longer confined to simply providing real services to the process of production, must in fact be seen as a thorough component of such process, which gets modified with it as the new technology is gradually developed and the productive structures are transformed.³²

The Lines of Development of the Analysis

What has just been said reinforces the image of the process of innovation as the building of a new technology and of its own productive capacity in a specific environment which contributes to determine the character and the direction of the change and is itself changed as the process goes on.

³¹ M. AMENDOLA, S. BRUNO, B. INGRAO, P. PIACENTINI, *Valutazioni di fattibilità di una analisi economica delle interdipendenze funzionali in relazione ai processi di innovazione tecnologica*, mimeo, 1984.

³² The analysis of the feedbacks between a changing environment and the change in behaviours has been developed by R.R. NELSON and S. WINTER, whose contributions on the argument have been collected in *An Evolutionary Theory of Economic Change*, The Belknap Press of Harvard University Press, Cambridge, Mass. 1982. For an approach trying to link the evolution of structural constraints to the behavioural degrees of freedom of economic agents, along lines similar to those sketched in this paper, see G. DOSI, *Technical Change and Industrial Transformation*, *op. cit.*, pp. 93-111.

A model reflecting the sequential character of such a process and including explicitly in the analysis the uncertainty associated with it, must take into consideration first of all the requirement of "flexibility", meaning capacity to change rapidly direction and to take into account the new environment emerging at each successive step. In a sequential process which amounts to a related sequence of choices, flexibility becomes then a criterion of choice in the sense of a preference for the decisions which imply the greater prospective range of options, and hence the greater prospective freedom of change. A first line of development of the analysis consists therefore in a more precise definition of the decision-generating process in conditions of uncertainty, with the requirement of "flexibility" in the above sense.³³

The increasing integration of the process of production into the environment, while calling for the greater prospective freedom of choice, constantly sets, on the other hand, well defined constraints to the actual strategic freedom. We have already mentioned the constraint represented by the illiquidity of investments and by the intertemporal complementarity of the process of production. More relevant in a process of innovation are however the illiquidities of human capital resource, which is called to play a paramount role in the productive transformations associated with the development of a new technology.

The singling out of such constraints and rigidities — which are typical expressions of a specific context and of its past history — and the study of the way they act upon the process of change, represent another development of the analysis, although along different lines from usual. The problem, in fact, must not be dealt with in terms of levels (and hence of the general availability) of a homogeneous labour force, but in terms of structure of a heterogeneous human resource³⁴ and of its distribution over the successive phases of the process of innovation. It is in fact generally the case that as the productive structures of the economy are transformed in accordance with technological advances, the mix of skills demanded is so modified that some specific inputs required in an initial phase may become redundant in a successive, more mature, phase, and so on.

³³ This line has been pursued by S. PARRINELLO in "La teoria delle scelte: azioni presenti e gradi di libertà di azioni future", Istituto di Automatica, Università di Roma, R. 81-05, May 1981, and "Flexibility of Choice and the Theory of Consumption", *Metroeconomica*, 1982. See also R.A. JONES and J.M. OSTRAY, "Flexibility and Uncertainty", *Review of Economic Studies*, January 1984, and M. AMENDOLA and J.L. GAFFARD, "A Sequential Approach...", *op. cit.*, Sept. 1983.

³⁴ On this point see S. BRUNO, "Heterogeneous Labour, Employment and Distribution: A Micro-Macro Theoretical Framework for the Analysis of Segmented Labour Markets", *Economia e lavoro*, April-July 1984.

Appropriate private and public policies to promote and sustain technical change will therefore differ according to the specific context in which the change takes place and to the current phase of the process of innovation.

The constraints reflecting the current state of the economy and limiting the choice set at each given moment, will themselves be modified by the decisions taken. No preassigned law of movement of given coefficients can expect to reproduce such a process, however. Once again, we are not confronted with changes in dimension of a given set up, but with modifications of the structure, and hence of the nature, of the environment expressing the existing constraints. And once again — whether we are considering financial, energetic or human resources, or any other relevant factor — a different outlook has different economic policy implications. The concept around which a coherent set of measures aimed at promoting and completing a process of change must be organized, is no longer *amount* (in the sense of “availability” or in the sense of “results”) but *role*, and more precisely specific role played over time.

The problem of expectations remains: certainly the most difficult one to bring into focus.

There seems to be no doubt that, once an innovative choice has been made and set into a process of change, an expectations function must reflect in some way the interrelations between decisions and constraints which make up the analytical articulation of the sequential process of innovation as portrayed here. But which expectations must be considered at the very moment of choice, and how are they formed when the mere outlook of a qualitative change cuts the link with the past but does not yet provide terms of reference for the future?

The answer to this question, as well as to the many other questions raised above, is beyond the scope of this paper. The poverty of precise results compared to the ambitious premises may appear discouraging, but what we had in mind, and what was in our opinion most needed, was to put the analysis of the changes in technology and in the productive structures of the economy into the right perspective, not to carry it out ourselves. In this case, as is often true in economics, relevant questions are much more important than irrelevant answers.

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