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Time to build and out-of-equilibrium growth process

Mario Amendola, Jean-Luc Gaffard

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ABSTRACT :

This paper proposes an analytical approach to growth modelling that focuses on the temporal and hence the organizational dimension of real production processes, rather than making use of a production function, which is a pure technical relationship. This approach takes advantage of the breakthroughs in economic theory by Georgescu-Roegen and Hicks. The step-by-step analysis of production in time proposed by Georgescu-Roegen has brought into light the idleness of capital equipment and of human resources as the main obstacle to growth, and given a robust basis to Smith's growth theory according to which the articulation between the division of labor and the extent of market is the main engine of growth. The analysis of the time dimension of production processes proposed by Hicks that focuses on the distinction between construction and utilization phases has opened the way for a comprehensive analysis of the type of disturbances – unemployment and productivity slowdown – which arise along an out-of-equilibrium growth path. These contributions provide the basis for the analysis of qualitative change as a learning process, whose evolution is not predetermined but depends on what happens along the way, that is, on the recurrent distortions in the structure of productive capacity due to co-ordination failures.

1. Introduction

We maintain that identifying the real nature of production processes, rather than focusing on consumers' preferences and the properties of technology as the only determinants of a long-run equilibrium, is essential for understanding the out-of-equilibrium process in which consists the dynamics of the economy.

The way we look at production – we shall see in particular in what follows – is the watershed between analytical approaches suited to deal with equilibrium or out-of-equilibrium phenomena.

The distinction made by Schumpeter between growth, explicitly defined as a quantitative phenomenon, and development, a "... discontinuous change that comes from

within the economic process because of the very nature of that process" (Georgescu-Roegen, 1974, 1976, p. 245) helps to grasp the point. That is, that qualitative change – a change that implies a structural modification, which can only be brought about through a process in real, irreversible time – is involved whenever a thorough dynamic problem is contemplated. Innovation, which implies creation of new resources and construction of different productive options, is the foremost example of qualitative change: but also a speeding up of the growth rate or a simple change of the technique in use partake of the same nature.

In all these cases, the previously existing productive structure is disturbed, its way of functioning is affected and as a result a problem of intertemporal complementarity arises which calls for co-ordination over time of production processes to render the process of change undertaken viable. The focus must therefore be in the first place on the time structure of production processes.

The coordination problems involved are far more reaching, though. As a matter of fact new aggregates of elements that exhibit different complementarity relations among them have to be shaped up for a different productive structure with its distinctive way of functioning to emerge: it is the nature of these relations, and the processes through which they are created and established, what really matters. Viability is the main problem associated with these processes, and interaction, complementarity and co-ordination over time, which determine how the processes themselves are actually shaped up, are the relevant issues for viability.

The remainder of the paper is structured as follows. Section 2 proposes a physiological analysis of production, which makes use of the flow-fund model elaborated by Georgescu-Roegen, in the perspective of bringing into light the idleness of capital equipment and of human resources as the main obstacle to growth, and giving a robust basis to Smith's growth theory according to which the articulation between the division of labor and the extent of market is the main engine of growth.

Section 3, makes use of the production analysis elaborated by Hicks focusing on the distinction between the construction and the utilization phase of any production process, to throw light on the main aspect of any qualitative change, that is, the distortion in the structure of productive capacity that generates a dissociation between costs and proceeds. Section 4 opens the way for a comprehensive analysis of the disturbances – unemployment and productivity slowdown – that arise along an out-of-equilibrium growth path. Section 5 stresses qualitative change as a learning process, whose evolution is not predetermined but depends on what happens along the way, that is, on the recurrent distortions in the structure of productive capacity due to co-ordination failures.

2. Complements and substitutes in the economics of production: towards a physiological analysis of economic change

"It is because time is such an elusive notion that it has been possible to treat it lightly, especially in economics. For most of the economic processes the time now is clock-time... Yet in economics time enters also in a role that cannot be associated with a clock. Whatever belongs to strictly human manifestation, expectations and innovations, is not tied to the clock" (Georgescu-Roegen, 1994, p. 242).

The most relevant aspect of the economic process is that 'production takes time'. The essence of the problem of the time dimension of production is that complementarity rather than substitution characterizes the production process. This is a point that, although in different analytical contexts and with different accents, both Georgescu-Roegen (1970, 1971, 1976, 1994) and Hicks (1970, 1973) hint at.

Georgescu-Roegen (1971) refers to the catalogue of feasible recipes that describe production processes and that "consists of a set of points in an abstract space, as opposed

to the Euclidian space" (p. 236). This set may be represented by a relation of the form:

$$Q(t) = F [E_i(t), S_j(t)] \quad 0 < t < T$$

where $Q(t)$ is the coordinate for the final output, $E_i(t)$ the coordinate for the *flow* factors (that enter the production process but do not come out of it, or come out without having entered) and $S_j(t)$ the coordinate for the *fund* factors (which "represent the material base of the process" (Georgescu-Roegen, 1965, p. 86) as they "enter and come out of the process in an economically, if not physically, identical form, and in the same amount" (ibid. p. 84), and hence can serve in any process over and over again, although needing maintenance); all defined over the time interval $(0 - T)$ which corresponds to only one process. As a consequence the factors included in any of the functionals (or of the point functions when there are complete synchronization) representing the catalogue of recipes, cannot be substituted for. They are *complementary* factors. In the functional F , S represents generically funds (equipment, labor skills, and the like) of various qualities, S_j meaning a certain amount of the fund of quality j . There may be no change corresponding to, for example, the substitution of more capital K (in the sense of machines or equipment) for less labor L . Substitution means rather than K_a and L_a are used instead of K_b and L_b .

In other words substitution concerns processes and not the coordinate (capital and labor) of one particular process. However, the substitution of a process b for a process a cannot be realized instantaneously. The reason is that the fund factors are specific to each process and that their accumulation and decumulation differ from accumulation and decumulation of a stock of commodities in that it cannot take place at any speed. It is in fact characterized by intertemporal complementarities.

Dissociating commodities from processes is a step with important analytical implications. It makes it possible to stress that "commodities are *not* produced by commodities, but by processes" (Georgescu-Roegen, 1974, 1976, p. 251). And that, whereas in a stationary state the attention can be confined to the production of commodities (the 'utilization' moment of a production process), this is no longer the case "in any non-stationary economic system" where "the production activity is aimed at two distinct objectives – to produce *goods* and to produce *processes*" (ibid.) and where the latter activity may come before the former.

The elementary process is the process by which a unit or a batch of product is produced from specific materials by some specific agents (funds). *Idleness* of funds characterizes any elementary production process. It is the main source of inefficiency of any productive system. And then, it prevents firms from investing in these factors, thus limiting the division of labor, which is the real source of the growth process as underlined by Smith (1776). How to reduce the idleness of funds is the real challenge. The degree of idleness is not a technical problem but an *organizational* one. Elementary processes may be "arranged *in series*, one following the other, as in a small artisan shop, or in the production of bridges (...). (They) may be also arranged *in parallel*, as in most bakeries or in ordinary farming (...). Finally,

they may be arranged *in line*, as they are arranged in a factory, and only in a factory” (Georgescu-Roegen, 1974, 1976, p. 239). Only an industrial type of organization of the production process, that is, a synchronization of elementary production processes allows to dramatically reduce the idleness of funds and to increase static efficiency. The division of labor, which characterizes the factory system, allows affecting specific factors to a particular production stage, and hence allows *synchronizing* different and successive stages of the production process, and strongly reducing or even eliminating the idleness of funds. “Because idleness of economic agents is the worst form of economic waste, the factory system represents an economic innovation of momentous importance (similar to, and just as anonymous as, the innovation of money)” Georgescu-Roegen, 1974, 1976, p. 240)

To be effective, the division of labor requires that the *market size* be large enough and the supply of natural resources be sufficient. Market size will be enlarged by entering export markets or by an increase of the real wages. Indeed, the physiological analysis of economic change proposed by Georgescu-Roegen is nothing but a formalization of the growth analysis by Smith who focuses on the articulation between the division of labor and the extent of the market. It points out the dependence between supply and demand both at the micro and at the macro level¹. Only a perfect synchronization of production processes allows sustaining a steady state (a regular growth rate of output). Only in this case, the standard production function is analytically valid because the time dimension is no longer relevant. However, any innovation or even a change in the growth rate of the economy breaks this peculiar arrangement. The factory system does away with the idleness of funds, guaranteeing static efficiency. But it also produces new processes, enhances innovation that implies a breaking up in the prevailing industrial structure, thus favoring dynamic efficiency but at the detriment of the static one.

The main issue about the production of processes concerns the ‘construction’ phase (which corresponds to a waiting period) and the costs associated with it. These costs are dissociated from proceeds in the sense that, by definition, they have to be paid before the corresponding proceeds are obtained. There is no longer a synchronization of the successive stages of the production process. Thus the first requirement of a proper analysis of non-stationary states of the economy (or of the firm) is a representation of production activity as the production of processes (and not only of commodities) with a focus on its time dimension. Activity analysis actually deals with processes rather than commodities in so far as it refers to complementary factors. However, with this kind of representation the substitution of the process for another is analytically instantaneous. As a matter of fact, the time dimension vanishes when *funds* (as defined by Georgescu-Roegen) are reduced to *flows*. In the activity analysis the performance

of the economy during a given period is adequately represented by the flows observed within the period itself. The production process is seen in fact as a continuous affair described only from the outside by flows. What was already inside the process at first and at the end is of no concern to the economist (Georgescu-Roegen, 1990, p. 210). All inputs (including capital goods) are then commodities which in any period have a complete reference back to the market and hence a price. The costs associated with a given productive capacity are immediately matched by corresponding revenues: the distinction between construction and utilization disappears and the possibility of dissociating costs from proceeds goes with it. Thus the attempt by Georgescu-Roegen himself (1974/1976, pp 245–251) to incorporate a flow – fund analysis of production into a multi sector model à la Leontief “raises a troublesome question of practical operationality” (ibid, p. 249). This is due to the fact that “capital equipment is specific, and hence cannot be used in a different process from that for which it has been designed” (ibid.)

3. Time and sequence: dissociating costs from proceeds

An equilibrium (point or path) is characterized by a given relation between the relevant economic magnitudes. This reflects the established (and in some way synchronized) functioning of a given, or regularly expanding, productive capacity, which also implies that costs and proceeds are somehow kept together. Whenever production, not simple exchange, is contemplated, the assumption that inputs do not come before output in an essential way is thus crucial for equilibrium analysis. Costs and proceeds can be written as a function of current output abstracting from the underlying productive capacity and focusing on its ‘utilization’ moment as represented by output levels.

Explicit consideration of time by dating the variables involved does not really change things by itself. Thus we need something more than simply stretching out ‘in time’ the process of production: we need to dissociate the accounting period from the duration of this process, in order to dissociate inputs from output and costs from proceeds. This we can do by plotting the production process over a sequence of periods, provided, however, this is a true sequence, that is a sequence of periods that from the accounting viewpoint do not collapse into a unique period. This requires that the costs are those actually incurred and the proceeds are those actually accruing in each given period – but that, at the same time, the different periods ‘belong’ to the sequence in the sense that they make up the sequence itself. What really makes different periods part of a sequence in the above sense is that they are linked with each other, and in such a way as to keep the time sequence right.

A production process extending over more periods and characterized by intertemporal complementarity certainly provides such link. A Neo-Austrian production process (Hicks, 1970, 1973) – that is, a process by which a flow of primary labor inputs is converted ‘in time’ into a flow of final output, and where capital goods are implied but regarded as intermediate products internal to the process

¹ This point is addressed by Lowe (1975) who brings into light that, according to Smith’s third law of dynamic motion, “it is the rate of increase in aggregate demand that governs the rate of increase in productivity” (p. 420).

and not explicitly shown – is the most obvious candidate for this role.² Its full vertical integration, in fact, makes it possible to focus on ‘one way’ intertemporal complementarity and at the same time, by canceling the reference back to the market ‘during’ the process, to dissociate ‘in time’ costs from proceeds imputing them to different periods. Thus, when we consider both a process of production articulated over time and a truly sequential context, inputs come before output in an essential way. But, once again, this can be hidden under an equilibrium sequence, characterized by a given age structure of productive capacity, which makes possible a synchronic representation of production that brings costs and proceeds together again. We must therefore be somehow ‘out of equilibrium’ for the analytical implications of a sequential context to come to light, even when the time structure of the process of production is explicitly taken into account. But what do we actually mean here by ‘being out of equilibrium?’ Reference to a Neo-Austrian analytical framework will help clarify this point.

Consider an economy where a single homogenous commodity is produced by means of a unique primary input – labor – with an elementary process of production taking place through a sequence of periods 0, 1, ..., n, n + 1, ..., n + N which make up a phase of construction c (from period 0 to period n) and, following it, a phase of utilization u (from period n + 1 to period n + N) of productive capacity. At each time t, if $\mathbf{a}_j = [a_{jk}]$ $k = 0, 1, \dots, n, n + 1, \dots, n + N$ is the vector of quantities of labor required by an elementary process and $\mathbf{b}_j = [b_{jk}]$ $k = n + 1, \dots, n + N$ is the vector of final output, we can write the accounting equations for total employment (L) and total final output (B) as:

$$L(t) = \sum_{k=0}^{n+N} a_k x_k(t)$$

$$B(t) = \sum_{k=n+1}^{n+N} b_k x_k(t)$$

where $\mathbf{x}_j[x_k]$ $k = 0, 1, \dots, n, n + 1, \dots, n + N$ is the vector of the number of processes of age 0, 1, ..., n + N,

In a steady state, we have $x_0(t) = Gx_0(t - 1) = Gx_1(t)$ and $x_1(t) = G^{-1}x_0(t)$ where $G = 1 + g$ and g is the steady growth rate.

Then

$$L(t) = x_0(t) [a_0 + a_1 G^{-1} + \dots + a_{n+N} G^{-(n+N)}]$$

$$B(t) = x_0(t) [b_{n+1} G^{-(n+1)} + \dots + b_{n+N} G^{-(n+N)}]$$

² In this analysis, capital goods exist and are an element of the production process, but each of them is specific of the production process in which it is embedded. By definition, there are no prices for such goods since they cannot be exchanged on the market once they have been built as they can only operate within the production process to which they belong. From a logical viewpoint, it is always possible to transform a vertically integrated model into a multi-sector model à la Von Neumann (Burmeister, 1974), but this would contradict the above mentioned assumption of non transferability that is essential for making endogenous the construction phase of capital equipment, and hence to properly analyze processes of structural change.

The bracketed expressions are independent of t, so the ratio $B(t)/L(t)$ is constant over time. Here the labor productivity only depends on the technical parameters and on the exogenous growth rate. As in steady state the real wage rate w is also constant over time, this implies the constancy of the ratio $B(t)/wL(t)$. Costs (wL) and proceeds (B) are then perfectly synchronized, and both can be made to depend on the same variable: the scale of activity of productive capacity in the utilization phase, which in this model reflects the current final output. As a matter of fact, while proceeds actually depend on $\mathbf{x}^u(t)$, costs depend not only on $\mathbf{x}^u(t)$ but also on the processes still in the phase of construction $\mathbf{x}^c(t)$. However, in equilibrium a given age structure of productive capacity, and hence constancy of the ratio between the above vectors, makes it possible to focus only on current final output (the ‘utilization’ moment) and to write costs and proceeds:

$$C(t) = C[\mathbf{x}^u(t)] \text{ and } R(t) = R[\mathbf{x}^u(t)]$$

A given and stable relation between the relevant economic magnitudes also implies a given relation between processes in the phase of construction and processes in the phase of utilization, and a given age structure of productive capacity. The productive structure thus defined has a ‘horizontal’ dimension, expressed at time t by the vectors of elementary processes at different stages of their life – still in the phase of construction or already in the phase of utilization – being carried on; which also implies a ‘vertical’ dimension (the time pattern of production associated with this age structure of productive capacity). These, in equilibrium, must be consistent with each other: then, together with construction and utilization, investment and consumption and supply and demand of final output are also harmonized, at each given moment of time and over time. When this is so the time dimension of production is left somewhat in the shade; we have just seen how we can in fact abstract from underlying productive capacity and concentrate on its utilization moment, and how costs and proceeds then become analytically, and from an accounting viewpoint, contemporaneous.

A qualitative change – as opposed to mere quantitative growth perfectly compatible with the equilibrium state just defined – implies instead a change in the way of functioning of the economic entity considered (the economy or the firm), that is, a structural modification which, according to the above definition, is characterized by a change in the balance between processes in the phase of construction and processes in the phase of utilization, and hence a change in the age structure of productive capacity with respect to its previous equilibrium configuration. As we have just seen, not only construction and utilization, but also investment and consumption, and supply and demand, are then no longer harmonized over time. This means it is no longer possible to focus on current final output abstracting from the underlying productive capacity and, in particular, from the time structure of the production process. The ratio $B(t)/wL(t)$ is no longer constant over time and, as a consequence, costs are dissociated from proceeds. When the ratio between the vectors $\mathbf{x}^c(t)$ and $\mathbf{x}^u(t)$ is no longer constant, costs and proceeds are affected in a different way,

as is the case when there is a breaking of the steady state, which thus implies separating inputs from output in time. The cost and the proceeds functions will become:

$$C(t) = C[\mathbf{x}^c(t), \mathbf{x}^u(t)] \text{ and } R(t) = R[\mathbf{x}^u(t)]$$

In this case, what happens to costs and proceeds over time depends on the way coordination issues are dealt with that is on behaviors and policies carried out in reaction to successive distortions.

4. Employment, productivity and the time structure of production

A first and more general meaning of being 'out of equilibrium' is then that a change in the balance of processes of production in different stages of their life is under way. When this is so, it is not possible to abstract from the underlying productive capacity, whose structure is continuously modified, and concentrate on its 'utilization' moment. The consequence, as already mentioned, is that inputs are separated in time from output and costs dissociated from proceeds. This happens whenever a qualitative change is contemplated. Then the 'definition' moment (technology) of the production process – that is, its physical characteristics, including its time profile – comes back into light: and this occurs in the first place, obviously, when a change in these characteristics (that is, a change in technology) is contemplated.

In the standard analysis, in which 'efficiency' is pursued, the mere appearance of a 'superior' technique pushes to its adoption³. However adoption, once again, is treated within an equilibrium framework. Thus it actually becomes an analytically instantaneous (total, or partial as in vintage models) process which does not allow the transition phase during which productive capacity necessarily gets distorted to show up. Consideration of the time dimension of production in vintage models, thus, is confined to the 'utilization' moment (the economic life of machines, that is, the extensive dimension of capital), and hence it has no 'essential' implications, as we have defined them, in terms of the relation between inputs and output.

On the other hand, we may want to stress the fact that a 'new' productive structure does not immediately come about after a modification of it is contemplated, but the economy must actually go through the phase of construction of a different productive capacity before this happens. This is what happens in the analysis of the Traverse (Hicks, 1973), which portrays the adoption of a superior technique as a process taking place sequentially over time. The explicit consideration of the time structure of the production process and of its intertemporal complementarity (with focus on the phase of construction of a 'new' productive capacity and on its coming necessarily before the phase of utilization) allows to bring into light that a change of the technique in use necessarily implies a change in the age structure of productive capacity and hence a

dissociation of inputs from output and of costs from proceeds. We are in fact here clearly in an 'out-of-equilibrium' context where the different specification of the cost and the proceeds functions – as defined in the previous section – comes to be stressed, due to the fact that the modification in the age structure of productive capacity shows immediately in the one function and not in the other.

The analysis of the Traverse carried out within this analytical perspective allows important insights: in particular, it makes possible a demonstration of the famous Ricardo 'machinery effect' according to which the introduction of machinery has an adverse effect on employment in the short run. Consider the case of the introduction of a new technology characterized by higher construction costs. The costs come earlier, and hence cannot be financed out of current production. This causes a distortion in the structure of productive capacity, a reduction of the investment in capacity – a reduction in the number of processes in the phase of construction – with respect to what happened with the old technique, and hence a temporary reduction of final output when, for the first time, the new production processes enter the utilization phase. As a consequence, along a fixed wages path, unemployment increases, while, with flexible wages and full employment, labor productivity declines. This is the essence of the so-called productivity paradox, which goes hand-to-hand with the machinery effect.

As a matter of fact any attempt to change a given productive structure implies bringing back into light the time articulation of the production process – its having to go first through a phase of construction of a different productive capacity in order to be able to use it later for current production – obscured by the synchronization of production in equilibrium. This is what Hicks means when he writes, in what might appear at first sight a rather cryptic way, that "Ricardo had learned to distinguish between investment at cost and investment of output capacity" (Hicks, 1973, p. 98). But the fact that there is a dissociation of inputs from output and of costs from proceeds whenever a change in the structure of productive capacity is contemplated, also implies that Ricardo 'machinery effect' is in fact much more general and takes place whatever the nature of the technical improvement considered, that is, whether the new production processes are more mechanized, the specific case stressed by Hicks, or not. This has been proved (Amendola, 1972) with reference to processes of production with a more general time profile whose life can be shortened or lengthened as the result of an optimizing behavior confronted with different values of the relevant economic variables (paramount, the value of the rate of interest in relation to the wage rate). A fall in final output, and the unemployment associated with it, is then shown to be the result of a scrapping of production processes – as a consequence of the introduction of a new technique whatever the nature of the technical improvement, in the specific case considered a neutral technical improvement – greater than in the equilibrium state associated with the old technique.

Here the arbitrary saving function considered by Hicks is essential. An optimal saving behavior which took into account the intertemporal complementarity of production

³ 'Superiority' and 'efficiency' are in fact defined in the same terms, whether techniques are represented by means of a production function or in different ways: e.g. in terms of wage-interest curves.

processes could possibly serve the purpose of maintaining full employment over time. But this – in the same way as the hypothesis of flexible real wages would artificially conceal the problem of technological unemployment by instantaneously re-absorbing it – would only lead to give up the idea that intertemporal complementarity of production matters. The theory that would emerge, then, would not be “a sequential theory, of the kind we are here endeavoring to construct” (Hicks, 1973, p. 56).

However, an analytical incongruity still besets Hicks’ analysis of the Traverse (or its generalization): the assumption of Full Performance, which makes it possible to stick to an equilibrium approach (even when scrapping occurs, as it reflects an intended behavior) in what is essentially an out- of- equilibrium context. Which comes down to an assumption of co-ordination of economic activity in a context where capacity is not adapted and that hence denies co-ordination.

Still, being able to throw light on what happens on the way is a momentous achievement, and not so much for the specific analytical results obtained as for the change of analytical perspective that this implies. As a matter of fact although ‘the way’ considered is still ‘the way to’ a predetermined point of arrival, Hicks himself lets it understand that the problem of convergence to this point (which is in the end why the equilibrium set up is called in) is not really the important thing, and that what happens on the way may matter in itself: “Convergence to equilibrium has been shown to be dubious, but it has also been shown to be unimportant. Even at the best, it will take a long time . . . and before the time has elapsed something new will surely have occurred. It is therefore of the first importance that something can be said . . . about the short-run and medium-run effects of an exogenous disturbance” (Hicks, 1975, p. 316)

Hicks’ analysis of the Traverse is certainly a piece of transitional dynamics, but it has two main limits. The sequence considered is fully predetermined as it portrays the passage from one given technique (with the associated equilibrium state) to another. The equilibrium approach followed does not allow co-ordination problems to arise: the assumptions that guarantee equilibrium imply that no decision process is actually envisaged. Removal of these limits, and more general assumptions than the specific ones made by Hicks, will make it possible to throw more light on the relation between technology and employment in the analysis of out-of-equilibrium processes of change.

A change in the balance of production processes, and a modification in the age structure of productive capacity, also obtains when, with no change in the technique in use, there is an increase in the rate of growth. This means in fact an increase in the number of processes in the phase of construction not matched for a certain time (that is, as long as the higher growth rate has not yet been reached) by a corresponding increase in the number of processes in the phase of utilization. Again, the cost and the proceeds functions are affected in a different way and costs are dissociated from proceeds. However, this case poses an additional problem. While in fact the introduction of a new technique can be financed out of current productive activity by diverting to the construction of the new productive

capacity the resources previously devoted to financing the production processes of the old type, this is no longer possible when an increase in the growth rate is considered. The costs incurred for bringing about such an increase – ‘sunk’ costs that can only be recovered over time – now cannot be financed with the proceeds of current productive activity; additional financial resources are in fact required as long as the age structure of productive capacity is not adjusted to the higher growth rate. The adoption of a new technique is always possible: the technical coefficients and the hypotheses as to the destination of existing proceeds will determine how (and if) the Traverse will actually be accomplished. An increase in the rate of growth, instead, will be possible only if additional financial resources are exogenously made available.

What in any cases makes it possible to focus on the time dimension of production (and hence on inputs coming before output in an essential way) is a change in the balance of production processes with respect to its equilibrium configuration (where production is somehow synchronized) which takes the economy out of equilibrium in the sense stressed above. Nevertheless this change can take place smoothly, with the existing production processes gradually transmuted into different ones until a new equilibrium configuration obtains. Suitable hypotheses⁴ reduce the process of change to a sequence that can be fully predetermined and where expectations play no role. In each period of the sequence leading to a configuration of productive capacity fully known beforehand, in fact, supply and demand for final output are kept in equilibrium. The change dealt with can also imply some scrapping of production processes. However, when this scrapping reflects an intended behavior, no true distortion of productive capacity occurs, and the equilibrium between supply and demand can still be maintained during the process of change, which is thus ensured to take place. Thus structural modifications do not necessarily stir out-of-equilibrium processes, which may imply a cumulative causation or erratic fluctuations. Although evoking an out-of-equilibrium context they can still be dealt with by turning to an equilibrium approach.

However, it must be stressed, this happens only in particular cases characterized by very strong assumptions. In general, structural modifications imply a distortion of productive capacity, which comes down to the abrupt disappearance of a part of the existing capacity, with the sudden arising of imbalances between supply and demand and investment and consumption. Via expectations, and in the attempt to correct these imbalances, a sequence ‘constraints-decisions-constraints’ sets in that results in an out-of-equilibrium process which most likely shakes the economy in such a way as to cast doubts on the viability of the change undertaken. Although true for all qualitative changes (with the specific exceptions just mentioned) this can be made more evident by referring to changes which

⁴ Like, in the analysis of the traverse, the existence in the economy of a single homogeneous commodity and the hypothesis of full performance, which imply that all output which is not consumed is invested (except a constant take-out).

imply shifting from an *ex post* to an *ex ante* view point, though.

5. The way ahead

We have shown that, for the time dimension of production to become 'essential' in the analysis, both a representation of the process of production that takes explicitly into account the phase of construction of productive capacity (and hence does not focus only on the 'utilization' moment of a given productive option) and an out-of-equilibrium context are required. When this is so the process through which a change takes place can be analyzed as such, not substituted for by a comparison between the situations prevailing before and after the change.

However, although bringing to light the time structure of the process of production, and stressing the implications (different in the two cases) of actually taking this time structure into account, both cases mentioned still stick to a new view of technology and production as they both concern given productive options. The analysis of the Traverse concerns in fact the adoption of a given (already defined) 'superior' technique. Even clearer is the standard viewpoint in the case of an increase in the rate of growth, where the whole point is the multiplication of processes of production not only perfectly defined but already established in the economy. What about, instead, the wider and certainly more interesting gamut of qualitative changes which also imply the appearance of altogether new productive options? The analysis of these changes need more than a representation of production that takes explicitly into account the phase of construction of productive capacity and its relation with the phase of utilization. It needs interpreting 'construction' no longer as adoption or actual embodiment but as 'creation anew'. Technology and productive options, then, are no longer given or exogenously determined: they are the result of the process of change, not its precondition. This requires to shift from the standard to a new view of the phenomenon of production; which not only has important implications for a great many problems (from the way in which we define the firm and its functions to the interpretation of the environment) but has got to do in the first place with the very modelling of processes of economic change.

But what does this change of perspective really mean? It must not be taken only, and so much, in the sense of stressing different viewpoints from which to look at a certain problem but rather in the sense that, by enlarging the cone of light so as to consider a wider gamut of aspects, we actually come to consider an essentially different problem.

When the standard viewpoint prevails a lot is 'given' as regards production. In particular, technology and the environment are essentially given: which does mean that technology is something that falls from the sky more or less fully realized – and hence has only to be adopted, as in the traditional representation of technical progress – and that the environment is just the stage on which adoption takes place and that matters just for the constraints that it imposes on the adoption process. The analysis of technological trajectories defined as the actualization of

the promises contained in a basic paradigm (Dosi, 1982), just to make an example, has in fact taught us that technology is actually developed through a sequential process that restricts the range of options left available as the technology gets more and more specified, and that the environment takes an active part in this process. This is certainly a significant step forward with respect to the naive interpretation of technology as something to be taken out of a shelf; however, it remains that it is the development of a specific technology, with given potential characteristics out of which a given environment will help to single out the ones that will be translated into the actual physical expression of the technology itself, that the model of the trajectory postulates and focuses on. Although apparently less is 'given' in this model than in the traditional one, and more is left to be determined by a process, still this process is somewhat confined to the definition and the building in a certain context of the productive capacity expression of a particular technology.

The crucial hypothesis, that characterizes both the traditional approach and the one focusing on technological trajectories, is that the resources that take part in the production process – be this simple adoption or actual specification of a technology – are seen as existing in their own right and are hence separated from the technology that they contribute to bring about. This also implies, in a wider sense, that these resources make up the environment in which production takes place and which is therefore given with respect to the production process itself, although helping to shape it. Resources, in terms of which both technology and the environment are defined in the end, must logically pre-exist them.

The standard viewpoint allows then focusing on (the adoption, the development, the more intensive utilization of) an essentially given technology within an essentially given context. In this sense the case of technological trajectories is not different from the cases of the Traverse and of an increase in the growth rate mentioned above: the object of the analysis remains a given technology, whether the latter is observed as a finished object or in the process of its forming. Thus, although representing an undeniable step forward in the description of specific technological advances and in their understanding, the evolutionary approach which is behind the analysis of technological trajectories – at least in the way in which it has been developed – does not really allow to focus on the thorough 'economic problem' at the heart of economic change, that is, the dissociation of inputs from output and of costs from proceeds that the change itself brings about while it is taking place. And this is so for the reason just mentioned: not to have in the end developed a theory of production different from the standard theory such as to overcome the dynamic limits of the latter.

A change of perspective does not mean to lock less "in the pond of *ceteris paribus*" – although it implies going to the extreme of actually considering nothing as given. It means instead changing the very object of the analysis and, together with it, the economic problem involved. Qualitative change interpreted as creation of altogether new productive options, not the adoption/development of something already essentially defined, comes into focus.

Innovation is the typical example of qualitative change originating within a process that takes place sequentially: a process through which a new productive option (with the corresponding specific capacity) is actually structured and, as we shall see, further still options are envisaged. A process of construction of new forms of production, which will only take on precise definition along the way, also implies the appearance of a new kind of output (to which, most likely, new forms of consumption are associated). On the other hand this kind of process can no longer be regarded as the simple assembling of given generic inputs⁵. The inputs as well will in fact undergo a modification while the process is taking place and the new productive option is being structured. Thus resources and technology are no longer separate: they become one and the same thing while the change is going on. The process of change is what brings about both, and a new and different environment together with them.

In the new perspective therefore we must move from the consideration of generic inputs to that of specific resources: that is, resources embodying particular characteristics, and potentialities, acquired through the process of qualitative change in question, which therefore comes down to a process of creation of resources. Within this perspective qualitative change is essentially a learning process, where learning is related to the abstract capacity of conceiving and implementing new productive options in general, and hence is seen as an enrichment of the potential creativeness of the human resource. However, this kind of learning is the joint product of another kind of learning, related to and taking place while the production process through which a specific productive option⁶ is actually being defined is carried out. Innovative production processes actually carried on and taking shape sequentially over time are then the carrier of learning resulting in a creation of resources (Amendola and Gaffard, 1988).

Interpreting production no longer as allocation of resources but as creation of resources – that is, changing the economic problem involved – has momentous analytical implications. In the first place, it means that we are after is no longer choice out of a given choice set in the light of some optimality criterion but modification and redefinition of the set itself. Optimal allocation solutions (equilibria) are defined with reference to given parameters (resources, technology, and so forth), which are instead made endogenous to a process of qualitative change. The attention therefore cannot be concentrated on the outcome of a process that cannot be specified *ex ante* as the effective constraints that set its trend are themselves modified while the process unfolds and in accordance to how it unfolds. What matters, then, is the process of change in itself, and hence the conditions for its *viability*, rather than the configuration that will result from it, and the characteristics of the latter. As a matter of fact the adaptive or

innovative behaviors that characterize out-of-equilibrium processes like qualitative changes may bring the economy beyond limits, which imply its collapse. These limits represent barriers within which the economy itself must be kept to remain viable. They may concern employment (not only production processes may be seriously affected but the society may not accept excessive levels of unemployment), indebtedness (which must not be so high as not to guarantee creditors against insolvency, in which case creditors would lose confidence and firms would go bankrupt), or else⁷. However, we have already stressed, this is true not only of changes that imply creation of resources and learning but of all qualitative changes characterized by structural modifications that can only be brought about through out-of-equilibrium processes (like, e.g., a speeding up of the growth rate). To analyze a qualitative change is to explain how, and under what conditions it takes place, to focus on how productive options are actually structured, rather than on the characteristics of particular productive solutions, and hence on comparison and choice.

This is a main difference between our approach and, say, [Pasinetti \(1981\)](#), who also deals with growth as a qualitative change. In his model (1981), changes in consumers' preferences at higher levels of real income result in rates of growth of demand that differ between commodities, so that the demand in some sectors cannot match the increases in productivity deriving from the learning by doing in production. However, changes in technology are introduced as movements of production coefficients over time, which are at each moment the result of an already realized process of adjustment. This puts the analysis in an *ex post* descriptive posture, which tells us nothing about the process that brought about the existing technological alternatives and productive structures or about the specific forces that generated them.

To focus as we do on how productive options are actually structured, on the other hand, affects both the modelling of the process involved and the kind of analysis we are to carry on. In the first place commodities are no longer defined with reference to a date, a place and a state of nature, as in general equilibrium models, but in terms of production processes with specific time profiles. Then we have a different interpretation of the terms 'exogenous' and 'endogenous'. In a model there are variables and parameters: the parameters (given magnitudes and coefficients) reflect the existing constraints. Exogenous, in the standard analysis, are the constraints, which exist outside and above the economy and which determine its behavior. Within this context, considering endogenous change means that something that was a parameter in the above sense is now made the object of a behavior explicitly considered in the model: the form of the behavior function, and its coefficients, become now the exogenous constraints.

⁵ And hence can no longer be specified in terms of given combinations of the inputs themselves (whether or not regarded at different moments of time) as is the case when an *ex post* representation of technology prevails.

⁶ Which, in an *ex post* perspective, will appear as a given productive capacity, with the specific physical assets, forms of organization and skills and qualifications of the labor inputs that it implies.

⁷ As an immediate consequence, the very image of the firm, and the definition of its tasks, also need to be revised. As a matter of fact, in this new light the firm can be no longer identified with a production function but must be regarded as an organization whose task is not to allocate given resources in view of efficiency but to make a process of creation of resources viable.

But once we recognize that the time over which change takes place is a continuing and irreversible process which shapes the change itself, as we have to do when we consider a qualitative change, “it is impossible to assume the constancy of anything over time. The only truly exogenous factor is whatever exists at a given moment of time, as a heritage of the past” (Kaldor, 1985, p. 61). In the analysis of an out-of-equilibrium process (and all the more in the analysis of a process of creation of resources), thus, we have to consider as a parameter, and hence as exogenous, not some given element chosen beforehand in reason of its nature or characteristics, but whatever, at a given moment of time, is inherited from the past. What appears as a parameter at a given moment of time is therefore itself the result of processes which have taken place within the economy: processes during which everything – including resources and the environment, as well as technology – undergoes a transformation and hence is made endogenous to the change undergone by the economy. Thus, while the standard approach focuses on the right place to draw the line between what should be taken as exogenous and what should be considered instead as endogenous in economic modelling – a line that moves according to what we want to be explained by the model – out of equilibrium (and all the more in an *ex ante* perspective) the question is no longer that of drawing a line here or there but rather one of time perspective adopted. Everything can be considered as given at a certain moment of time, while everything becomes endogenous over time.

We have considered out-of-equilibrium contexts in which changes are brought about gradually and smoothly, so that no viability issue is involved. However, we have stressed that more generally qualitative change causes a distortion of productive capacity, which stirs an out-of-equilibrium process that the economy must go through for the change undertaken to take place. When we are ‘out of equilibrium’ in this stronger sense the relevant problem is the viability of the out-of-equilibrium process, and this problem is not one calling for general analytical solutions as in the usual perspective of formal (allocation) models⁸. A construction process (and all the more a creation process) that builds up along the way can be explored, and its viability ascertained, working out the evolution of the economy along the sequence of periods through which the intertemporal complementarities and the interactions that

characterize the functioning of the economy trace out the effects of the initial structural modification (Amendola and Gaffard, 1998). An analysis that, on the other hand, has policy implications that stress interventions quite opposite to those preached by the prevailing equilibrium growth modelling (Amendola and Gaffard, 2006)

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⁸ The suggestion that rational expectations would not allow cumulative processes of this kind is not relevant here, as out-of-equilibrium contexts are characterized essentially by the fact that the agents are involved in a learning process which is not consistent with rational expectations.