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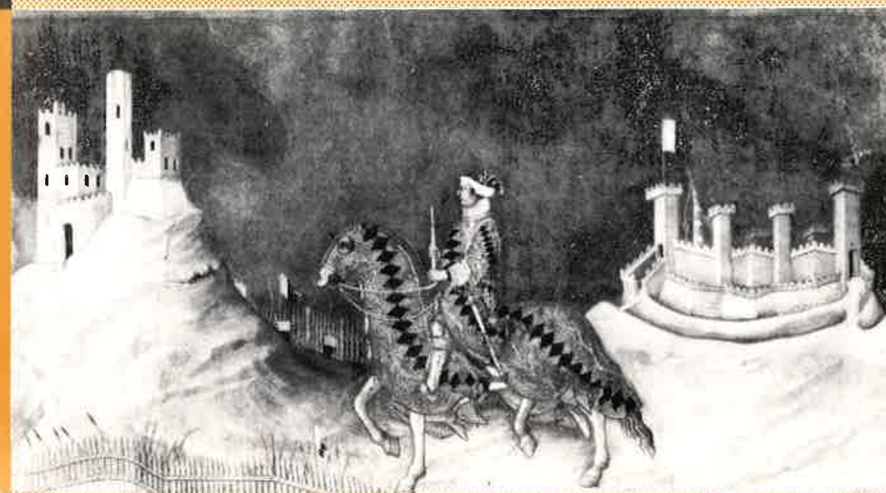
Facoltà di Scienze Economiche e Bancarie

QUADERNI DELL'ISTITUTO DI ECONOMIA

M. Amendola - J.L. Gaffard

INNOVATION AS CREATION OF TECHNOLOGY: A SEQUENTIAL MODEL



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INNOVATION AS CREATION OF TECHNOLOGY: A SEQUENTIAL MODEL

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Contents

*The features of the model**

1. Innovation, in this model, is portrayed neither as the diffusion/absorption of a given technology into the prevailing economic structure, nor as the development of a new technology, from an initial impulse, in a particular environment, but as a process of creation of technology: where technology no longer appears as a specific way (with its own physical counterpart) to solve a given problem, but rather as an envitonment characterized mainly by a labour resource capable of devising and implementing different solutions to different problems.

The process of innovation is then defined as a sequential process of research and learning, which sets in as the result of an innovative choice and of the subsequent carrying out of innovative processes of production, and which brings about entirely new skills and qualifications thus modifying the environment itself and permitting to widen the existing range of productive problems and solutions.

Technology, from an analytical point of view, is then the result of the process of innovation, and not a precondition of it.

2. The analysis is carried out with reference to a Neo-Austrian frame-

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work, which helps bringing to the fore both the role played by the labour resouerce in the process of innovation and the sequential character of the process itself, whose direction and content cannot be predetermined but are assumed to take shape as technology builds on technology step bu step.

The representation of a fully vertically integrated process of production, which is articulated sequentially in time but must be taken as a whole over time, provides a first thread stringing in successive periods. The technical intertemporal complementarity of the process of production, on the other hand, is matched by the intertemporal complementarity of a decision process conceived as a related sequence of choices. A sequential framework "constraints-decisions-constraints" can thus be defined: the decisions taken in each period depend on existing contraints which, owing to the above mentioned intertemporal complementarities, reflect the choices made up to moment considered, while to-day's decisions, in the same way, go to modify the constraints which will arise tomorrow, and so on.

This framework sets the stage for the analysis of the process of innovation, in which the effects of a process of learning besides the already mentioned intertemporal complementarities, are taken into account in the shaping of the pattern of interactions between constraints and decisions. It will be shown, in particular, that while the appearance of new specific labour inputs as a result of learning is the backbone of the process of innovation, bringing about new technology and hence new options as the process goes on, the structure of the labour resource at each given moment sets

a constraint on the range of the actually feasible choices; but this constraint is modified at each successive step, getting less stringent as we proceed on an innovative path and the labour resource becomes richer and more articulated.

3. The emphasis on the labour resource in only too natural in a setting characterized by processes of production featuring heterogeneous labour as the only primary input, and where the capital goods are specific and internal to each process, and hence are implied but not shown.

Learning, however, affects not only the labour resource, that is the production side of the economy; it brings also about a continuous modification of the consumers' preference system which represents, as we shall see, an important aspect of the process of innovation. The labour constraint, on the other hand, is not the only constraint limiting the range of the feasible choices and the level of the economic activity. A financial constraint, represented by the resources available at the beginning of each given period to finance the labour force required to carry on the processes of production, is also considerd; and it may be more or less stringent than the labour constraint.

We are dealing with a monetary, and not a barter economy, in the sense that the sequences taking actually place in the economy depend strictly on the existence of money: in particular, the fact that exchanges are made and wages are paid in money terms adds a sequence of the exchanges, which takes place within each period, to the sequence of production, which extends over successive periods. The resources required to carry out the processes of production are thus financial resources and not physical output: a capital "fund" which is made up of money (when, for simplicity, no other financial asset is considered) but which does not coincide with the latter. Money, in fact, can also be stored, to stock the decisions of the producers and/or the consumers when these are postponed waiting for more information to come in an uncertain context; and the changes in the proportion of it actually devoted to production and/or consumption are in this model a main determinant of the problem of an innovative choice and of the actual evolution of a process of innovation.

Finally, the sequence analysis of the Swedish school is certainly in the background; but the consideration of a Neo-Austrian context and of the role played by the constraints has brought us to make use of a stock-flow approach as the better suited for the analysis of the carrying of a desequilibrium down a sequence, as it is typically the case with a process of innovation.

4. The model which embodies the above mentioned features is used to analyse the consequences of a disequilibrium arising in an economy which is growing at a constant rate making use of a well established routine technology. The disequilibrium which takes the form of an excess supply is assumed to be the result of a change in the producers' behaviour or in the consumers' preference system reflecting a research of flexibility in a context

which has acquired a certain degree of uncertainty.

The answer to such a disequilibrium can be either a quantitiative adjustement consisting in a simple revision of the final output and investment targets of processes of production which keep being carried out according to the established technology, or, when the disequilibrium is rightly interpreted as the sign of a structural change, an innovative choice bringing about a process of creation of technology, which represents a qualitative answer to a qualitative problem.

Pattern of evolution of the economy have been simulated both in the case of a routine choice and of an innovative choice, bringing to light the course of employment, the time profile of the indebtment and the behaviour in time of all the other relevant magnitudes. Simulation is aimed at suggesting problems, solutions and policies which at the moment do not appear to be susceptible of treatment in purely analytical terms: the results obtained confirm the validity of the analysis carried out.

I. THE ANALYTICAL FRAMEWORK

1. The process of Production

1.1. Routine processes

The process of production, defined ad a scheme for converting heterogeneous labour inputs into final outputs, goes through a sequence of periods which, following Hicks' device, are grouped in two phases: the phase of construction and, following it, the phase of utilization of (a unit of) productive capacity. This is a useful device to exhibit some important consequences of the technical intertemporal complementarity of the process of production, but the sequence of elementary periods -each characterized by the application of fresh labour to production and, when the process has reached the phase of utilization, also by the carrying out of a round of current final production- must be taken as a whole to represent a fully vertically integrated process of production. At the same time the distinction between the phase of construction and the phase of utilization must not be interpreted as marking necessarily the appearance of physical equipment; it does certainly no harm to keep thinking traditionally in terms of plants and "machines", but what is really meant here with the phase of construction is more generally the preliminary setting of the stage for actual final production, whether it involves or not physical capital goods.

The processes of production carried out in the economy are defined as either "routine" (x) processes, or "innovative" (y) processes.

Routine processes of production are the expression of an already established and fully developed (in the sense that no substantial improvements or refinements are expected) technology. To such a technology the productive capacity of the economy and the structure of the labour resource, which is its meaningful expression in a model where the only inputs shown are labour inputs, are assumed to be already perfectly adjusted.

An elementary routine process, which permits to obtain from a unit of productive capacity a composite basket of non storable commodities and/or services whose characteristics are also fully defined and perfectly known by the consumers, is described by:

1) a matrix $\underline{\underline{A}}$, whose elements represent the quantities of the different types of labour (h=1,2,...,s) required by the process in the different periods of its life (k = 1, 2, ..., m, m+1, ..., m+M), where m and M are the lenght of the phase of construction and the lenght of the phase of utilization respectively;

2) a vector $\underline{\underline{\alpha}}_0$ whose elements represent the heterogeneous labour requirements to start the process of production;

3) a vector of final output $\underline{\underline{c}}$, whose elements refer to the amounts of final output obtained in the different periods of the process.

$$\underline{\underline{A}} = (\underline{\underline{A}}^{c} : \underline{\underline{A}}^{u})$$

$$\underline{\underline{A}}^{c} = (\alpha^{c}_{hk}) \quad k = 1, 2, \dots, m \, ; \, h = 1, 2, \dots, s$$

$$\underline{\underline{A}}^{u} = (\alpha^{u}_{hk}) \quad k = m+1, \dots, m+M \quad ; \quad h = 1, 2, \dots, s$$

$$\underline{\underline{\alpha}}'_{0} = (\alpha_{10} \; \alpha_{20} \dots \; \alpha_{s0})$$

$$\underline{\underline{c}}' = (c_{m+1}, c_{m+2}, \dots c_{m+M})$$

where the prime denotes transposition.

1.2. Innovative processes

An innovative process of production, on the other hand, is not the expression of an already established technology in a perfectly adjusted productive context, but a moment of a transformation under way: an intermediate step in the construction of a new technology which will have different developments according to the different paths opened by different successive stps, and to the different choices made in a related sequence.

The profile and the characteristics of the process of production will thus change at each successive step, this change being the expression of

the technological and productive transformation going on. The elements of the matrix $\underline{\underline{B}}$ and of the vector $\underline{\underline{\beta}}_{0}$, which are the exact replica for an innovative process of production of the matrix $\underline{\underline{A}}$ and of the vector $\underline{\underline{\alpha}}_{0}$ for a routine process, must not therefore be considered as technical coefficients in the same way as the elements of the latter, but can be seen as the initial requirements for starting and carrying out an innovative process: requirements which will change together with the process of production itself as technology builds on technology. We assume, in particular, that labour requirements will decrease, starting from the moment each particular type of labour is first applied, at a rate depending on the acquaintance with the new productive problems: the latter being a function of the number of innovative processes of production carried out from the moment 0, when an innovative choice has first been made, up to the particular period considered; that is:

$$\underline{\underline{B}}(t) = (\underline{\underline{B}}^{c}(t) : \underline{\underline{B}}^{u}(t))$$

$$\underline{\underline{B}}^{c}(t) = (\beta^{c}_{hk}(t)) \quad ; \quad k=1,2,\dots,n \, ; \, h = 1,2,\dots,s$$

$$\underline{\underline{B}}^{u}(t) = (\beta^{u}_{hk}(t)) \, ; \, k=n+1,\dots,n+N; \; h = 1,2,\dots,s$$

$$\underline{\underline{\beta}}'_{0} = (\beta_{10}(t), \beta_{20}(t), \dots, \beta_{s0}(t))$$

with

$$\beta_{h0}(t) = f_0 \left(\sum_{T=0}^{t-1} y_0(T) \right);$$

$$\beta_{h0}(0) = \bar{\beta}_{h0} \;;$$

$$f'_0 < 0 \;;\; \forall h$$

$$\beta_{h1}(t) = f_1 \left(\sum_{T=1}^{t-1} y_1(T) \right);$$

$$\beta_{h1}(1) = \bar{\beta}_{h1} \;;$$

$$f'_1 < 0 \;;\; \forall h$$

....

$$\beta_{h\,n+N}(t) = f_{n+N} \left(\sum_{T=n+N}^{t-1} y_{n+N}(T) \right) \;;$$

$$\beta_{h\,n+N}(n+N) = \bar{\beta}_{h\,n+N} \;;$$

$$f'_{n+N} < 0 \;;\; \forall h$$

where f'_0, f'_2, ..., f'_{n+N} are the first derivatives of the functions. In the same way the elements of the final output vector

$$\underline{\underline{d}}'(t) = (d_{n+1}(t), d_{n+2}(t), ..., d_{n+N}(t))$$

refer to amounts of non storable commodities and/or services whose composition and features will change together with the profile of the process of production, as the process of innovation goes on.

2. *Innovation as a learning process*

The process of innovation -conceived as a process of creation of technology associated with the transformation of the environment- is fuelled by a process of learning which sets in as the result of an innovative choice and of the carrying out of innovative processes of production.

Learning consists in a widening of the available information in the uncertain context of the research of new solution to (new) productive problems, and concerns both the production and the consumption side of the economy. It takes the form of the acquisition of higher and sometimes entirely new skills, and, we shall see, of a change in the consumers' preference system.

2.1. Changes in Technology as the appearance of new specific labour inputs

The upgrading and the greater articulation of the structure of the labour resource as more and more innovative processes of production are carried out, suggests new approaches and permits to define new types of processes of production, thus bringing about continuous changes of the technology. The specificity of the newly appearing labour inputs, acquired as a result of the process of learning on an innovative path, consists in fact in particular skills which imply thinking and organizing the productive problems in altogether original ways.

Technology, thus, does no longer appear as a specific way (with its own physical counterpart) to solve a given problem, but as an environment characterized by a labour resource capable of devising, and implementing, different solutions to different problems. While in the traditional approach the process of innovation is seen as the adjustment of the economy and of its resources to a given (superior) technique, here it is a modification of the existing resources -namely the appearence of entirely new skills, and hence of new specific labour inputs- which will change the environment itself, suggesting new productive problems and new solutions.

We assume therefore that the productive capacity of the economy reflects the way in which the processes of production are actually articulated,

and that the latter are shaped according to the particular features and the structure of the existing labour resource.

A labour availability vector can then be written at each time t

$$\underline{\underline{L}}_s^S(t) = \begin{bmatrix} l_1^S(t) \\ l_2^S(t) \\ \cdot \\ \cdot \\ \cdot \\ l_s^S(t) \end{bmatrix}$$

whose elements represent the different skills of the heterogeneous labour resource, and where the term "skill" is comprehensive of all the relevant characteristics (qualification, mobility, readiness to accept over time or to perform certain jobs), of the latter. We assume further that the skills are ranked in an increasing order, the lower indexed elements corresponding to the lower skills, and that those who have different skill and can thus perform different jobs are classified under the item corresponding to their higher skill at the moment.

This labour availability vector gets modified as time goes by both in a routine context and in an innovative context, but in a different way.

When only routine processes of production are carried out according to a given technology, and there is no learning, only external inflows (outflows) reflecting demographic and educational factors and affecting the size of the different elements of the vector must be considered. This can affect all the elements of the vector in the same proportion or each of them in a different way, thus altering or less the structure itself of the vector. What we are dealing with, in any case, are changes in absolute and/or relative size: that is a quantitative phenomenon.

When innovative processes are considered, on the contrary, the process of learning must be taken into account, besides the already mentioned demographic and educational factors. The effect of learning on the labour resource is twofold. On one side, as more and more innovative processes are carried out and the workers employed in them get more and more acquainted with the new productive problems, they gradually acquire higher skills within the range of those associated with the existing profiles of the process of production. We have thus an internal upgradind process resulting in an outflow from each element of the vector and in a corresponding inflow in the next of kin higher indexed element, the net additional balance representing the change in the size of each element due to such a process. Again, we are considering only changes in size, of a quantitative nature.

Learning, however, means not only this, but also the appearance of entirely new skills, that is of skills which are not associated with the existing profiles of the process of production, but which will themselves bring about new such profiles. Thus as time goes by and more innovative processes are carried out, new elements representing new skills are added to the existing ones, so that not only the size of its elements but the dimension itself of

the labour availability vector is modified.

Changes in the labour resource, in other words, are not only of a quantitative kind, but also a qualititive character.

A different labour avaibility vector will thus define the structure of the labour resource at the beginning of each successive period (assuming that the elementary period of production is the span of time over which the changes take discontinuously place): each successive vector having generally elements of a greater size and, when learning is considered, also a greater dimension (for simplicity, only one element is added each period to the vector, that is:

$$\underline{L}^S_s(t) = \begin{bmatrix} l^S_s(t) \\ \cdot \\ \cdot \\ \cdot \\ l^S_s(t) \end{bmatrix} \qquad \underline{L}^S_{s+1}(t+1) = \begin{bmatrix} l^S_1(t+1) \\ \cdot \\ \cdot \\ l^S_s(t+1) \\ l^S_{s+1}(t+1) \end{bmatrix} \qquad \underline{L}^S_{s+2}(t+2) = \begin{bmatrix} l^S_1(t+2) \\ \cdot \\ \cdot \\ l^S_{s+1}(t+2) \\ l^S_{s+2}(t+2) \end{bmatrix}$$

Each element of the availability vector, in each given period, is the result of demographic and educational factors, and, when it takes place, of the learning process, that is:

$$l^S_h(t+1) = l^S_h(t) + a_h l^S_h(t) - b_h l^{DI}_h(t) + b_{h-1} l^{DI}_{h-1}(t)$$

where

a_h = proportion of workers of the h-skill accruing in the period t+1, and depending on the hypotheses made on demographic rules and educational policies. Thus a_h can be a scalar or a more or less complicated function, which can be different for each different element of the vector or the same for all of them.

b_h = proportion of workers of the h-skill employed in the innovative processes in the period t, $l_h^{DI}(t)$, acquiring a higher skill in the period t+1, and hence moving to the h+1 element of the vector $\underline{\underline{L}}_{s+1}^{S}(t+1)$.

and where

$$b_h(t) = b_h\left(\sum_{T=0}^{t} y(T)\right),\ 0 = \text{moment when the innovative choice has first been made}$$

and hence

$$b_h(t) - b_h(t-1) > 0$$

assuming that

$$\sum_{T=0}^{t} y(T) > \sum_{T=0}^{t-1} y(T)$$

that is assuming that it is not the mere passage of time which matters for learning to take place but the fact that as time goes by more innovative processes are carried out, so that the internal updrading due to learning is an increasing function of the number of those processes carried out up to the particular period considered.

The labour availability vector in the same period can then be written

$$\underline{\underline{L}}_{s+1}^{S}(t+1) = \begin{bmatrix} \underline{\underline{L}}_{s}^{S}(t) \\ \cdots \\ 0 \end{bmatrix} + \begin{bmatrix} a_1 \cdots 0 \\ \cdots\cdots \\ \cdot\ \cdot\ \cdot \\ \cdot\ \cdot a_s\ \cdot \\ 0\ .\ 0 \end{bmatrix} \begin{bmatrix} \underline{\underline{L}}_{s}^{S}(t) \\ \cdots \\ \cdots \\ 0 \end{bmatrix} - \begin{bmatrix} b_1 \cdots 0 \\ \cdot\ \cdot\ \cdot \\ \cdot\ \cdots \\ \cdot\ \cdot\ b_s\ \cdot \\ 0 \cdots 0 \end{bmatrix} \begin{bmatrix} \underline{\underline{L}}_{s}^{DI}(t) \\ \cdots \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \cdots 0 \\ .\ b_1\ . \\ \cdots \\ 0\ ..b_s \end{bmatrix} \begin{bmatrix} 0 \\ \cdots \\ \underline{\underline{L}}_{s}^{DI}(t) \\ \cdot\ \cdot\ \cdot \end{bmatrix}$$

where $\underline{\underline{L}}_{s}^{DI}(t)$ is the vector whose elements represent the different types of labour employed in the innovative processes in period t, and where the last two terms on the R.H.S., which reflect the effects of the internal upgrading due to the learning process and hence show the appearance of an additional element respect to the preceding period, must be considered only when innovative processes are taken into account and the learning process operates over the vector $\underline{\underline{L}}_{s}^{DI}(t)$.

2.2. *The labour constraint*

The structure of the labour resource, as shown by the labour availability vector, sets a constraint both on the number and on the type of processes of production which can be carried out in each given period, as only those processes can be started and/or kept alive for which the required labour inputs are available in the right proportions. Given in fact a labour demand vector resulting from the producers' decisions on routine and innovative processes

$$\underline{\underline{L}}_s^D(t) = \begin{bmatrix} l_1^D(t) \\ \cdot \\ \\ \cdot \\ l_s^D(t) \end{bmatrix} = \underline{\underline{L}}_s^{DR}(t) + \underline{\underline{L}}_s^{DI}(t)$$

and assuming, as we are, that the structure of the supply of labour is perfectly adijusted to the structure of the labour requirements for routine processes, the vector $\underline{\underline{L}}_s^{DI}(t)$ must be confronted with the avilability vector

$$\underline{\underline{L}}_s^{SI}(t) = \underline{\underline{L}}_s^{S}(t) - \underline{\underline{L}}_s^{DR}(t),$$

and if the structure of this residual supply does not coincide with the struc-

ture of the labour demand for the innovative processes, and

$$l_h^{SI}(t) < l_h^{DI}(t) \text{ for some } h=1,2,\ldots,s$$

we shall have a "constrained" labour demand vector for innovative processes

$$\hat{\underline{\underline{L}}}_s^{DI}(t) = \min_h \begin{bmatrix} \dfrac{l_h^{SI}(t)}{l_h^{DI}(t)} \end{bmatrix} \underline{\underline{L}}_s^{DI}(t)$$

$$\hat{\underline{\underline{L}}}_s^{DI}(t) = C(t)\, \underline{\underline{L}}_s^{DI}(t)$$

limiting the number and the type of innovative processes which can be actually carried out -since each type of process requires a particular combination of skills in given proportions- so that the aggregate labour demand vector becomes

$$\hat{\underline{\underline{L}}}_s^{D}(t) = \underline{\underline{L}}_s^{DR}(t) + \hat{\underline{\underline{L}}}_s^{DI}(t)$$

This constraint, however, is not strictly rigid; it is modified by the process of learning in the longer run, as it has been shown in particular in the previous paragraph, but can also be made less stringent in the very short run. The hypothesis that those who are able to perform different jobs are classified under the item corresponding to their higher skill, in facts, gives "malleability" to the labour availability vector, in the sense of a certain flexibility towards the lower layers. Thus in each given period, if possible and necessary, the vector itself can be restructured, moving the workers from the higher to the lower-skill elements, to suit better the labour demand vector.

A less stringent labour constraint, on the other hand, implies both an enlargement of the range of the feasible processes (including already known types of processes of production which were not feasible in the past because of the total or partial lack of some kind of labour now available, and entirely new processes defined by the appearance of entirely new skills), and an increase in the absolute number of processes of any kind which can be actually started and carried out.

2.3. The consumers' preference system

Learning, however, has two faces. In the new technologies the production and the consumption side are more and more related. As a result of the greater acquaintance with new productive problems, new forms of consumption appear which, too, helps to define new products and to articulate new processes of production.

This implies that as the process of innovation goes on, not only the productive structure of the economy, reflected in the characteristics of its labour resource, but also the structure of consumption, described by the consumers' preference system (see paragraph 4.3) changes with the technology. As to the changes in the consumers' preference system we assume in particular that the degree of preference for the output of the innovative processes increases as more of these processes are carried out, and as the consumers get more acquainted with products whose modifications they help to define.

3. The economy

3.1. Productive capacity

The state of the economy at each given time reflects not only the technical intertemporal complementarities of the production process, but also the decisions taken in a related sequence up to the moment considered.

In particular, the actual lifetime of the different processes of production is the result of the successive decisions of the producers on current production and on investment, which can imply the scrapping of the processes before the end of their physical life. The productive capacity of the economy in each period is thus characterized by the number and type of processes of production of different age to which labour is still applied, by the number and type of processes scrapped (to which labour is no longer applied), and by the number and type of processes which are started anew (rate of starts) in the same period.

Let $\underline{x}^c(t+1)$ and $\underline{x}^u(t+1)$ be the vectors whose elements represent the number of the routine processes, in the 1 to m periods of the construction phase and in the m+1 to M periods of the utilization phase respectively, to which labour is applied at time (t+1), and $\underline{y}^c(t+1)$ and $\underline{y}^u(t+1)$ the corresponding vectors for the innovative processes, and let $\underline{u}^c(t+1)$, $u^u(t+1)$ and $v^c(t+1)$, $v^u(t+1)$ be the vectors of the routine and of the innovative processe respectively, in the construction and in the utilization phase, whose elements represent the processes scrapped at(t+1).

These vectors are defined

$$\underline{x}^{c'}(t+1) = (x_1^c(t+1), x_2^c(t+1), \dots, x_m^c(t+1))$$

$$\underline{x}^{u'}(t+1) = (x_{m+1}^u(t+1) \; ; \; x_{m+2}^u(t+1), \dots, x_{m+M}^u(t+1))$$

with $\underline{x}'(t+1) = (\underline{x}^{c'}(t+1), \underline{x}^{u'}(t+1))$

$$\underline{y}^{c'}(t+1) = (y_1^c(t+1), y_2^c(t+1), \dots, y_n^c(t+1))$$

$$\underline{y}^{u'}(t+1) = (y_{n+1}^u(t+1) \; ; \; y_{n+2}^u(t+1), \dots, y_{n+N}^u(t+1))$$

with $\underline{y}'(t+1) = (\underline{y}^{c'}(t+1), \underline{y}^{u'}(t+1))$

$$\underline{u}^{c'}(t+1) = (u_1^c(t+1), u_2^c(t+1), \dots, u_m^c(t+1))$$

$$\underline{u}^{u'}(t+1) = (u_{m+1}^u(t+1) \; ; \; u_{m+2}^u(t+1), \dots, u_{m+M}^u(t+1))$$

with $\underline{u}'(t+1) = (\underline{u}^{c'}(t+1), \underline{u}^{u'}(t+1))$

$$\underline{v}^{c'}(t+1) = (v_1^c(t+1), v_2^c(t+1), \dots, v_n^c(t+1))$$

$$\underline{v}^{u'}(t+1) = (v_{n+1}^u(t+1) \; ; \; v_{n+2}^u(t+1), \dots, v_{n+N}^u(t+1))$$

with $\underline{v}'(t+1) = (\underline{v}^{c'}(t+1), \underline{v}^{u'}(t+1))$

The rates of starts of the routine and of the innovative processes at (t+1), on the other hand, are defined respectively by the scalars $x_0(t+1)$ and $y_0'(t+1)$, such that

$$x_0(t+1) \geqq 0 \quad ;$$

$$y_0(t+1) \geqq 0$$

The values actually taken by the above mentioned vectors and scalars, and hence the particular configuration of the productive capacity of the economy, will depend on the particular solution of the model in each successive period (see paragraph 4.2).

3.2. Macroeconomic magnitudes

As to the functioning of the economy, we assume that it is characterized by the presence of a medium of exchange that we shall call "money". Exchanges are made, and wages are paid, in money terms; which implies in particular that the resources required to start and keep carrying out the processes of production are financial resources and not physical output. Borrowing and lending are not considered for the moment, so taht every one (producers as well as consumers) is obliged to limit his spending in any period to what he receives in that period, plus the saving that he himself has made in the past. The only exception is represented by an exogenous inflow of money, decided upon and supplied by the Governement to the producers as the only instrument available to pursue his policy (if any), and measuring the indebtment of the producers themselves.

In such an economy the relevant macroeconomic magnitudes are:

The total current output, reckoned as the money value of aggregate final output in each given period, and given by

$$P(t+1) = \underline{\underline{c}}'\,\underline{\underline{x}}^{u}(t+1) + p(t+1)\left[\underline{\underline{d}}'(t+1)\,\underline{y}^{u}(t+1)\right]$$

where the price of the output of the routine processes is set equal to one in terms of money, and p(t+1) is the price of the output of the innovative processes in the period (t+1), always in terms of money.

Writing

$$\underline{\underline{c}}'\,\underline{\underline{x}}^{u}(t+1) = R\,(t+1)$$

and

$$\underline{\underline{d}}'(t+1)\,\underline{y}^{u}(t+1) = I\,(t+1)$$

we have

$$P(t+1) = R\,(t+1) + p\,(t+1)\,I\,(t+1).$$

The Wages Fund, that is the amount of financial resources ("money") required by the labour applied to start and to keep carrying out routine and/or innovative processes of production, both in the phase of construction and in the phase of utilization, in the current period, given by

$$W(t+1) = \underline{\underline{w}}'(t+1)\,(\underline{\underline{A}}\,\underline{x}(t+1) + \underline{\underline{B}}(t+1)\,\underline{y}(t+1) + \underline{\underline{\alpha}}_0\, x_0(t+1) + \underline{\underline{\beta}}_0(t+1)\, y_0(t+1))$$

$$\underline{\underline{w}}'(t+1) = (w_1(t+1)), w_2(t+1), \ldots, w_h(t+1), \ldots, w_s(t+1))$$

where $\underline{\underline{w}}'(t+1)$ is the row vector of the money wage rates corresponding to the different types of labour employed in the processes of production. We assume in particular that the real wage rates are constant in time, and hence that the money wage rates adjust in such a way that

$$w_h(t+1) = \omega_h \frac{R(t)+p(t+1)I(t)}{R(t)+p(t)I(t)}\ ; \quad h=1,2,\ldots,s,$$

where ω_h is the constant real wage rate of type-h labour input.

The money value of the aggregate demand for final output at the ruling prices which will be defined in paragraph 4.1

$$P^*(t+1) = R^*(t+1) + p(t+1)I^*(t+1)$$

The money value of producers' demand for final output (consumption out of profits)

$$Q(t+1)$$

The exogenously determined inflow of financial resources ("money")

$$\Delta M(t+1)$$

which is a difference between loans and repayments.

II. SEQUENCE ANALYSIS

4. The "Single Period" Analysis

The relations between the relevant magnitudes of the economy reflect the sequential structure of the model, both within each period and between successive periods.

Let us consider first what happens in the "single period", which is made here to coincide with the elementary period of the process of production. The single period analysis shows how certain decisions at the beginning of the period lead to determinate results at the end of it.

In each period -over which fresh labour is applied to the processes of production and, when these have reached the phase of utilization, a round of final production in carried out- decisions must be taken concerning both the production and the consumption side of the economy. Production and consumption decisions are assumed to depend:

a) on existing constraints, which delimit the range of the feasible choices;

b) on producers and consumers' expectations.

The single, or "decision period" is thus defined as such that changes in expectations and in the constraints do not occur within it, but only at the junction between one period and the next. It is further assumed that

prices, set by the producers at the beginning of each period, are maintained unchanged throughtout it whatever the market conditions.

4.1 Producers' decisions

At the beginning of each period the producers must take two kinds of decisions:

1) decisions on current output (and on its price);

2) decisions on investments.

These decisions are constrained by the existing financial and labour resources and reflect respectively the short term and the long term expectations of the producers.

a) current production.

Decisions on current final production are decisions on the rate of utilization of the existing productive capacity, which is in turn the result of decisions taken in the past, given the technical intertemporal complementarities of the processes of production. They concern the amount of production, and, when more than one type of process of production is carried out at the same time, also its composition: they are therefore decisions on the number and on the type of processes, already in the utilization phase, to which labour must be applied in the current period.

We assume that, at the beginning of each period, the money value of total final production is determined on the basis of the expected money value of aggregate final demand in the same period

$$P(t+1) = eP^*(t+1)$$

and that these short term expectations extending over the single period, are obtained in the most simple way, by considering a value of the final demand resulting from a growth rate equal to the one realized in the previous period and by adding to it $p(t)\Theta(t)$, that is the part of that demand which could not be satisfied and is therefore expected to be shifted to the current period

$$eP^*(t-1) = P^*(t)(1 + \frac{P^*(t)-P^*(t-1)}{P^*(t-1)}) + p(t)\Theta(t)$$

When more than one type of process of production is carried out at the same time, the producers must determine the composition of final output together with its aggregate value: they must determine R(t+1) and I(t+1), as well as the money price of the output of the innovative processes, p(t+1), which we assume to be fixed by the producers at the beginning of the period and kept unchanged throughout it whatever the demand conditions.

Given the budget constraint

$$P(t+1) = R(t+1) + p(t+1)\, I(t+1)$$

and assuming that the whole amount of I which can be obtained with the existing productive capacity is ecpected to be absorbed by the market, whatever the price charged for it, and hence is actually produced, that is

$$eI^*(t+1) \geqq I(t+1) = \underline{\underline{d}}'(t+1)\, \underline{\underline{y}}^u(t+1)$$

where $\underline{\underline{y}}^u(t-1)$ is such that $\underline{\underline{v}}^u(t+1) = 0$

the composition of output will be chosen (and the price p(t+1) associated with the latter) which is optimal according to a utility function which the producers expect to be the consumers' utility function in the current period. Let this function be

$$U = R^{\gamma} \quad I^{\delta}$$

where $\gamma + \delta$ = constant = 1 and $\delta(t+1) = e\delta^*(t+1) = \delta^*(t)$

that is the consumers' preference for the output of the innovative processes expected by the producers in period (t+1) is equal to the preference the consumers have shown in the previous period t.

We shall then have:

$$R(t+1) = P(t+1) \quad \gamma(t+1)$$

and

$$p(t+1) = \frac{P(t+1)}{I(t+1)} \delta(t+1)$$

Given therefore P(t+1) and I(t+1), which are determined by the expectations function and the technical intertemporal complementarities, the price p(t+1) will be the higher the greater the expected degree of preference of the consumers for the output of the innovative processes, while R(t+1), of course, will be the lower.

Thus in this model the composition of output (of demand) does not depend on the relative prices of the commodities considered, as in the traditional analysis. The (relative) price p(t+1), in fact, is determined together with the composition of output, which depends in turn on an expected composition of demand reflecting the expected utility function of the consumers.

b) investments

Investments decisions consern 1) the number and the type of the processes of production whose construction, already started, must be continued in the current period, and 2) the rate of starts, i.e. the number and the type of the processes which must be started anew. These decisions on how much and how invest are determined simultaneously by the existing financial and labour constraints and by the long term expectations of the producers, given a flexibility criterion which will be immediately defined.

As to the long term expectations, we assume that they reflect the degree of confidence of the producers on the information (both on the market and on the technology) they have, that is on the degree of variability of their beliefs. The more they expect to learn in the future relative to what they know, and hence the greater the variations they are anticipating in their beliefs, the less they are attracted by long term commitments -like investments whose irreversible character does not permit to take soon full advantage of new information- and the more they research a flexible position, i.e. a position that leaves available a greater range of future options, as it is the case with the possession of liquid assets.

One way of taking into consideration the state of long term expectations as just defined, is to assume that the available financial resources -that is the internal resources resulting from the sales of the previous period, and equal to the aggregate value of demand P* less the part of it not satisfied by internal market (import S and the shift of demand $p\Theta$) plus the external resources ΔM- once assured consumption out of profits Q, are not fully channelled by the producers into the Wages Fund available at the beginning of each period for carrying out the processes of production. This Fund can then be written

$$W(t+1) = \varrho(t+1)\,(P^*(t) - S(t) - p(t)\Theta(t) + \Delta M(t+1) - Q(t+1))$$

$$0 < \varrho(t+1) < 1$$

where the flexibility parameter translates the long term expectations of the producers, and which for the moment we assume to be exogenously determined.

4.2. *The solution of the model*

a) The solution under alternative constraints

Decisions on current production and on investments in each period are the outcome of the short and of the long term expectations of the producers, as just defined, and of the existing financial and labour constraints (the problem of the choice between routine processes and innovative processes will be discussed in particular in paragraph (6).

Given the state of the expectations and the Wages Fund, these decisions determine the size and the structure of the demand for labour which is defined by the column vector.

$$\underline{\underline{L}}^D_{s+1}(t+1) = \begin{bmatrix} l^D_1(t+1) \\ \cdot \\ \cdot \\ l^D_h(t+1) \\ \cdot \\ \cdot \\ \cdot \\ l^D_{s+1}(t+1) \end{bmatrix}$$

where

$$l^D_h(t+1) = \Sigma_k\, \alpha^c_{hk}\, x^c_k(t+1) + \Sigma_k\, \alpha^u_{hk}\, x^u_k(t+1) +$$

$$+ \Sigma_k\, \beta^c_{hk}(t+1)\, y^c_k(t+1) + \Sigma_k\, \beta^u_{hk}\, y^u_k(t+1) +$$

$$+ \alpha_{h0}\, x_0(t+1) + \beta_{h0}(t+1)\, y_0(t+1)$$

This vector implies values of the vectors $\underline{\underline{x}}^c$, $\underline{\underline{x}}^u$, $\underline{\underline{y}}^c$, $\underline{\underline{y}}^u$, and of the scalars x_0 and y_0, which represent the solution of the model under the financial constraint given by the Wages Fund, after having made the scrapping (if) required according to the scrapping rules defined in what follows.

For this solution to be feasible, however the resulting labour demand must be compatible with the existing labour resources, that is $\underline{\underline{L}}^D_{s+1}(t+1)$ must be matched with the labour availability vector $\underline{\underline{L}}^S_{s+1}(t+1)$, eventually restructured as identicated in paragraph 2.2. If the structure of demand does not coincide with the structure of supply, there will be a labour constraint which will prevail over the financial constraint, and the Wages Fund will become

$$W(t+1) = \underline{\underline{w}}'(t+1)\, \hat{\underline{\underline{L}}}^D_{s+1}(t+1)$$

where $\hat{\underline{\underline{L}}}^D_{s+1}(t+1)$ is the constrained labour demand vector, already defined in paragraph 2.2.

This will determine a different solution -with different values of

$\underline{\underline{x}}^c$, $\underline{\underline{x}}^u$, $\underline{\underline{y}}^c$, $\underline{\underline{y}}^u$, x_0, y_0- implying an excess of liquidity over the amount determined by the long-run expectations of the producers as reflected by the parameter ϱ.

b) scrapping rules

The solution of the model determines the actual configuration of the productive capacity of the economy, which reflects the technical intertemporal complementarities of the processes of production and the scrapping (if any) made according to the criteria adopted. This configuration in the period (t+1) is described by

$$\underline{\underline{x}}^c(t+1) = \underline{\underline{J}}^c_x \underline{\underline{x}}^c(t) - \underline{\underline{u}}^c(t+1) + \underline{\underline{E}}^c_x x_0(t)$$

$$\underline{\underline{x}}^u(t+1) = \underline{\underline{J}}^u_x \underline{\underline{x}}^u(t) - \underline{\underline{u}}^u(t+1) + \underline{\underline{E}}^u_x x^c_m(t)$$

$$\underline{\underline{y}}^c(t+1) = \underline{\underline{J}}^c_y(t) - \underline{\underline{v}}^c(t+1) + \underline{\underline{E}}^c_y y_0(t)$$

$$\underline{\underline{y}}^u(t+1) = \underline{\underline{J}}^u_y \underline{\underline{y}}^u(t) - \underline{\underline{v}}^u(t+1) + \underline{\underline{E}}^u_y y^c_n(t)$$

where $\underline{\underline{J}}^c_x$, $\underline{\underline{J}}^u_x$, $\underline{\underline{J}}^c_y$, $\underline{\underline{J}}^u_y$, are matrices of the type

$$\begin{bmatrix} 0 & & 0 \\ I & & 0 \end{bmatrix}$$

of dimension mxm, MxM, nxn, NxN, respectively, and $\underline{\underline{E}}^c_x$, $\underline{\underline{E}}^u_x$, $\underline{\underline{E}}^c_y$, $\underline{\underline{E}}^u_y$, are column vectors of the type

$$\begin{bmatrix} 1 \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{bmatrix}$$

of dimension m, M, n, N respectively.

The products

$$\underline{\underline{J}}^c_x \underline{\underline{x}}^c(t)\ ,\quad \underline{\underline{J}}^c_y \underline{\underline{y}}^c(t)\ ,\quad (\underline{\underline{J}}^u_x \underline{\underline{x}}^u(t),\ \underline{\underline{J}}^u_y \underline{\underline{y}}^u(t))$$

reflect the fact that the processes in the mth, nth (m+Mth, n+Nth) period of the construction (utilization) phase in period t, pass to the utilization phase (disappear) in the period (t+1). The products $\underline{\underline{E}}^u_x x^c_m(t)$, $\underline{\underline{E}}^u_y y^c_n(t)$, on the other hand, register the processes which pass from the construction to the utilization phase in period (t+1), while the products $\underline{\underline{E}}^c_y x_0(t)$, $\underline{\underline{E}}^c_y y_0(t)$ register the new born processes in the same period.

As to the scrapping, we assume that the processes to which labour is not applied in a given period are scrapped, and cannot be brought back into production through successive applications of labour. This scrapping of both the processes in the phase of utilization and the processes in the phase of construction obeys to a flexibility criterion implying that in each period the choices are made which leave available the greater range of future options.

This means, as we shall see in a moment, that first is determined the amount of final output to be obtained from the existing capacity; but as we have assumed that the whole of the output which can be obtained from the innovative processes already in the phase of utilization is actually produced and absorbed by the market, this also implies that only the routine processes in the phase of utilization are considered for scrapping. We assume, in particular, that the scrapping of such processes depends on the gap between the inherited productive capacity and the value of the aggregate final production decided for the current period, that is

$$u^u_k(t+1) = F_k \left[x^u_{m+1}(t),\ x^u_{m+2}(t),\ \ldots,\ x^u_{m+M+1}\ x^c_m(t),\ D(t+1) \right|$$

$$k = m+1, \ldots, m+M$$

$$v^u_j(t+1) = 0,\ j = n+1, \ldots, n+N$$

where

$$D(t+1) = \underline{\underline{c}}'\ J^u_x\ \underline{\underline{x}}^u(t) + c_{m+1}\ x^c_m(t) + p(t+1)\ (\underline{\underline{d}}'(t)\ J^u_y\ \underline{\underline{y}}^u(t) +$$

$$+ \underline{\underline{d}}_{n+1}(t)\ y^c_n(t)) - P(t+1)$$

The functions F are such that, if scrapping is required, the older processes are scrapped first: they are in fact nearer to the moment they will stop producing; and less expected output, caeteris paribus, means less expected revenue, a stronger financial contraint and hence a smaller range of future options.

The remaining financial resources determine the scrapping of the processes in the phase of construction as well as the current rates of starts of new processes, which depend on the same variables. In particular, the scrapping functions are given by

$$u^c_k(t+1) = G_k\ (x^c_1(t), \ldots, x^c_{m-1}(t), y^c_1(t), \ldots, y^c_{n-1}(t), x_0(t), y_0(t), \tau\ (t+1);$$

$$k = 1, \ldots, m$$

$$v^c_j(t+1) = G_j\ (x^c_1(t), \ldots, x^c_{m-1}(t), y^c_1(t), \ldots, y^c_{n-1}(t), x_0(t), y_0(t), \tau\ (t+1));$$

$$j = 1, \ldots, n$$

and the rates of starts are given by

$$x_0(t+1) = G_x\,(x_1^c(t), \ldots, x_{m-1}^c(t), y_1^c(t), \ldots, y_{n-1}^c(t), x_0(t), y_0(t), \tau(t+1));$$

$$y_0(t+1) = G_y\,(x_1^c(t), \ldots, x_{m-1}^c(t), y_1^c(t), \ldots, y_{n-1}^c(t), x_0(t), y_0(t), \tau(t+1));$$

where

$$\tau(t+1) = (W(t+1) - \underline{\underline{w}}'(t+1)\,(\underline{\underline{A}}^u\,\underline{\underline{x}}^u(t+1) + \underline{\underline{B}}^u(t+1)\,\underline{\underline{y}}^u(t+1))$$

and where the Wages Fund W(t+1) is replaced by

$$\underline{\underline{w}}'(t+1)\,\underline{\underline{\hat{L}}}^D_{s+1}(t+1)$$

when there is a labour constraint which reduces the amount of the available financial resources which can be absorbed by the economy.

The functions G are such that the younger processes are scrapped first: they are in fact the less irreversible proceses, that is the processes which have already swalloved less resources, and are also farther from the moment they will start obtaining final output.

To sum up, the processes of production are scrapped, if necessary, in a order reflecting a flexibility criterion focussing on expected final output (both its amount and its nearness in time) as an index of a less stringent

expected financial constraint. In this perspective, the distance from the moment the final output will first be obtained becomes relevant for the processes still in the phase of construction, and the length of time over which it will still be obtained for the processes already in the phase of utilization. Thus, when there is a reduction of resources, the first to be cut will be the rate od starts of new processes; then the processes in the phase of construction (first the younger, then the older), and last the processes in the phase of utilization (first the older, then the younger).

4.3. Consumers' decisions

Expectations and the available money income determine the consumer's decisions in each given period.

a) the aggregate demand and its composition

Decisions on aggregate final demand and -when more then one type of output is available on the market- on its composition, reflect the consumers' preference system (we assume, for simplicity, that consumption out of profits Q is exogenously determined).

In an uncertain and, to a certain extent, irreversible (due to non-zero transaction costs) context, the decision process is represented by a related sequence of choices. To describe it we are not using an intertemporal utility function, which would not allow to take into account the consideration that more information -both on the arguments entering the preference system and on their caracteristics- can accrue as the economy proceeds on an innovative path. Consumers do not know precisely the temporal structure of their preference system, but know that its ordering can change together with the state of the economy. Therefore, the greater is the degree of variability they anticipate in their preference system, the larger will be the set of future options they want to leave available, and hence the greater the amount of their income they want to keep in liquid form.

We assume in particular that, in each period, a consumers' utility function whose arguments are the different commodities available on the market, is fully specified. Before determining the composition of their demand, however, the consumers fix the proportion of income which they want to devote to current consumption and the proportion they want to keep in liquid form. The flexibility parameter σ, reflecting the consumers' long term expectations on the degree of variability of their preference system, will thus determine the fraction of the money income available in each period actually devoted to purchase final output in the same period

$$P^*(t+1) = \sigma(t+1)\,(W(t+1) + Q(t+1) + p(t)\,\Theta(t))\;;$$

$$0 < \sigma(t+1) < 1$$

The smaller σ, of course, the greater the consumer's research of flexibility and viceversa. Once decided upon that, and given the price $p(t+1)$

which is set by the producers and hence is a parameter for the consumers, the composition of final demand is determined as the solution of

$$\text{Max } U = R^{\gamma^*}\, I^{\delta^*}$$

which is the current period consumers' utility function, under the budget constraint

$$P^*(t+1) = R^*(t+1) + p(t+1)\, I^*(t+1)$$

$$R^*(t+1) \geqq 0 \quad ; \quad I^*(t+1) \geqq 0$$

We have already underlined (in paragraph 2.3) that on an innovative path the consumers' preference system undergoes a change as the result of a greater diffusion of products and/or services which they get to know better and better. A first effect of the greater acquintance with new forms of consumption -which the consumers too contribute to define- is an increase of the degree of preference for the output of the innovative processes, that is of the parameter δ^* of the period- utility function. Given the assumption that the output of the innovative processes produced and brought to the market is fully absorbed because of its novelty, we can refer to the cumulated output produced up to the period considered as an indication of the degree of diffusion of the new products, and write

$$\delta^*(t) = \delta^*(\sum_{T=n+1}^{t-1} I(T));$$

$$\delta^*(n+1) = \bar{\delta}^*$$

$$\Delta\delta^*(t) > 0$$

assuming that

$$\sum_{T=n+1}^{t-1} I(T) > \sum_{T=n+1}^{t-2} I(T)$$

where δ^*, exogenously determined is the degree of preference for I when it first appears on the market and the consumers don't know anything about it (under the hypothesis that an innovative choice has first been made at time 0).

From

$$\delta^*(t+1) > \delta^*(t)$$

and given that

$$\delta(t+1) = e\ \delta^*(t+1) = \delta^*(t)$$

it follows that

$$\delta^*(t+1) > \delta(t+1).$$

This, provided that this effect is no more than compensated by a great enough difference between P(t+1) and P*(t+1) validates the hypothesis that I is always fully absorbed by the market, that is

$$I^*(t+1) \geqq I(t+1) .$$

A greater acquaintance with the new products, however, might not only attract an increasing share of the fraction of income actually devoted to the purchase of final output, but might also bring about an increase of this very fraction. It might in other words have an effect on the long term expectations of the consumers, increasing the degree of confidence in the market and thus reducing the degree of variability they anticipate in their preference system (i.e. their research of flexibility and hence their research of liquid assets) represented by the parameter σ.

We can thus make a reduction of the fraction of the available income actually subtracted to consumption a function of the diffusion of I, and write

$$\sigma(t) = \sigma(\sum_{T=n+1}^{t-1} I(T));$$

$$\Delta\sigma(t) > 0$$

5. *Linking on the Periods*

5.1. *Disequilibrium: the efforts to right it*

Producers and consumers' decisions are not necessarily mutually consistent; they can thus bring about a final demand whose aggregate value P*(t+1) does not coincide with the value of current production P(t+1).

This can result in a disequilibrium on the market of the "routine" output (i.e. $R(t+1) \gtrless R^*(t+1)$), and/or on the market of the "new" output (i.e. $I(t+1) < I^*(t+1)$), and this disequilibrium cannot be taken care of by price changes as we have assumed that prices are fixed at the beginning of the period and kept unchanged throughout it. This fix-price hypothesis -which might appear akward in the case considered of non storable goods, where there are not stocks in the economy to take the strain of supply -demand inequalities- has been made on purpose to bring out the problem of saturation of demand (namely when $R^*(t+1) < R(t+1)$, and there is an excess supply of R which goes to waste): a problem which has been generally overlooked, due to the dominant neoclassical utility approach to the structure of consumption, which implies widespread substitution and hence relies on the compensation effect through relative prices upon demand.

In the opposite case, that is when

$$R^*(t+1) > R(t+1) \quad ,$$

we assume that the excess demand for the "routine" output is satisfied through the imports S, that is

$$S(t+1) = (R^*(t+1) - R(t+1))$$

An excess demand for I, on the contrary, cannot be satisfied abroad because -given the novelty of the output of the innovative processes and the changes in its characteristics as a result of the particular development of the technology as it takes place in the specific home environment- it is available only on the internal market.

The excess demand

$$p(t+1)\,\Theta(t+1) = p(t+1)(I^*(t+1) - I(t+1))$$

stocked in terms of money, is therefore shifted to the following period (i.e. to t+2) increasing the income available in it (see paragraph 4.1).

Assuming that the economy is in a stock equilibrium at the beginning of the period (that is that everybody is holding the stocks desired with respect to the existing expectations), the inequality between current supply and current demand (flow desequilibrium) will thus necessarily bring about a stock disequilibrium at the end of the period.

An excess supply (i.e. $R(t+1) > R^*(t+1)$) in fact, will leave the producers with a stock of goods which they do not desire to hold. As these goods go to waste, and the funds which were invested in them are lost, the producers will be left with a debt.

An excess demand, on the other hand:

a) will result in imports, that is in the decumulation of foreign stocks which are called to take the strain of the internal disequilibrium, when - $R^*(t+1) > R(t+1)$;

b) will leave the consumers with a stock of money, which they do not desire to hold, to carry forward, when $I^*(t+1) > I(t+1)$.

5.2. *The sequence "constraints-decisions-constraints"*

Disequilibrium arising in a given period is a good starting point for considering how successive periods are strung in a sequence in this model, thus setting the stage for the analysis of a process of innovation conceived as a sequential process. The efforts made by those left in a state of disequilibrium to right it, are in fact the main determinant of what will take place in the following periods.

These efforts, in the first place, pass through a revision of short-term expectations, which represent the most immediate link between one period and the next. The appearance, for example, of an excess supply (flow disequilibrium) in a given period will bring about expectations of a lower demand in the following period. A stock disequilibrium, implying a reduction of the

degree of utilization of the existing capacity, no longer adapted to expected demand, is the sign of the carrying of the disequilibrium down the sequence.

This as to the decisions concerning current production. Investment decisions too, however, are affected indirectly by a revision of short term expectations. A lower expected demand and hence a lower utilization of capacity in a given period means in fact less final output, less revenues, and hence less internal resources available in the following period. Given ϱ, that is the state of long-term expectations, and given consumption out of profits Q, this implies less room for the investments, which will be cut according to the scrapping rules adopted.

The association -within each given period- between short-term expectations and current production decisions on one side and between long-term expectations and investments decisions on the other, thus collapses when successive periods are taken into account in a stock-flow perspective. A revision of the short-term expectations in a given period may in fact bring about a modification of the constraints in a successive period thus affecting, as just shown, the investment decisions of that period.

This is what happens when producers give a quantitative interpretation to the appearance of an excess supply, and consequently react revising downwards current production. Disequilibrium, however, might be the symptom of a dissatisfaction with the existing situation on the part of the consumers (who might have reduced their demand because they want something different, even if not yet fully specified, and not only less of the existing commodities) and/or on the part of the producers (who might be in search of an altogether different, even if not yet clearly defined, approach to production), implying a modification of the long-term expectations and hence of the flexibility parameters ϱ and/or σ; and it might be correctly read as such by the producers.

The door would then be open for the research of a qualitative answer (and not a simple quantitative adjustment) to a qualitative problem: that is for considering innovative choices. Thus an initial change in long term expectations resulting in a reduction of demand in a given period, if correctly interpreted, would not only have an influence on how much to invest in the following periods through a modification of the financial constraint brought about by a revision of short-term expectations, but could also cause at once a revision of the decision on how to invest, that is on the type of processes of production to carry out.

The technical intertemporal complementarities which characterize fully vertically integrated processes of production, on the other hand, establish links between successive periods other than those represented by the expectations and their modifications. Investment decisions of whatever kind mean in fact the setting in of irreversible processes, implying a spreading in time of requirements of labour and financial resources which represent thorough constraints for the decisions to be taken in a series of successive periods.

The intertemporal complementarities of the decisions generating process and of the process of production determine in this way a pattern of

interactions between "decisions", which in each period depend on expectations and on the existing constraints, and the "constraints" themselves, which are modified from period to period as the result of decisions taken in the past but reverberating their effects on the present.

When innovative choices are considered, the effects of a process of learning associated with the carrying out of innovative processes must also be taken into account, in the shaping of this pattern of interactions. Learning affects in the first place the labour resource, bringing about higher skills and new specific labour inputs which imply releasing the labour constraint and opening new paths along which to move the following steps. But learning affects also the consumers' preference system, revising both the degree of preference for the "new" commodities and the degree of confidence on the market, thus reducing the consumers' research of flexibility and helping to release the financial constraint.

In what follows we shall analyse both the case of a routine choice (quantitative adjustment) and of an innovative choice (qualitative change). We shall see in particular that for an innovative choice to be viable it must have the character of a real qualitative change, that is it must be interpreted as a process of learning in the above sense. When on the contrary the process of innovation is portrayed traditionally as the diffusion of a given technique, strong instability phenomena can bring the economy to a deadlock; and the same is most likely to happen, sooner or later with a routine choice.

6. Patterns of evolutions of the economy

In this paragraph we consider the different patterns of evolution of the economy under alternative choices which represent the different answers to the problem with which is confronted a system that is undergoing a structural change. The analysis is carried out simulating the sequences which correspond to different values given to the parameters of the model.

The setting of the stage is a steady growth sustained by a constant rate of growth of the exogenously determined magnitudes of the economy: namely the external financial resources ΔM, consumption out of profits Q, and the supply of the different types of labour represented by the different elements of the availability vector $\underline{\underline{L}}^{s}$. The economy portrayed is assumed to make use of a well established and fully developed technology to satisfy with what is going on.

At a given moment (T=0) a change in the information structure reflecting saturation of demand of the existing commodities and/or the perception of a possible exploitation of new (scientific) knowledge is assumed to increase the degree of variability of the beliefs of consumers and/or producers and hence to decrease the value of ϱ and/or σ. This brings about directly or indirectly (through a reduction of the Wages Fund) a decrease in final demand which results in a flow-disequilibrium in the same period.

This supply/demand disequilibrium can be either considered as the result of a mistake in formulating short-term expectations or rightly regarded

as the sign of a structural change, that is as the result of a modification of long-term expectations.

6.1. The Routine Choice

We define as a routine path, the path followed by the economy when the answer to the disequilibrium consists in a simple revision of the final production and investment targets of processes of production which keep being carried out according to the established technology. On such a path there is no labour constraint, and hence there is only the financial resources constraint. The level of the activity along the path thus depends on the amount and the destination of the financial resources as determined by the values assigned to the exogenously determined parameters ΔM and Q.

Three scenarios have been drawn in consequence. In the first we assume that the growth rate of ΔM and Q is first adjusted to the lower level resulting from the initial fall in final demand and hence forward adjusted to the actual growth rate of the economy. In the second ΔM and Q are kept growing at the original rate whatever the actual growth rate of the economy. in the third the growth rate of ΔM is adjusted to the actual growth rate of the economy.

The simulation shows that in the first scenario, once the values of ϱ and/or σ are reduced in the period 0 and a disequilibrium appears in the same period as a consequence, the newly adjusted growth rate of ΔM and

Q permits to re-establish the supply/demand equilibrium from the next period onwards. The growth of the economy is thus immediately stabilized at the new lower rate, unless of course there are further reductions in ϱ and/or σ.

This lower rate, however, implies that some processes in their phase of utilization must be scrapped, and this will go on as long as the inherited productive capacity is not fully adapted to the expectations of final demand, that is as long as the economy remanis in a state of stock disequilibrium. During the same period, the funds which were invested in those processes are lost as the processes themselves no longer exist: but the producers are left with the corresponding debts, so that this stock disequilibrium implies in turn an increase in the debts-resources ratio.

Finally, unemployment of all types of labour increases with an unchanged technology, as the growth rate of labour demand reflecting the new lower rate of growth of the economy becomes smaller than the unchanged growth rate of the labour supply resulting from the demographic and the educational factors.

In the second scenario, the initial fall in the growth rate is not accepted, and ΔM and Q are kept growing at the original rate so as to maintain at the same rate the growth of the economy. The results of the simulations suggest that two phases can then be traced out. In the first one the economy converges to the original growth rate through a damped oscillatory movement reflecting the fact the supply/demand equilibrium cannot be restablished

-as in the first scenario- and excess supplies keep alternating with excess-demands. This depends in particular on the role played in the model by the imports, which, while taking the strain of supply/demand inequalities in a given period, result in lower available resources in the following one. Unemployment and the debt-resources ratio, on the other hand, increase: but at a lower rate than in the first scenario.

In a second phase -when, after the period of construction, the oscillations in the rate of strats which have taken place during the first phase strat producing their effects- the oscillatory movement becomes explosive, increasing enormously the level of the indebtment, unemployment and the imports, and bringing the economy to an unbearable state of affairs. Convergence in the first phase, however, takes a very long time, shifting out of sight this second phase and thus rendering plausible the second scenario as a viable option.

The third scenario finally considers the case in which ΔM is adjusted to the actual growth rate but consumption out of profits Q is kept growing at the original rate. This maintains the level of activity in a first phase, during which the economy appears to converge to the original growth rate, but at the same time reduces the Wages Fund and hence, given the scrapping rules, the rate of starts. When the effects of such a reduction take place, the growth rate strats falling until the economy gets to a point where there are non more resources to finance the processes of production.

These are the results when we assume a once for all reduction in the flexibility parameter ϱ and/or σ. If on the contrary we assume that the period disequilibrium between supply and demand has also an effect on long term expectations governing investments, thus bringing about further reductions of ϱ, and hence in the available financial resources, instability prevails at once, whether we are in the first, in the second or in te third scenario.

6.2. The Innovative Choice

An innovative choice is characterized by the setting in of a process of learning resulting in a continuous upgrading and enrichment of the labour resource -thus bringing about new technology and new options- and by a continuous modification of the consumers' preference system (however, in the simulations, the appearance of entirely new skills is not considered). The development of such a process is hampered by a labour constraint which might arise since the beginning due to the particular labour requirements for carrying out the innovative choice, and by a structure of demand reflecting the consumers' preferences which does not match the structure of supply, with the result of an increase in imports that would reduce the financial resources available for fuelling the process itself.

The profile of the process is determined by what happens after the first appearance of the final output of the innovative processes of production that is during what Hicks has defined the Early Phase in his analysis of

the "traverse".

During this phase learning in consumption brings about an increase in the value of δ^* which reflects the degree of preference for the new output, and which may be perceived at once by the producers ($\delta(t) = \delta^*(t)$) or with a certain delay ($\delta(t+1) = \delta^*(t)$).

In the first case, if both the exogenously chosen value of δ^* at $t = (n+1)$ and its increase over time (which, we recall, reflects past rates of starts of innovative processes) are such as not to bring about a shortage of productive capacity for the output of the routine processes R, there will be neither imports S nor a shift of demand $p\,\Theta$. Provided there is no other reason for the arising of a supply/demand disequilibrium, as it is the case when the growth rates of ΔM and Q are immediately adjusted to the lower growth rate brought about by the initial disturbance, the growth of the economy will be stabilized at that rate. The innovative choice will be then viable, but it will not bring back the economy to the original growth rate thus not permitting to reabsorb unemployment which will on the contrary keep growing together with the debts-resources ratio.

In the more realistic case of a one period-delay in the adjustment of δ to δ^* a flow disequilibrium resulting in a shift of demand $p\,\Theta$ cannot be avoided. This will certainly cause expected demand and hence the value of aggregate final output to increase in the following period, but such an expansionary effect, given certain conditions, might be contrasted by the imports which would result from an excess of the demand for the output of the routine processes over the existing capacity and which would reduce the resources available for financing the growth of the economy, thus being an instability factor which might bring the economy to a deadlock. This secondary effect, however, would not take place if the intensity of learning in consumption as expressed by the increase in δ^* were strong enough to divert a sufficient amount of demand towards the output of the innovative processes; and such an intensity should be even stronger here than in the previous case of an immediate adjustment of δ to δ^*, in which the possibility of shortage of capacity could arise too.

A similar problem, that is an expansionary effect contrasted by an inports leak, would arise if producers and/or consumers reduced their research of flexibility and increased the values of the parameters ϱ and/or σ; such a behaviour, however, is most likely to be the result of a strong learning process, that is of a process that would in itself reduce the extent of the problem.

Learning in consumption in the Early Phase, whose role in determining the evolution of the economy has just been underlined, depends however on what has been taking place during the period corresponding to the length of the phase of construction of the routine processes, which, following Hicks again, we shall call the Preparatory Phase.

The important thing, during this phase, is what happens to the rate of starts of new processes of production. It is such a rate of starts, in fact, which determines both the flows of output and hence the internal resources

available for financing the growth of the economy, and, since $\delta^* = \Sigma I$, will determine also the intensity of the learning in consumption during the Early Phase.

The rate of strats, in turn, depends essentially on the particular labour requirements for carrying out the innovative choice. Higher construction labour requirements for all types of labour, on one side, imply a higher absorption of resources per unit process and hence a reduction of the number of processes which can be started for given financial resources. A change in the structure of the types of labour required, on the other side, even if it does not imply higher labour requirements for all or some of the different types of labour, makes appear a labour constraint which can prevail over the financial resources constraint thus reducing again the rate of starts.

Two cases can now be considered: the traditional case of a once for all change in the labour requirements and/or in their spreading in time, that is the case of the appearance of a new, superior technique to be adopted by the economy through a diffusion process; or the case we have been treating of a sequential process of creation of technology characterized by a learning in production, besides the learning in consumption, bringing continuously about modifications in the structure of the labour resource and lower labour requirements. In the latter case, with a labour constraint which becomes less and less stringent and with continuously decreasing labour requirements, the rate of starts will become higher and higher with respect to the case of simple diffusion, thus fuelling a stronger learning in consumption process in the Early Phase. Learning in production, which defines a truly innovative process, will thus prevent the economy from getting to a deadlock, as it might happen in the case of simple diffusion.

In the above sense, that is in the sense of favouring the process of learning with the positive implications we have just underlined, the most favourable out of the three scenarios we have been simulating is the one considering an immediate adjustment of the growth rate of ΔM and Q to the actual growth rate of the economy. The lower growth rate with respect to the other scenarios considered will bring in fact about during the Preparatory Phase a greater scrapping of routine precesses, which implies more resources available for financing the starting of innovative processes and hence a more intense learning.

If such a learning is strong enough, the only flow disequilibrium which can arise in the Early Phase is an excess demand for the output of the innovative processes (depending on the delay between δ and δ^*, and on the increase of ρ and σ) which will be shifted to the following period bringing about an increase in the relative price of that output and thus increasing the proceeds which will be available in the next period for financing the growth of the economy; and so on if ΔM and Q are continuously adjusted to the new higher growth rate. Such a process, which will permit first to reduce the growth of the unemployment and then to reabsorb it gradually, can be explosive. The growth rates of ΔM and Q can however be adjusted in such a way as to stabilise the growth rate of the economy at a level

which, while allowing the reabsorption of unemployment, will also permit to reduce gradually the debt-resources ratio which would otherwise keep growing.

Conclusion

The simulations performed show that a routine choice as an answer to a given disturbance is either not viable -in that it takes the economy to a deadlock-or, in the only case in which it is viable, is characterized by an increase in unemployment and in the indebtment which cannot be stopped and hence will sooner or later become unbearable.

The viability of an innovative choice, on the other hand, has been seen to depend on the intensity of the learning process which characterizes innovation as a creation of technology. A policy aiming at maintaining in a first time the growth of the economy at the rate attained immediately after the original disturbance appears as the most favorable to an increase of intensity of the learning process which will permit, in a second time, to speed up the rate of growth of the economy in such a way as to reabsorb unemployment and to reduce the indebtment.

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