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Design, Innovation and Long Cycles in Economic Development

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TECHNOLOGY AND CONDITIONS OF MACROECONOMIC DEVELOPMENT: some notes on adjustment mechanisms and discontinuities in the transformation of capitalist economies

Giovanni Dosi

This paper concerns the role of technology and innovation in shaping the pace and direction of economic change. In particular, we will address the following question: are there some fundamental characteristics of technical change which can account for long-term cycles and/or long-term changes in the rate of macroeconomic growth? In order to develop our argument, we shall briefly discuss some fundamental features of technology and the mechanisms of interaction between the latter and the economic environment. We will then develop the argument in relation to the power and scope of the homeostatic forces present in the capitalist system and suggest that technology is likely to play an important (although by no means exclusive) part in the explanation of long-term changes in the rate of macroeconomic activity. This paper is very impressionistic and relies very little on systematic empirical analysis. Its prime aim is to discuss a theoretical framework whereby we can account for the complex set of interactions in which technology plays a part.

It is an evident stylized fact of modern economic systems that there are forces at work which keep them together and make them grow despite rapid and profound modifications of their

industrial structures, social relations, techniques of productions, patterns of consumption. We must better understand these forces in order to explain possible structural causes of instability and/or cyclicity in the performance variables (such as the rates of macroeconomic growth). The relative dynamic stability of industrial economics and their regularities were what classical economists found fascinating and worth studying - I must confess that I, too, find that same object fascinating and relatively unexplored since then.

It might be useful to start from a more explicit definition of "dynamic stability" and homeostasis. We probably live in the first social structure where technological, social and economic change is a fundamental feature of its functioning. For the first time, what we could call the "bicycle postulate" applies: in order to stand up you must keep cycling.(1) However, changes and transformation are by nature "disequilibrating" forces. Thus, there must be other factors which maintain relatively ordered configurations of the system and allow a broad consistency between the conditions of material reproduction (including income distribution, accumulation, available techniques, patterns of consumption, etc.) and the thread of social relations. In a loose thermodynamic analogy, it is what some recent French works call "regulation".(2) This important concept has clearly nothing to do with the meaning in which it sometimes is used by American neo-classical economists, but hints at the presence in the system of inner adjustment processes, institutions and servo-mechanisms which are vaguely similar to a thermodynamic system of engines and thermostats, whereby the structures of feedbacks prevent it from overheating, exploding or stopping. The problem of long-term cycles or, in any case, changes in the rates of macroeconomic activity pertain precisely to this level of analysis: are there structural features which produce crises in the regulatory set-up so that the engine tends to stop or to explode?

Let us heroically subdivide the overall socio-economic fabric into three domains, which we will call (i) the system of technologies, (ii) the "economic machine", (iii) the system of social relations and institutions.

These three domains clearly interact with each other. Our analysis will start from the following hypotheses:

1. Despite powerful interactions, each of these three domains has rules of its own which shape and constrain every inducement and adjustment mechanism between them.
2. There is a limited number of configurations of these three domains which allows a relatively "well-regulated" and smooth consistency between them. These define, so to speak, the "possible worlds".
3. Unbalanced or "crisis" configurations do not necessarily also embody the necessity of the transition to other (more balanced or "smoother") ones.

We shall clarify these points in relation to the interaction between the "system of technologies" and the other two.

Some properties of technical change

I firmly believe that the idea of "production possibility sets", with the corollary of technology as a malleable and reactive black box, to use Rosenberg's terminology,(3) has been one of the most damaging products of the neo-classical approach to economic theory. It has been developed without reference to any "stylized fact" of the production process or the historical pattern of technical change, but it is a core

All these considerations taken together lead us to conclude that the adaptiveness of the technological system to a given economic and social environment is bound and limited. Conversely, each state of the "technological system" defines a relatively limited set of possible macroeconomic conditions and social relations. In order to obtain an intuitive idea of these two points, the reader - through some reductio ad absurdum - may think of the enormous social need of labour-saving innovations in Florence at the end of the 15th century or the desperate requirement by the Roman Empire of a modern telecommunications system. Obviously, neither of them was accomplished. The serious point is that the homeostasis between the technological system and the other two defined above is only a limited one. Thus, this allows the possibility of major discontinuities, crises and fluctuations in the economic system itself.

We must now push the analysis a step further and explore whether there are factors at work which may also help in producing these discontinuities.

On the duality of technical change

Technical change is fundamentally about two things: either producing existing commodities or services with fewer inputs (i.e. more efficiently), or producing new commodities or services. In practice, product innovations of one sector are often process innovations for other sectors which are using them. The distinction, nonetheless, is theoretically fruitful. We just mentioned that process innovations necessarily imply some input saving. We can be more precise and suggest that in capitalist economies where conflict over labour processes, income distribution and power and structural features, labour saving must be one of the fundamental dimensions of most technological

trajectories. Moreover, any labour saving "upstream" (i.e. in the production of commodities which are also productive inputs) represents an input-saving, in value terms, "downstream". Finally, let us just mention our belief (which we share with classical economists) that developed industrial systems are (i) functionally characterized - in normal circumstances - by reproducability and not scarcity, (ii) demand-pulled in terms of macroeconomic activity, and (iii) balance-of-payment constrained. Under these conditions, paramount importance must be given to the broad duality of technical change which on the one hand continuously saves labour(8) and, on the other hand, creates new markets or expands existing ones by means of changing costs and prices of each commodity and service. The balance between demand creation(9) and labour displacement defines the endogenously generated rates of macroeconomic activity and utilization of the labour force. Amongst recent economic contributions, the issue is analysed in depth by Pasinetti,(10) who defines the general conditions of macroeconomic stability in a multi-sector model characterized by technical change. In terms of interpretation of long waves in economic activity - as we shall see below - Freeman, Clark and Soete(11) focus on changing patterns of this duality of technical innovation.

Notably, prevailing economic theory can assume that a compensation effect between the two fundamental results of technical change does generally exist owing to the properties of the duality price/quantities in general equilibrium frameworks. We already had the chance above of criticizing one of the core assumptions of that theory, namely the idea of production possibility sets. Symmetric with that, and equally essential, there is another core assumption based on consumption tests, characterized by wide substitution possibilities and well behaved with

assumption of the neo-classical theory of value which - in its clearest form - stands or falls with it.(4) Thus we should not be very surprised that, over the last hundred years, mainstream economists have been relatively more interested in the possible existence of contingency markets for red herrings than in the overall patterns of technical change. However, in the past two decades, a few important contributions have revived what we would call, "grosso modo", a classical approach to technical change. We must mention, among others, Freeman, Nelson and Winter, Rosenberg, and Sahal. Along these lines, in another work,(5) we argue the general existence of "technological paradigms" and "technological trajectories". What these concepts try to capture are a few fundamental properties of technology and innovation which are worth recalling.

a. The "system of technologies" (techniques of production, nature of the products, the processes of their generation, the directions of progress, etc.) embodies rules and procedures which, at least in the shorter term, maintain some degrees of autonomy with respect to the forces of economic inducement.

b. Technical progress is a strongly selective activity which embodies normative rules similar to positive and negative heuristics (telling the directions where to go and where not to go).

c. Technical change can be distinguished between the emergence of new technological paradigms and "normal" technical progress along the technical and economic dimensions of the "trajectories" which a paradigm defines.

d. The process of generation and selection of new technological paradigms does not depend only upon economic factors, but also the timing and the nature of scientific advances and "lato sensu" institutional factors.

e. Economic inducements, in the form of changing patterns and levels of demand, income distribution, and relative prices, are clearly powerful forces which shape the directions and the rates of "normal" technical progress. Moreover, they may represent an incentive or an obstacle to the emergence of new paradigms, but they are not by any means a sufficient condition for that emergence. Finally, it must be stressed that even the inducement mechanisms of normal technical progress occur within the boundaries defined by the paradigms and the trajectories.

f. The distinction between major changes in technological paradigms and "normal" progress broadly corresponds to the distinction between continuities and discontinuities in the process of technological advance.

g. The nature of technological progress is such that, regarding process innovation, new techniques are generally superior to the old ones irrespective of income distribution.(6) This does not mean that changes in distributive shares do not affect the direction of change. They do affect it (within the mentioned boundaries). However, the "better" techniques that are at last developed would have been adopted even at the "older" income distribution. This introduces important irreversibility properties into the system.

h. As highlighted by Rosenberg,(7) there are often complementarities and interdependencies between different technological paradigms and trajectories. The phenomenon provides a thread of technological stimuli, incentives, bottlenecks to overcome, opportunities to sieze, etc. Even if all these mechanisms are ultimately related to the economic use of technologies, they contribute to provide an inner momentum to technical change which is not simply "reactive" to the economic environment.

respect to relative prices.(12) We believe that this second core hypothesis does not generally hold, either. Let us suppose, instead, that:

(i) there are relatively stable "baskets of consumption", which depend on income levels and distribution, and institutional factors (the modes of social organization, the culture of social groups, etc.);

(ii) the prevailing force of change in these baskets of consumption are changes in per capita income and in cultural traits, so that long-term consumption patterns broadly follow Engel's curves;

(iii) changes in relative prices do not induce generalized substitution, but primarily affect the form and steepness of Engel's curves themselves(13) (in regard to final goods) or the process of diffusion of innovations (in regard to producer goods).

If these alternative hypotheses on consumption patterns are adequate "stylized facts", then duality of technical change becomes a crucial knife edge in modern growth. The homeostasis between productivity effect (labour saving, increasing division of labour, economies of scale, learning-by-doing, etc.) and demand effect (creation of new commodities and markets, induced demand by means of decreasing prices of the commodities in terms of income, and more generally endogenously generated growth of income)(14) cannot be guaranteed ex hypothesi.

Freeman, Clark and Soete(15) argue that a fundamental mechanism which generates long waves is the changing balance between product and process innovations. In another work(16) we try to prove on theoretical grounds that Freeman-Clark-Soete's hypothesis has rather general macroeconomic implications: other things being equal, process innovations have a lower

impact on aggregate demand than equivalent product innovations.(17)

An enormous amount of work still has to be done in order to develop multi-sector dis-equilibrium models embodying reasonable assumptions on the nature of technical change and the patterns of consumption. Moreover, it is still extremely difficult to link the foregoing considerations with aggregate growth models, roughly speaking, in the post-Keynesian tradition.(18) In any case, the appreciation of the possibility of imbalances between the dual effects of technical change allows the identification of what we could call the Keynesian gap, i.e. the difference between endogenously generated rates of macroeconomic activity and those which would correspond to the full employment of the labour force.(19) In order to prove that these Keynesian gaps are possible and likely in the long term, we need to follow a few theoretical steps, namely:

a. Are there major discontinuities in technical innovation, so that new paradigms operate a clustering effect upon bunches of innovation?

b. Can one define long-term shifts between process and product innovations, capable of affecting the balance between the dual features of technical change?

c. Even if the answer to the previous point is a positive one, are there compensating mechanisms within the "economic machine", so that long-term changes in productivity need not show in changes (with the opposite sign) in the rate of macroeconomic growth and/or of the utilization of the labour force?

For the time being we will limit the discussion to a closed economy context. In a later section of this paper we will introduce the incentives and constraints provided by international inter-dependencies.

Regarding question a, the foregoing discussion on the technological paradigms, the likely interdependencies between different technological trajectories, the partly exogenous timing of paradigm generation, etc. can be considered as a strong argument supporting the hypotheses of discontinuities and clustering in technological innovation.(20) We shall focus instead on questions b and c.

A few hypotheses on productivity trends, consumption patterns and overall regulation

We have already mentioned that the assessment of the balance between product and process innovation is very difficult in practice, since outputs of some sectors are often inputs for others. From a theoretical point of view we can define two pure "ideal types". First, a pure process innovation is one which affects the input coefficients of any one vertically integrated sector(21) defined by the manufacturing of an existing commodity without creating any new vertically integrated sectors or directly affecting the levels of demand of other existing ones.(22)

Conversely, a pure product innovation is that which creates ex novo a new vertically integrated sector without substituting for existing ones. In actual fact, most innovations can be placed on a continuum between these two extremes. However, the net balance of their dual impact on aggregate levels of demand will depend, ceteris paribus,(23) on their nearness to either extreme.(24) There are, in our view, two reasons why there is likely to be a long-term changing balance between process and product innovations. The first is, loosely speaking, "natural", in the sense that it is related to the inner features of technological trajectories. It is likely that the mechanisation of the processes associated with the production of innovative

commodities and their use will take time and require the technological paradigm to be relatively established. Moreover, economies of scale in production will be exploited only beyond a minimum scale of production and a minimum level of standardization of the products. Finally, the range of new products which can be developed on the ground of a given technological paradigm is limited by both the nature of the paradigm itself - including the physical limitations and trade-offs it embodies - and by the "stickiness" of consumption baskets, in the case of the final goods. (We shall come back to this point below.) These characteristics of technological paradigms and trajectories are clearly consistent with Abernathy and Utterback's(25) and Freeman-Clark-Soete's(26) analyses of technological patterns.

There is another set of macro-social and macroeconomic factors which can account for long-term changes in the process-bias (i.e. an increasing productivity effect) of technical change. To repeat, inducement mechanisms, from economic signals to the directions of technical change, are always at work, within the boundaries defined by the trajectories of normal technical progress. It is likely that periods of sustained rates of macroeconomic growth with associated low levels of unemployment exert a structural influence on income distribution, increasing the wage share in income, and on the levels of industrial conflicts, related to the modes of the labour process and, lato sensu, to power. These issues, in the long-wave context, are analysed in depth by Salvati(27) who discusses Kalecki's and Phelps Brown's theories and by Screpanti(28) who develops an exciting model of long waves related to working-class conflicts and insurgencies. With regard to the issue we are discussing here, it is plausible to assume that increasing wage shares and increasing levels of conflict will stretch

paradigms and trajectories to the limit in order to find labour-saving techniques.

Even these scattered remarks allow us to see that the long-term changes in the net balance between the dual properties of technical change is nothing but the "economic tip" of a much greater set of functional relations which hint at the requirement of consistency between the "technological system", the institutional set-up and the economic machine, which we mentioned at the beginning of this paper. More precisely: the dual economic features of technical progress - which determine the endogenously generated levels of aggregate demand - are affected by the pattern of consistency (or the "mismatching") between:

a. the nature of the fundamental technological paradigms;
b. the nature of production and labour processes associated with them;
c. the rules of the game between the major social groups (which, notably, is a fundamental force in determining levels and changes in productivity - for given techniques - and income distribution);
d. the baskets of consumption, which, as already mentioned, are a function of income levels, income distribution and, given the latter, of the ways a society organizes the use of non-working time, the provision of services, etc.

We may illustrate this point with extremely "unscientific" and impressionistic remarks on the post-war "golden age" of development.(29) On the technology side, the sustained rates of growth were based on the rapid growth of a few fundamental technologies, e.g. automobiles, petrochemicals, electrical consumer durables, capital equipment related to mechanized mass-production and "Tayloristic" productive processes.(30)

On the labour-process and institutional sides, the "Tayloristic" workers have been, despite profoundly different institutional arrangements across countries, one of the fundamental constituents of some kind of "corporatist bargain" involving political commitment to full employment by the major western governments, a more or less explicit indexation of real wages on productivity increases, a relatively large control of corporations on labour processes guaranteed by the control of the trade unions upon the shop floor.(31) These are broadly the features of the overall "monopololistic regulation" of the systems analysed by Aglietta, Boyer, and Mistral.(32) On the consumption side, the "baskets" for the majority of the population in developed economies were enlarged to include new durables and/or the substitution of durables for traded services, as argued by Gershuny(33) (e.g. substitution of automobiles for public transportation, etc.). Notably this enlargement was allowed by both rising income levels and the "corporatist arrangements" on real wage rates.(34)

Contextually, the smooth working of the forces endogenously generating aggregate demand within the "economic machine" were allowed, among other things, by relatively low levels of industrial conflicts: what are sometimes called "optimistic animal spirits" implied relatively high levels of investment generated both via the accelerator and autonomously, in relation to the opportunities offered by technical progress and new potential markets. "Well-regulated" patterns of consistency between the three fundamental systems (technology, economics and institutional frameworks) can generate "virtuous circles". However, one can also see how the golden-age conditions can reach critical thresholds and, so to speak, "cooling feedbacks".

Again, let us just make a few scattered and impressionistic remarks on the recent crisis

period. Even leaving aside exogenous shocks, it is reasonable to assume that inner trends have been at work, making the continuation of golden-age conditions increasingly difficult. For example:

(i) The increasing levels of industrial and political conflict around the end of the sixties must have had some effect on the rate of investment, even if we hold the innovation opportunities constant.(35)

(ii) There certainly is some truth in the suggestion that market saturation started to appear for the most dynamic items of final demand (e.g. consumer durables such as cars, brown and white goods, etc.). This is obviously not because people have all their "needs" satisfied, but significant additions to the basket of consumption (e.g. the "electronic home", etc.) require deep and long-term changes in the cultural patterns of use of time, the modes of social organisation, etc. At the same time, non-marketed(36) and/or "positional" services have become increasingly important. The problem is that most of these services could hardly become an "engine of growth" because they are not available under capitalist conditions of production of constant/increasing returns. Some of them are intrinsically "positional"(37) and scarce (such as spending a vacation in the Galapagos). Others have a politically-determined scarcity (such as health, education, etc.). Neither can experience for the time being the virtuous circle conditions between increasing demand and increasing supply productivity which characterize manufacturing production.

(iii) Both technical progress on existing technologies and industries (such as cars) and the emergence of new technologies and new industries (such as microelectronics) have undermined the size and strength of the social constituencies which were behind the Keynesian-corporatist social bargain of the "golden age". This has

happened both to the composition of industrial capitalism and to the structure of the working class. Think, for instance, of the changing balance of power in the USA between the old unionized companies on the East Coast and Great Lakes, and the new West Coast and Southern companies. More generally, one can find an archetypical illustration of this point in the ebb of the political and contractual bargaining strength of auto workers from the sixties to the eighties, throughout OECD countries.

These few notes cannot provide any analysis of the transition from post-war high-growth conditions to the present crisis. We just wish to illustrate how trends endogenous to the relationship between technological conditions, economic forces and institutional arrangement may lead to crisis feedback or, at least, a cooling down of growth patterns and increasing levels of social strain. The relative autonomy of the inner rules of the three mentioned fundamental systems is fully at work. The search for a new structural framework of regulation between the three is long, painstaking, often requires major crisis (and sometimes war), and success is not guaranteed. Certainly, the emergence of new fundamental technological paradigms changes the scope of "possible worlds", and both demands and tends to induce far-reaching transformations in the economic structure and in social relations. However, I believe, technology alone can neither produce those qualitative transformations in the economy which guarantee long-term dynamism and stability of growth, nor adjust the modes of reproduction of societies structurally characterized by the possibility of conflict over labour processes, income distribution and, ultimately, power. To focus the imagination on this point, take the example of the "Tayloristic" paradigm in mechanical manufacturing. Certainly it allowed the "Fordist" pattern of industrial relations,(38)

but by no means produced it, and even less did it produce Roosevelt and, later, the post-war macro-social and macroeconomic arrangements.

The foregoing discussion leads us to support the hypothesis that major discontinuities in both the overall functional relations between technology, economics and institutions and, more specifically, in the net macroeconomic impact of technical change, are possible and likely. However, must these discontinuities reflect themselves in long-term discontinuities in the rates of growth and/or of employment?

Adjustment mechanisms and rates of macroeconomic activity: is structural unemployment possible in the long term?

Even after allowing a changing macroeconomic impact of technical change, one must prove that these changes are sufficient to generate long-term changes in the rate of activity of the economic system. In other words, one must prove that, beyond short-term frictions, adjustment rigidities, etc. there is within the economic system an insufficient homeostasis so that there can be major discontinuities in the rates of investment and long-term lack of clearing of the labour market. This is a crucial theoretical point for any theory of long waves or long-term fluctuations, as we are reminded by Salvati(39) (1977), in the sharpest criticism of Freeman's theory of long waves that I am aware of, coming from within the same family of non-believers in Say's Law. On this issue, I will be able only to suggest some hypotheses and outline many unsolved questions in search for a sound theoretical treatment.

Following Salvati, let us recall the simple mathematics of Harrod's growth model:(40)

$$\dot{n} + \dot{\pi} = (I/Y)(Y/K) \qquad 1$$

where the dots stand for the percentage rates of growth and the symbols mean the labour force (n), labour productivity (π),investments (I), income (Y) and the capital stock (K). The equation simply states a condition: if we want to have and keep full employment, the "natural" rate of growth (that equal to the sum population and productivity growth), on the left-hand side, must equal the ratio of investment to income(40) times the inverse of the capital/output ratio (i.e. the "warranted" rate of growth), on the right-hand side. Are there forces which can maintain the effective rate of growth at that level or push it there from initial conditions of disequilibrium?

The changing balance between productivity effect and demand effect, discussed in the previous section, implies both changes in $\dot{\pi}$ and (I/Y). For convenience, let us subdivide the total investment between that part (I_a) which is strictly autonomous, in the sense that it is related to levels of innovative opportunities which are exogenous to the macroeconomic forces we consider here, and the other part (I_i) which is macroeconomically induced via multiplier/accelerator mechanisms ($I = I_a + I_i$). Suppose productivity increases and innovation-related investment opportunities decrease. Then a gap between the warranted and the natural rates will emerge or will increase, other things being equal. Notably, our hypotheses on the nature of technologies and technical change rules out the possibility of the powerful compensation mechanism based on changes in the capital/output ratio, since the universe of best-practice techniques is likely to be very limited and there might well be inferior or superior techniques irrespective of income distribution. The irreversibility properties of technological dynamics show their effect. However, this is only the beginning of an answer. We may just mention a

few important issues which, in my view, still remain open:

a. What happens to the effective rate of growth once we allow for reasonable assumptions on microeconomic behaviour and abandon the implicit one-sector one-commodity formulation of the model? Will the effective rate tend to converge on that warranted rate defined in the aggregate? Two ambitious and exciting models have recently been proposed, with different approaches, by Pasinetti(41) and Nelson and Winter.(42) Pasinetti essentially provides a system of reference for the changing equilibrium conditions which must be fulfilled in the presence of many sectors characterised by different rates of productivity increase and changing demand patterns. Behavioural assumptions, however, are absent and we do not know what are the actual paths of adjustment of the system. Nelson and Winter's evolutionary theory, on the contrary, is based on a complex set of microeconomic assumptions on firms operating in environments characterized by technical change. There, however, we face somewhat opposite difficulties in the sense that there is no easy link with macroeconomic variables such as income distribution or saving propensities at aggregate level.

b. What is the precise relationship between income distribution (and the related rate of profit) and the rates of investment?(43) The importance of that relationship should be clear. If the elasticity is high, then we are in the presence of a strong fluctuation-generating mechanism (both up and down). Take the example above, with increasing π and decreasing innovation-related investment opportunities. Suppose, however, that a certain period of relatively high unemployment decreases the workers' bargaining power and with that also the wage share in income. Even if the capital/output ratio does not change, investment elasticity to the profit rate should increase the "autonomous" rate of investment associated with given innovation-related opportunities. I_a will thus increase. What happens to the aggregate investment is more complicated since wages are also an item of aggregate demand, almost certainly with higher consumption propensities than profits: therefore a relative decrease in wages decreases the size of the multiplier and, through that, the accelerator effect on induced investments. A clear answer on the relationship between income distribution and rates of accumulation will not be given until we are able to assess, theoretically and empirically, the relative balance between "autonomous" and "induced" investment (as defined above) and the elasticity of investment to profit rates.(44)

These brief comments could only be headings of long analyses. What they show in any case is that, once we abandon orthodox general equilibrium hypotheses, no straightforward and evident homeostatic mechanism can easily be found to stabilize the growth rates in the long term around full-employment values.

Cycling together: dynamism and constraints of the international economy

Modern developed economies, it was hinted above, are "demand-pulled" on macroeconomic grounds. When we allow for international trade, exports become a crucial item of aggregate demand. At the same time, imports, bearing a rather stable relation to income, constrain the maximum rate of growth compatible with a balanced foreign account. The relationship between foreign trade and domestic growth is sometimes expressed through the "foreign trade multiplier".(45) This is standard macroeconomics of the

Keynesian tradition. We simply want to mention some implications of the patterns of technical change, suggested above, for the open-economy case. Technical progress is generally associated with (different degrees of) private appropriation of differential innovative capabilities as a corporate asset.(46) It is possible to show that such an appropriation also holds, by implication, for countries and not only for individual companies: other things being equal, the innovative process represents a divergence-generating mechanism, in terms of incomes and wage rates (in international currency), while, conversely, technological diffusion can be considered a convergence mechanism.

In another work,(47) we try to show how the rates of growth of each economy are constrained by the relative rates of innovation and/or imitation. There are rather strict conditions in the international arena which define the knife-edge of boundaries and stimuli to national growth possibilities. We can describe them impressionistically with the metaphor of two or more cyclists riding a tandem.(48) A priori, there is a wide range of velocities at which they can go. However, the speed at which each one of them cycles must be strictly coordinated. Otherwise, there are two possibilities: either the strongest one is capable and willing to pull the others, or the velocity is likely to adjust to the rhythm of the slowest one.

The countries on the technological frontier must be willing to bear the "newcomer's burden", in two senses. First, they must provide a sustained rate of innovation which can induce in the long-term a sufficient stimulus for internal growth and, in the longer term, for international technological diffusion. The fulfilment of this condition alone, however, is by no means sufficient, and if the rate of innovation is higher than the rate of diffusion, it may even become

perverse in the sense that it can induce divergence and increase the foreign balance constraints of late-coming countries. In these circumstances, the second requirement is that the country on the frontier (a) is successful in maintaining high rates of domestic macroeconomic activity (which obviously affect the foreign trade multipliers of the other exporting countries), and (b) provides a system of international payments and transfers on capital account which can finance the higher rates of growth of the late-coming countries. With these considerations in mind, one can appreciate the long-term implications of Mistral's hypothesis(49) that phases of economic growth are characterized by specific regimes of international economic relations and the dominance of one particular national economy.

There is an intuitive empirical reference in the British technological and economic hegemony until the "great depression" in the second half of the 19th century or the American technological and political leadership in the post-war "golden age". Conversely, periods of crisis and depression are generally characterized by the transition of the technological leadership between different countries(50) and the collapse of a regime of international payments (e.g. the crisis of the gold standard, or more recently the Bretton Woods system). Thinking of the role of technology factors in the recent crisis, one must mention:

a. the end of an era characterized by a generalized American technological advantage and fast rates of imitation by the rest of OECD countries and a few NICs;

b. the emergence, as a major technological and industrial power, of Japan, who, however, is unwilling and incapable of assuming the same role of sponsor of the international system which the US performed so well, both through the spontaneous behaviours of American multi-national

corporations and an explicit policy of world political hegemony;

c. more generally, profound signs of technological divergence within the industrialized countries (both in terms of innovative capabilities and rates of productivity growth).

Also at this international level, a phase of "virtuous circles" and smooth international consistency seems to have ended.

Some conclusions

I hope the sketchy hypotheses and remarks of this paper have helped to illustrate the role of technology in shaping and constraining the overall "regulation" of the system. The presence of inner rules within the three fundamental domains of technology, economic mechanism and institutions (plus the set of international inter-dependencies provided by the international arena) accounts for (i) the existence of some degrees of independence of each of them; (ii) the lack of complete homeostasis between them; (iii) the possibility of both "virtuous circles" and crisis configuration in their functional feedbacks. Our argument supports the existence of discontinuities of technical change itself (the emergence of new paradigms with their exogenous timing) and of discontinuities and mismatchings between technological paradigms, on the one hand, and forms of accumulation, patterns of consumption, institutional arrangements, on the other hand. The search for different configurations within the set of "possible worlds" allowed by new technological paradigms is a difficult process, often ridden with breakdowns and crises.

In relation to the economic system, we tried to show the bound nature of the induction mechanisms from economic signals and incentives to technical change. Moreover, on the ground of

given technological paradigms and trajectories, there may not be any economic adjustment mechanism powerful enough to compensate for long-term changes in the balance between the dual effects of technical change, which can at the same time enhance productivity and create new demand. Finally, technical change - in the form of different rates of innovation and diffusion of innovation between countries - contributes toward defining the changing patterns of competitiveness and thus the foreign trade multiplier and the balance of payment constraints that each national economy has to meet.

Throughout our argument, we have been referring to "discontinuities" instead of the more precise and demanding term "long waves". Should these discontinuities, whose existence has been the thrust of this paper, also have a regular wave-like form? I must confess that I have much less interest in an exact periodization. The nature of the functional relations which can induce increasing strains on virtuous circles in the overall regulation of the system, and specifically in economic performance variables such as growth rates and unemployment rates,(51) is quite complex: believing that there are cycles of exactly the same length and of exactly the same form requires, in my view, a little bit of mysticism. The two arguments I know of that I found most convincing are the time-lags required in investment and scrapping decisions and, even more, the timing of the social learning and collective cultural change related to generational turn-over.(52)

Around fifty years is more or less the time span of two generations, which may embody the traits of different cultural attitudes, varying adaptability to different institutional arrangements, defeated hopes or rising expectations, etc.(53)

In any case, the search for a nicely fitted cyclical form should not obscure what I believe to be the core of the long-wave discussion: namely, the relationship between forces of inner adjustment and long-term discontinuities, both within the economic system and between the economy, technological possibilities, and institutional set-ups.

Notes

1. I borrowed this expression, suggested in another context, from M. Salvati.
2. cf. M. Aglietta, "A Theory of Capitalist Reputation", London, New Left Books, 1979; R. Boyer and J. Mistral, "Accumulation, Inflation, Crises", Paris, Press Universitaire de France, 1978.
3. See N. Rosenberg, "Inside the Black Box: Technology and Economics", Cambridge University Press, 1982.
4. I owe the full appreciation of this point also to the comments by M. Lippi. The role played by the idea of production possibility sets in the entire framework of neoclassical general equilibrium is masterly illustrated by F. Hahn (The Neo-Ricardians, "Cambridge Journal of Economics", 1983), who develops a sophisticated and very subtle argument suggesting that (neo-) Ricardian theories of value and income distribution are a very special case of general equilibrium analysis.
5. G. Dosi, Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change, "Research Policy", 1982. A different version with a discussion of the long-wave issue is in C. Freeman, "Long Waves in World Economy", London, Butterworth, 1983.
6. We argue this point at greater length in Technological paradigms and technological trajectories, in C. Freeman, op.cit.
7. N. Rosenberg, op.cit.
8. Note that we are not talking here of possible labour-saving biases (i.e. whether technical progress is more labour-saving than capital-saving, etc.), but of the very fact that it displaces labour in so far as it increases labour productivity.
9. Clearly, we are talking of both demand for consumption goods and production inputs.
10. L.L. Pasinetti, "Structural Change and Economic Growth", Cambridge University Press, 1981.
11. C. Freeman, J. Clark and L. Soete, "Unemployment and Technological Innovation: A Study of Long Waves and Economic Development", London, Frances Pinter, 1982.
12. This can clearly be seen in general equilibrium analysis: the neoclassical duality between prices and quantities is founded on the symmetric possibility of substitution between techniques and between consumption bundles. The theory stands or falls with it, in the sense that both processes of substitution are necessary in order to yield the traditional properties of the model - in its simplest form - related to market clearing, relations between income distribution and marginal productivities, etc. Having, at least, substitution in consumption is necessary for the clearing properties of the model to hold.
13. A more thorough argument along similar lines in in L.L. Pasinetti, op.cit.
14. In this context we use the term "endogenous" to mean both growth related to multiplier/accelerator effects and to innovation-induced investments.
15. Op.cit.
16. G. Dosi, "On engines, thermostats, bicycles and tandems, or, moving some steps toward economic dynamics", Brighton, SPRU, University of Sussex, 1982.
17. By "equivalent" we mean innovations that involve the same amount of capital investment.
18. A la Kalecki, Harrod, Kaldor, Pasinetti, J. Robinson.
19. Note that here we are completely neglecting the specific economic causes of the "gap" and any normative issue related to whether simple "exogenous" creation of aggregate demand is feasible and/or politically possible.
20. For in-depth discussions within the recent long-wave debate, about the clustering of innovations, see Freeman, Clark and Soete, op.cit., and J.J. van

Duijn, "The Long Wave in Economic Life", London, Allen & Unwin, 1983.

21. For a discussion of this concept, see L.L. Pasinetti, op.cit.
22. In the sense that process innovations are not associated with the increasing use of any input.
23. This assumption of the stability of all other economic conditions is clearly unrealistic. We shall discuss this precise issue below.
24. Again, for a formal demonstration, we must refer to Dosi, "On engines...", 1982, op.cit.
25. cf., for example, W.J. Abernathy and J.M. Utterback, Dynamics of innovation industry, "Technology Review", 1978.
26. C. Freeman, J. Clark and L. Soete, op.cit.
27. M. Salvati, Politican Business Cycles and Long Waves in Industrial Relations: Notes on Kalecki and Phelps-Brown", in C. Freeman, op.cit.
28. E. Screpanti, Long economic cycles and recurring proletarian insurgencies, "Review", 1983.
29. cf. M. Salvati, "Sono possibili politiche economiche 'post-keynesiane'? (ovvero: sono i politici vittime di economisti defunti, o viventi?), Turin University, 1983.
30. cf. R. Coombs, "Long Waves and Labour Process Change", paper prepared for the Conference on Long Waves, Paris, Maison des Sciences de l'Homme, 1983. He convincingly argues the importance on a macroeconomic level of capital equipment related to what he calls "secondary" mechanization (as distinguished both from "primary" mechanization, linked with steam engines and bench production, and "tertiary" mechanization linked to automation and electronic machinery).
31. On the features of the "golden age", see M. Salvati, "Sono possibili...", 1983.
32. M. Aglietta, op.cit.; R. Boyer and J. Mistral, op.cit.; R. Boyer, Les transformations du rapport salarial dans la crise: une interpretation de ses aspects sociaux et economiques, "Critiques de l'economie politique", 1981.
33. J. Gershuny, "After Industrial Society, The Emerging Self-Service Economy", London, Macmillan, 1978; and Social innovation: change in the mode of provision of services, "Futures", 1982.
34. An ambitious analysis of long-term changes in the mechanisms of formation and macroeconomic role and wages is in R. Boyer, Les salaires en longue periode, "Economie et Statistique", 1978, and R. Boyer, 1981, op.cit.
35. Cf. E. Screpanti, op.cit.
36. Cf. J. Gershuny, 1982 Boyer, 1981, op.cit., and R. Boyer and J. Mistral, op.cit., and the bibliography quoted there.
37. À la F. Hirsch ("Social Limits to Growth", London, Routledge & Kegan Paul, 1977).
38. For a description and discussion, see R. Boyer, Les transformations du rapport salarial dans la crise. Une interpretation de ses aspects sociaux et economiques, "Critiques de l'economie politique", 1981; and R. Boyer and J. Mistral, op.cit., and the bibliography quoted there.
39. M. Salvati, "Technology, Long Waves and Structural Unemployment", paper prepared for the group on "Science and Technology in the New Socio-economic Context", Paris, OECD, 1977.
40. Which is identical to the saving propensity, ex post by definition, and ex ante if we are in equilibrium (remembering that we are still considering a closed-economy case and we are neglecting government spending).
41. L.L. Pasinetti, op.cit.
42. R.R. Nelson and S. Winter, "An Evolutionary Theory of Economic Change", Cambridge, Mass., Belknap Press, Harvard University, 1982.
43. On this issue, cf.: J. Mazier, B. Loiseau and G. Winter, Rentabilite et accumulation du capital dans les economies dominantes, "Economie et Statistique", 1977; R. Boyer and J. Mistral, op.cit.; M. Aglietta, op.cit.; A. Lipietz, Conflicts de repartition et changements techniques dans la theorie Marxiste, "Economie Appliquée", 1980; A. Lipietz, "Derriere la crise: la tendance à la baisse du taux de profit", Paris, CEPREMAP, 1981; E. Mandel, "Long Waves in the History of Capitalist Development", Cambridge University Press, 1980.
44. Of course, the question would become somewhat simpler if one fully accepted a "Cambridge" income distribution, whereby it is the rate of growth which determines the rate of profit. In that case, however, we run into some difficulties in explaining the microeconomic conditions consistent with that hypothesis. Moreover, we feel quite uneasy in ruling out any institutional force as determinant of income distribution.
45. If we consider exports as the only "autonomous" item of demand, then we can write:

$$Y = \frac{1}{m} X \qquad (2)$$

where m=import propensity in income, Y=income, X=exports. Considering two autonomous items (exports and innovation-related investment), and starting from the accounting identity

$$Y = C + X + I_a + I_i - M \qquad (3)$$

dividing by Y and re-arranging, we obtain

$$Y = \frac{1}{s + m - \lambda v} (X + I_a) \qquad (4)$$

assuming that the ratio of induced investment to income (I_i / Y) is linear in the capital/output ratio (λv), and s=saving propensity (i.e. 1 - C/Y).

Equation 4 simply states the "propulsive" effect that both innovation-related investment and exports have on income. It is not possible to discuss here the conditions under which the income, so obtained, is an equilbrium one.

46. We study this point at length in "Technological Paradigms and Technological Trajectories", in C. Freeman, op.cit.
47. cf. Dosi, 1982, op.cit.
48. Ibid.
49. cf. J. Mistral: "La diffusion internationale inegale de l'accumulation intensive et ses crises", Paris, CEPREMAP, 1981; Competitivite et formation de capital en longue periods, "Economie et Statistique", 1978.
50. For an historical analysis, see Freeman, Clark and Soete, op.cit.
51. We would choose first of all these two indicators of the possible discontinuities and long waves.
52. cf. Phelps-Brown, quoted in Salvati, 1983, op.cit. and Screvanti, 1983, op.cit.
53. See Screpanti, 1983, op.cit.