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THE NEW TECHNOLOGIES:
An integrated view, July, 1986

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This paper is an English translation, by the author herself, of a paper that until now has only been published in Spanish. The editors of this working paper series are of the opinion that the paper - although written 24 years ago - represents such an important element in the writings of Carlota Perez that it should be made available also to the English-speaking research community. The paper presents an early notion of a techno-economic paradigm and - although internet was years away from being available - it is indeed an outline of the paradigm we presently live in. Many of the issues raised here, like alternative sources of energy and biotechnology, are still with us today, and many of the predictions have proved to be based on accurate perceptions.

English version of the original Spanish; "Las Nuevas Tecnologías: Una Visión de Conjunto", in C. Ominami ed., LA TERCERA REVOLUCION INDUSTRIAL: IMPACTOS INTERNACIONALES DEL ACTUAL VIRAJE TECNOLOGICO, Grupo Editor Latinoamericano, Buenos Aires, 1986, pp. 44-89.

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Introduction

Interest in technical change has grown explosively in the last decade. Industrial policy, both in developed and developing countries, increasingly includes an explicit technology component. For this reason technological forecasts are becoming a prerequisite for planning. Two questions then arise: How reliable are technological forecasts? How useful are they as a guide for development strategies?

Past experience is highly uneven. In general there would seem to be a gap between the capacity for extrapolating trends in technology itself and that for predicting rates of diffusion in the productive sphere. This gap is wider the newer the technology and becomes narrower as the diffusion process develops, when related social and economic factors have become manifest revealing the selection criteria.

In fact, the world of the technically feasible is far greater than that of the economically profitable and that of the socially acceptable. And the two latter sets do not coincide either. This could mean that pure technological forecasting would be of limited use as a guide for development policy. A fuller exploration is required in order to identify the economic and social forces that drive and influence the course of technical change, as well as the forms in which technology influences the economy and society. This paper is an attempt in that direction.

The first part presents a set of categories with which to approach the analysis of technical change. In the second part, a hypothesis is presented about the constitution and diffusion of successive “techno-economic paradigms”. The crystallization of each paradigm would produce a radical shift in the course of evolution of the technologies of a given period, resulting in profound structural change in the economic sphere. The third part examines the way in which such a process of structural change would demand equally profound transformations in the socio-institutional sphere.

Following this general model of analysis, it is suggested that we are at present in a period of global technological transition, which offers new opportunities for outlining development strategies. Profiting from these new possibilities would require understanding the defining features of the new techno-economic paradigm, which, in the present case would be the system of technologies based upon microelectronics. Part four, then, examines some of these features, pointing to the specific ways in which they influence the direction of technological evolution in products, production processes and in the forms of organization of the firm. Part five explores the possible impact of the new prevailing technological model upon other new technologies, specifically: new energy sources, new materials and biotechnology. The final section is a discussion of some of the implications of the technological transition for development strategies.

I. How to put some order into the variety of technical change

Today we are in the midst of vast technological transformations in the most diverse spheres of economic activity. When speaking of new technologies a wide set of important developments comes to mind, including microelectronics, biotechnology, new materials, new sources of energy, telecommunications, advances in space and military technology. How then to arrive at an overall view? A systematic analysis requires the introduction of a set of tools for classification.

To begin with, it is important to insist on the Schumpeterian[1] distinction between invention, innovation and diffusion.

The invention of a new product or process occurs within what could be called the techno-scientific sphere and it can remain there forever. By contrast, an **innovation** is an economic fact. The first commercial introduction of an invention transfers it to the techno-economic sphere as an isolated event, the future of which will be decided in the market. In case of failure, it can disappear for a long time or forever. In case of success it can still remain an isolated fact, depending upon the degree of appropriability, its impact on competitors or on other areas of economic activity. Yet, the fact with the most far-reaching consequences is the process of massive adoption. **Diffusion** is what really transforms what was once an invention into a socio-economic phenomenon.

In terms of assessing the overall impact, one would then be interested in being able to predict the rate of diffusion of certain important innovations. This however is not easy. It implies the introduction of those economic, social and political variables likely to influence their generalization. A typical case where difficulties for prediction have been enormous has been the diffusion of nuclear energy confronted with widespread social and political resistance. Yet, it does not appear easy either to forecast innovations, even less, inventions. What is then the logic behind the process of technical change, which makes forecasting possible?

This leads us to another form of classification in the field of technical change: the distinction between incremental and radical innovations.

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[1] Schumpeter, J.S. (1939).

Incremental innovations are successive improvements upon existing products and processes. From an economic point of view, as C. Freeman[2] observes, this type of change lies behind the general rate of increase in productivity and determines the gradual modification of the coefficients in the input-output matrix, but it does not transform its structure. Increases in technical efficiency, productivity and precision in processes, changes in products to achieve better quality, reduce costs or widen their range of uses, are characteristic features of the evolutionary dynamics of every particular technology. The logic guiding this evolution, called "natural trajectory" by Nelson and Winter[3] and "technological paradigm" by Dosi[4], is analyzable and makes the course of incremental change relatively predictable. Given a technical base and the fundamental economic principles, it is possible to forecast with a reasonable degree of certainty that microprocessors, for example, will become smaller, more powerful, faster in operation, etc. Once catalytic refining was introduced, and knowing the profile of demand for oil derivatives, it was natural to expect that technological evolution would lead to successive improvements geared to increasing the yield of gasoline to the detriment of the heavier products with lower demand and lower prices. In the process industries, after the discovery of Chilton's Law, according to which doubling plant capacity only increased investment cost by two-thirds, it was easy to expect a trend towards obtaining those scale economies in a whole range of industries.

However, that succession of improvements tends to reach limits. Typically, the rhythm of introduction of changes is slow at the beginning, accelerates as the trajectory parameters are clearly identified and slows down again as diminishing returns begin to be encountered. The technology of the given product or process has reached maturity and, unless a radical innovation introduces a fresh trajectory, productivity will stop growing and profits will tend to fall.

A **radical innovation** is the introduction of a truly new product or process. Due to the self-contained nature of the trajectories of incremental change, it is practically impossible for a radical innovation to result from efforts to improve an existing technology. Nylon could not result from successive improvements to rayon plants, nor could nuclear energy be developed through a series of innovations in fossil fuel electric plants. A radical innovation is, by definition, a departure, capable of initiating a new technological course. Although the willingness to adopt radical innovations tends to be greater when the previous established trajectory approaches exhaustion,

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[2] Freeman, C. (1984). See also C. Freeman and C. Perez (1986).

[3] Nelson, R. and Winter, S. (1977).

[4] Dosi, G. (1982).

these can be introduced at any point in time and cut short the life cycle of the products or processes they substitute. There are also radical innovations that give birth to a whole new industry. Television, for instance, not only introduced a manufacturing industry but also programming and broadcasting services, which in turn widened the scope of the advertising industry. In this sense, important radical innovations tend to transform the structure of the input-output matrix, adding new columns and new rows.[5]

It would seem then that forecasting is only on firm ground in relation to incremental innovations. However, the most useful predictions would be those capable of capturing the lines of force leading to structural change. To approach this type of phenomena, we need concepts that will take us beyond the classification of individual innovations. Truly significant transformations arise from the interrelation among innovations. This leads us to two further categories for the analysis of technical change: technological systems and technological revolutions.

Technological systems are constellations[6] of innovations, technically and economically interrelated and affecting several branches of production. Rosenberg[7] has described the way in which innovations that increase the speed of operation of machine-tools, for instance, induce innovative efforts in cutting alloys capable of withstanding greater temperatures and speeds and how, in general, incremental trajectories in a product, process or branch of industry tend to encounter bottlenecks which become incentives for innovations—even radical ones—in other industries. Nelson and Winter[8] identify generic technologies, whose natural trajectory of evolution encompasses that of a whole set of interconnected radical innovations.

In petrochemical technology, for instance, one can identify several related but distinct families: synthetic fibers which transform the textile and garment industries; plastics, whose multiple impact as structural material generates whole new lines of equipment for extrusion, molding and cutting, transforms the packaging industry and opens a vast universe of innovations in disposable products; and so on.

From the vantage point of a technological system, then, there is a logic, which joins successive interrelated radical innovations in a common natural trajectory. Once this logic is established for the system, it is possible to forecast a growing succession of new products and processes, each of

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[5] Freeman, C., op. cit.

[6] Keirstead, B. S. (1948).

[7] Rosenberg, N. (1975).

[8] Nelson, R. and Winter, S., op. cit.

which, taken individually appears as a radical innovation, but when located within the system can be considered as an incremental change. The series of durable consumer goods, made of metal or plastic with an electric motor, which begins with the vacuum cleaner and the washing machine and approaches exhaustion with the electric can-opener and the electric carving knife, is a banal example of this type of logic in the area of products. The succession of plastic materials with the most diverse characteristics, obtained applying the same principles of organic chemistry, is an example in the field of intermediate products with enormous impact in generating innovations in the user industries. The "Green Revolution", with the introduction of growing families of oil driven agricultural machinery, together with multiple petrochemical innovations in fertilizers, herbicides and pesticides, is an example of the coherent evolution in the logic of a productive system.

An important point concerning the global impact of a new technological system is made by Freeman[9] emphasizing the multiple characters of the contributing innovations. They are not merely technological. Each technological system brings together technical innovations in inputs, products and processes with organizational and managerial innovations. The technological constellation of the "Green Revolution" led to single-crop farming in great expanses of land and induced changes in the organization of production and distribution as well as in the structure of ownership. The automobile, the assembly line, the corporate structure, the networks of parts suppliers, distributors and service stations, are only some of the elements of the technical, economic and social constellation gradually built around the internal combustion engine.

However, a technological system is not the highest level of generality for analyzing the apparently limitless variety of the world of technologies. As noted by Schumpeter[10], there are radical innovations with such an obvious capacity to transform the whole of the productive system that they merit the title of **technological revolutions**. Each of these revolutions is, in fact a constellation of technological systems with a common dynamics. Its diffusion the length and breadth of the productive sphere tends to encompass almost the whole of the economy. These revolutions lead to profound structural change and lie at the root of each great phase of prosperity in the world economy. The Industrial Revolution in England; the "Railway Era" in mid-nineteenth Century; electricity and basic steel in the "Belle Époque"; the internal combustion engine, the assembly line and petrochemistry in the recent post-war boom, are all examples of this type of all-pervasive revolu-

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[9] Freeman, C., Clark, C., Soete, L. (1982).

[10] Schumpeter, J.S., op. cit.

tions, capable of transforming the ways of producing, the ways of living and the economic geography of the whole world.

These revolutions generate, therefore, massive and fundamental changes in the behavior of economic agents. What type of mechanism would be capable of serving as guiding force for a shift of this sort? Economic theory holds that investment decisions are taken on the basis of the relative costs of labor and capital. But, as Freeman[11] points out, one cannot suppose that a long-term decision would be taken on the basis of small temporary variations in relative factor costs; not even on the basis of a significant variation if there are no reasons to believe that it is more or less permanent. In this context, I have advanced the hypothesis[12] that each technological revolution is based upon a radical and enduring shift in the relative cost dynamics of all possible inputs to production, giving clear signals that some are likely to decrease and others to increase for a relatively long period. This predictability becomes then the platform for the construction of a new "ideal type" of productive organization, defining the contours of the most efficient and least cost combinations for a given period and serving, therefore, as an implicit "rule of thumb" for technological and investment decisions. In practice, then, the diffusion of each specific technological revolution would be guided by a "techno-economic paradigm" increasingly rooted in collective consciousness, until it becomes the "common sense" of engineers, managers and investors, for most efficient and best productive practice.

This would mean the establishment of a general logic capable of guiding not only the course of incremental innovations but also the search for radical innovations, new technology systems and their growing interconnectedness, on the basis of identifiable common principles. Forecasting, then, becomes possible on a vast scale, and so does the identification of valid criteria to assess the relative importance of the various technology systems of a given period and the probability of their diffusion.

II. Techno-economic paradigm as "common sense" models in the productive sphere

In order for a technological revolution to spread from branch to branch and on a world scale, more than word about a new technical potential is required. Coherent diffusion demands a simple vehicle of propagation, accessible to millions of individual decision makers. I have suggested that

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[11] Freeman, C., Clark, C., Soete, L., op. cit. Ch. 4.

[12] Perez, C. (1985).

the organizing principle of the selection and structuring mechanism of each paradigm can be found in an input—or set of inputs—capable of exercising a determining influence on the behavior of the relative cost structure. This would be the vector carrying the new paradigm into the common sense thinking of engineers and managers.

This input or "key factor"—as we shall call it—comes to play such a steering role by fulfilling the following conditions:

a) Its relative cost must be obviously low and with a clearly decreasing trend;

b) Supply must appear as unlimited, for all practical purposes, regardless of the growth in demand

c) Its potential for all-pervasiveness in production must be massive and obvious; and

d) It must be at the center of a system of technical and organizational innovations, clearly recognized as capable of changing the profile and reducing the costs of equipment, labor and products.

This conjunction of characteristics holds today for microelectronics. For this reason, it increasingly steers engineering and managerial common sense towards its intensive use, gradually shaping the new best practice frontier, both for existing industries and for new branches. Until recently, it held for low cost oil, which, together with petrochemicals and other energy intensive materials, drove the mass production paradigm, fully deployed after World War II and now exhausted. In the upswing unleashed towards the end of last century the role of key factor fell upon low cost steel, which fostered the growth of heavy mechanical, electrical, civil and chemical engineering. The Victorian boom in mid-nineteenth Century—the "Railway Era"—was based upon the availability of low cost coal for cheap transportation systems based on the steam engine.

Of course, none of these inputs was new from a technical point of view. Each of them had a long history of development under the previous paradigm or even much further back in time. Steel diffused as a technical variant of iron for special purposes, until the Bessemer and Siemens Martin processes slashed its cost to a tenth and opened the way for its becoming the basic material for shipbuilding, civil engineering and electrical generation equipment. Oil had been used for limited purposes until the internal combustion engine made it central for all sorts of transportation. And this use, together with oil fuelled generation of electricity, became cheap when low-cost free-flowing oil, especially from the Middle East, came on stream. Electronics began with tubes, then transistors made a giant step forward in reliability and cost reduction. But, for a long time electronics developed within—and submitted to the logic of—the mass production, energy intensive paradigm, helping to widen the range of innovations in durable consumer goods, defense equipment and furthering the development of process control instruments for the chemical industries. Its universal applicability only became visible when its original control functions fused in synergetic fashion with data processing. And this all-pervasiveness only turns into techno-economic logic when large-scale integration resulted in increasingly powerful, ever cheaper, microprocessors and other electronic chips. Into the future, one could perhaps speculate that biotechnology might follow an analogous path, arriving at some form of radical cost-cutting breakthroughs, after growing and developing for some time as an increasingly important technology system, submitted to the logic of the microelectronics led paradigm.

What is truly new then is not the mere technical fact. The breakthrough occurs when technology and economics converge in a dramatic reduction in the relative cost of the key input—or set of inputs—, as a result of a series of events, some due to chance, other motivated, including the formation of a constellation of radical technical and organizational innovations. And these technological breakthroughs are more likely to occur—or to be fully recognized, exploited and widely applied—when the set of technologies based on the prevailing key factor is exhausting its potential to contribute to increases in productivity.

It is important to note that the exhaustion of a paradigm manifests itself in multiple ways. Any set of trends pushed to its ultimate consequences tends to absurdity. The “hippie” rebellion against massification and consumerism; the growing worker resistance against the rigidity and monotony of the assembly line; the ecological movement against pollution, waste and natural resource depletion, are the social counterpart of what in the techno-economic sphere are the problems confronted by engineers and managers in trying to continue increasing productivity, profits and markets or to add new products to the series within the well trodden technology systems. In this context, it is possible to interpret the controversial “Limits to Growth” report as the extrapolation of a paradigm beyond its useful life.

As a matter of fact, what supports the unavoidable diffusion of a new paradigm the length and breadth of the economy is its capacity to overcome the specific limits encountered by the previous paradigm, while offering a quantum jump in potential productivity, opening truly new investment opportunities and initiating new trajectories of technological evolution. That debottlenecking potential at a relatively low cost provides the impulse for the massive shift in the decision-making criteria applied by managers and engineers for innovating and investing.

Furthermore, the process tends to be self-reinforcing. As a new techno-economic paradigm diffuses, a strong bias is introduced in the direction taken by technical and organizational innovation. Thus, the supply of inputs and capital equipment, which increasingly incorporates the new principles, tends to reduce the range of available technical options, further propelling the generalization of the new model of production and of its accompanying organizational forms. Eventually, the global product mix becomes key-factor-intensive, favoring the growth of those branches that make best use of its particular advantages. Gradually, for each type of product, clearer and clearer signals indicate the natural innovative trajectories, optimal scales of production, relative prices and even the typical forms of competition in each market. This process unfolds until the new parameters and the new ideal model for best productive practice become integral part of everybody's common sense reasoning.

The process also involves profound changes in the relative importance of the various branches of the economy. Each great upswing in the economy is driven by different motive branches. Thus, the areas of fastest capital accumulation, where the largest firms concentrate, are precisely those where the particular key factor of each period is produced and those where its advantages for a quantum jump in productivity are best realized. Equally, the deployment of each paradigm tends to require the massive growth of a specific infrastructural network, destined to generate its main externalities and facilitate the construction of the specific web of inter-branch relationships characteristic of each period. Up and downstream from the main branches and facilitated by the growth of the infrastructural network (and the decreasing cost of access to it), a new set of induced branches and activities appears and multiplies. These branches serve to complete the new and growing structural network of the economy. Their proliferation is a feature of the upswing periods of long waves in economic growth.

We suggest, then, that each long phase of prosperity is characterized by the construction and generalization of a new specific web of inter-branch relationships and driven by the growth of motive branches, different from those that propelled the previous upswing. That is in fact the process we understand as structural change.

It must be recognized, of course, that these classifications of branches and even the identification of a single key factor do inevitable violence to the richness and profound complexity of structural transformations. The effort should be interpreted as an attempt to find ways of focusing the analysis as well as useful categories for conceptualizing structural change.

In order to give an approximate view of how these concepts can be used to identify the main techno-economic forces within a paradigm and how it substitutes another, we shall briefly mention some of the elements in the present transition. In part four, these will be discussed in more detail.

Let us first review the main features of the waning techno-economic paradigm, which took shape in the 1920's and 1930's and shaped the mode of growth of the economic upswing unleashed after the Second World War. The key factor of that paradigm was low-cost oil, together with energy-intensive materials, especially plastics (from oil). The model of efficiency for plant organization was the continuous process or assembly line for turning out massive quantities of identical products. The ideal type of firm was the "corporation", governed by a professional multi-layered administrative and managerial hierarchy, clearly separated from the production plants; its structure included an R & D department and market behavior took an oligopolistic form. The motive branches, where the giant corporations concentrated, were oil, petrochemicals, automobile and those producing other energy-intensive goods for consumer and defense markets. The interrelated growth of these central branches led to the proliferation of the service sector (from gasoline stations and supermarkets to the advertising industry and the diversified banking and financial sector), as well as to that of the construction industry. The system required growing quantities of specialized labor, for both plant and office work. It benefited from economies of agglomeration; it was based on and propelled by the expansion of a network of roads and of a system of distribution of oil and its products (including electricity), to feed the energy-intensive lifestyles, modes of production and transportation.

Today, given the ample availability of low-cost microelectronics—and the consequent low cost of information processing—a new techno-economic paradigm is taking shape and diffusing. It is no longer "common sense" to continue along the now expensive path of energy and materials intensity. The "ideal type" of productive organization, which has been developing since the 1960's tends to fuse administration, production and distribution in a single integrated system—a trend we shall call "Systemation"—for the flexible production of a diverse and changing set of information-intensive products and services. The motive branches of the economy would presumably be the electronics and information sectors—particularly components and capital equipment—propelling and propelled by the expansion of a vast infrastructural telecommunications network. The occupational profile tends to reduce the requirements of middle range qualifications and increase those at the upper and—in the longer run—the lower range of the scale, while demanding basic multi-purpose skills and flexibility for information handling, rather than narrow specialization. Trends towards the constitution of networks and systems seem to spring up in all spheres of activity, while **diversity** and **flexibility** tend to replace uniformity and repetitiveness as best "common sense" practice.

We are then saying that "new" technologies do not all have the same importance as forerunners of the shape of the future. The technology that acts as the vector of the paradigm serves as organizing framework and imprints its seal on the path followed by all others. In the present case, the evolutionary paths in the fields of materials, energy and biotechnology, will tend to submit to the logic of the technological model defined by microelectronics. For this reason, forecasts of the development and diffusion of these technologies would have to take the new paradigm as a frame of reference. In part five, after examining the characteristic features of the productive model generated around microelectronics, an exploration of that type will be undertaken.

However, before entering the analysis of the new technologies, it is important to discuss the consequences of structural change upon the socio-institutional framework within which it evolves, as well as the inverse influences. After all, the object of technological forecasts is guiding socio-institutional decisions. Let us then examine the form this interaction takes in times of transition.

III. Structural change and socio-institutional transformations

A process of structural change in the economic sphere of the sort we have been describing cannot occur without conflict. As a matter of fact, the difficulty of that process could be the explanation of the great economic crises that have taken place every forty to sixty years since the Industrial Revolution. Schumpeter characterized economic crises with a paradoxical expression: "creative destruction". And, he described the great economic upswings of the long—or Kondratiev—waves as "the deployment of a technological revolution and the absorption of its effects.[13] The problem is that the effects are truly dramatic.

Once the main guiding elements of a paradigm are established and the radical shift in the relative cost structure becomes clearly visible, the new ideal model grows in complexity and coherence, going far beyond mere technical change. In practice, it affects almost every aspect of the productive system. The whole constellation, once crystallized, involves:

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[13] Schumpeter, J.S., op. cit.

a) New concepts for organizational efficiency at the plant level;

b) A new ideal model for the management and organization of the firm;

c) A significantly lower level of labor requirements per unit of output, with a different skill profile;

d) A strong bias towards the intensive use of the new key factor in technological innovation;

e) A new pattern of investment favoring sectors directly or indirectly related with the key factor and connected to the new infrastructural network, itself the object of a wave of investment;

f) A bias, therefore, also in the overall product mix, resulting from higher rates of growth in key factor related sectors;

g) A redefinition of optimal production scales leading to a redistribution of production between larger and smaller firms;

h) A new pattern of geographic location of investment as the new model redefines comparative advantages and disadvantages!

i) New areas of concentration of the most powerful firms, replacing those prevailing in the previous paradigm.

Clearly, such deep-going changes, even occurring gradually, as it actually happens, end up creating chaos in all markets. Their assimilation demands, therefore, substantial changes in the prevailing socio-institutional framework, which had been established to cater to the requirements of the previous paradigm.

Even in the case of an office, when word-processors, fax-machines, modems and other automatic equipment for handling and transmitting information are introduced, it is soon found that massive personnel retraining, a redefinition of space use and functions, new norms of interrelation and a rethinking of the whole system are required in order to reap all the potential benefits of the new equipment. In the same manner, when a new techno-economic rationality propagates in the productive system, it becomes necessary to effect vast transformations in society as a whole to allow the deployment of its growth potential.

In fact, the global economic upsurge does not occur in the first few years, not even in the first decades of diffusion of the new techno-economic paradigm. The elements that will eventually compose it appear gradually in the midst of a world dominated by the previous paradigm. Computers, integrated circuits, numerical control machine tools and even some robots began diffusing in the 1960’s in the world of oil and automobiles. Equally, the internal combustion engine, automobiles, the assembly line and the first synthetic materials appeared early in this century in the world of low cost steel, when growth was driven by heavy electrical, mechanical, civil and chemical engineering. In neither case was it possible to perceive, from those early beginnings, the magnitude of the structural transformation that was to come. The technical frontier is clearly visible as shown by the relative accuracy of past forecasts in this area. In 1937, it was estimated that 78% of technological advances predicted in a Scientific American study in 1920 had been correct.[14] But, the shape and rhythm of diffusion, the economic and social viability, are not equally visible at first. However, as one firm after another and one branch of production after another approach the limits of the traditional trajectories, see their productivity levels stagnate and their profit levels threatened, the rhythm of adoption of the various elements destined to conform the new paradigm accelerates as well as the pace of generation of complementary innovations. Thus, conditions begin to be created for more reliable and integral forecasting efforts.

Yet, this series of successive changes in more and more points of the economic system is not perceived in the aggregate until transformations have reached a certain critical mass. This process of gradual abandonment of a declining productive model and growing adoption of the new is characteristic of the downswing decades of Kondratiev long waves.

Social institutions and the general framework of socio-economic regulation[15] face a chaotic and unaccustomed situation, in the face of which long time effective recipes become powerless. There ensues a growingly severe mismatch between a socio-institutional framework geared to support the deployment of the waning paradigm and the new requirements of a techno-economic sphere brimming with change. Further still, the persistent application of the old recipes, actually aggravates the situation and could lead to a collapse.

The crisis is truly a process of “creative destruction” but not only in the economy but also in the socio-institutional sphere. The new upswing can only be unleashed by means of vast socio-institutional innovations, in response to the requirements of the new paradigm and geared to facilitating the full transformation seething in the productive sphere.

Last time around, to overcome the great depression of the 1930’s, it was necessary to surmount the prevailing notions about the superiority of free market mechanisms and accept the establishment of a massive and sys-

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[14] U.S. National Resources Committee (1937).

[15] A similar interpretation of the relationship between the socio-institutional framework and the underlying technology, based on the concept of “Regulation”, as well as an exhaustive analysis of what he terms the “Fordist” mode of regulation of production and consumption is found in Aglietta, M. (1976). See also the subsequent publications of Boyer, R., Lipietz, A. and Coriat, B.

tematic State intervention in the economy following Keynesian principles. The list of institutional innovations then introduced to regulate the growth of demand for mass production is certainly impressive. At the national level, it goes from the direct manipulation of demand mechanisms through fiscal, monetary and public spending policies, to the official recognition of labor unions, collective bargaining and the establishment of a social security net, passing through the reduction of the working week and year. On the international level, these arrangements were complemented by U.S. hegemony, Bretton Woods, the U.N., the GATT, the Marshall Plan, the IMF, the World Bank, gradual decolonization and other measures geared to facilitating the international movement of trade and investment, as well as to maintain political stability. However, almost every one of these innovations, effective and widely accepted until now, is being questioned more or less virulently by one or another social group. Overcoming the crisis requires the establishment of new rules of the game, new regulatory mechanisms and new institutions.

This process of social and political innovation is naturally long and full of conflicts. Nevertheless, production cannot be re-launched upon a lasting expansion path without re-establishing structural coherence, by arriving at a socio-institutional context capable of favoring the deployment of the new techno-economic potential.

Of course, the construction of a coherent socio-institutional framework, just as that of a techno-economic paradigm, is a gradual trial and error process, driven by the need to confront the various manifestations of the crisis and often hindered by the inertia of existing institutions and vested interests, associated with the old mode of growth.

Yet, we are not making a case for mere technological determinism. What a paradigm determines is the vast range of the possible. Within it, the various social forces play out their confrontations, institutional experiments, agreements or compromises. The result is the framework that will ultimately mold, orient, select and regulate the actual path the new potential will follow.

This means that each crisis, each period of technological transition, is a point of indetermination in history. A quantum jump in potential productivity opens the way for a great increase in the generation of wealth. But the specific commodities that will compose that greater wealth and the way it will be distributed will depend on the socio-political framework arrived at. Historically, each transition has modified both the conditions of the various social groups within each country and the relative position of countries in the generation and distribution of world production.

For each country, whatever the level of development reached in the previous wave, the need appears to make internal changes and to participate in the construction of a new world order. If the hypotheses presented here are a good approximation of the nature of the crisis and the means to overcome it, then, the best way to find criteria for a successful transition and make a leap in development prospects is a deep understanding of the new paradigm. This is possible because when the crisis becomes visible the paradigm has already diffused enough to be analyzed.

This suggests a different type of forecast. One geared to capturing the logic of development and interrelation of the new technologies and to detecting the shifts away from previous practices. Drawing the contours of the new paradigm defines the space open for creativity and decision-making, both in specific branches and in the economy as a whole and can also reveal some of the new institutional options.

What follows is an exploration of that sort, trying to sketch the main features of the paradigm. Later we shall make use of those features to assess their influence on the path of development of other new technologies.

IV. An exploration of the features of the new paradigm

From the previous discussion it should be clear that the effort we propose to undertake is not centered upon the electronics industry itself but in the trends generated in the whole of the economy by its development and the diffusion of its products.

We begin by examining the elements most closely related to the shift in the dynamics of relative costs; the impact this shift is likely to have on innovation trajectories and upon the mix of new products. Then, the new best practice production model, based on the characteristics of the new equipment, is analyzed. Finally, we try to identify the direction of change in the forms of organization and management of the firm.

NEW PARAMETERS FOR INNOVATION TRAJECTORIES

The central feature of the new paradigm is the trend towards increasing the information content of products, as opposed to energy or materials content. This is a direct consequence of the radical and continuing change in the relative cost structure towards ever cheaper information handling and transmission. For this phenomenon to introduce a bias in innovation, it is not necessary to assume that the costs of energy and materials will tend to increase constantly in absolute terms. It is enough to suppose that the diminishing cost and the growing potential of microelectronics will tend to widen the gap into the future. With this prospect, one can extrapolate forward the already observed new trends in product and process design.

A. New guiding concepts for incremental product innovations

An immediate effect of the availability of cheap microelectronics is its insertion in traditional products, adding a new trajectory with new guiding concepts. This translates into redesign and successive modifications with new aims: On the one hand, minimize size, moving parts, energy and materials inputs, as well as energy consumption in use. On the other, maximize electronics, versatility and what could in general be termed information contents. This has been happening in a whole range of products, from watches, calculators and sewing machines to machine tools and automobiles. Possibilities are vast and far from being fully exploited. And these optimization parameters apply also to new products, as is clearly visible in the case of the successive generations of computers.

Once on the path of exploiting the possibilities intrinsic to electronics, new target-features appear indicating the best direction for product innovation. Small is more beautiful and more profitable than big; versatile, compatible, adaptable, are better than rigid. A programmable product is better than a dedicated one. A product capable of modular growth is superior to one with defined and static scale and potential. A product with greater speed of operation and response is preferable to a slower one. Any product capable of joining a network or becoming the center or an element of a system is better than an isolated one. Distributed “intelligence” is more efficient than centralized control.

This new scale of values is transmitted to users through advertising, turning consumers into a further reinforcement of the new innovative path.

B. New trajectories for radical product innovations

Microelectronics components and the waves of propagation of their applications generate clearly defined paths towards multiple chains of radical innovations in products.[16] Together, they can be seen as a great technology system composed of several subsystems.

The central technology system is the one driven by the microelectronic components industry itself. Its requirements in inputs, special materials, chemicals and equipment are a tremendous force giving impulse to radical innovations upstream.

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[16] For a detailed prospective assessment of microelectronics based technologies, see Bessant, J., Guy, K., Miles, I., Rush, H. (1985).

In interaction with the provision of ever cheaper, more powerful, more densely packed and faster components, grows a network of applications subsystems. One of them, that of computers, follows a set of trajectories: one towards increasing processing power; another towards very specialized equipment; another towards a basic product for individual use, increasingly versatile and ever cheaper and finally a trend towards the growing interconnection of all types of equipment in ever more powerful, flexible and complex networks. All these trajectories widen into the future with the target of “artificial intelligence”.

Around computers, the model of the “Office of the Future” is constructed, opening a chain of radical innovations to automate and interconnect all information handling activities. This trajectory is joined by another technology sub-system based on digital telecommunications for the transmission of information in whatever form: voice, data or images. This subsystem constitutes the infrastructural network of the paradigm. The conjunction of information handling and transmission innovations propels follow-up innovations in an increasing number of traditional branches, from the television industry that moves towards interactive cable systems, passing through the revolution in financial and banking services, to the introduction of new requirements for buildings, to be taken up by the construction industry and its suppliers. More important still, this conjunction gives birth to two new branches with long innovation trajectories into the future: the software and systems industry and the data processing industry.

Next to the “Office of the Future” appears the “Plant of the Future”. Once the principle of information handling with programmable digital equipment is established, new lines of successive innovations in capital goods open up, encompassing more and more activities for the production of goods and services and for the interconnection between plant and office. These innovations are not limited to the automation of manufacturing proper (computerized machine tools or robots). They include a vast field of new instruments for such peripheral or auxiliary activities as research, design, quality control, process control, environmental control, fault diagnosis, and many others, as well as systems for interconnecting them. In turn, the specific requirements of these applications give signals for the development of various related technologies in new materials, opto-electronics, sensors, etc.

These vast opportunities for introducing innovations in an ever-growing spectrum of applications and in an ever wider range of activities, multiplied by the number of successive generations of each equipment, indicate that the evolutionary trajectories of these new technology systems will stretch a very long way into the future. These series of innovations widen even further the field of action for the software industry

The particularly explosive growth of innovation possibilities in the area of capital goods is the most powerful vehicle of propagation of the new model of organization of production and management of the firm. It is also the main impetus for upstream innovations in materials and downstream innovations in products and services. This contrasts with the previous paradigm for which it could be said that the dynamics of innovation was greater in the areas of materials, chemistry and final goods (consumer and defense), and that these set the requirements for innovation in capital goods.

Having said this, in the area of consumer goods, there are also ample trajectories for radical innovations based on the availability of low cost microelectronics. Beyond the gradual “electronization” of traditional consumer durables, the introduction in the home of the computer, the video-recorder, the digital telephone, the electronic oven and other isolated products, creates the basis for a new synergy analogous to that of plant and office. The common digital language of all those products provides a potential for interconnection between them and with the outside world through the telecommunications network. This synergy can open the way for an innovative dynamics bringing forth successive products for the “Computer Integrated Home”. But, beyond physical products, it is likely that this line of development would open up a chain of innovations in interactive information services, beginning with interactive cable TV, on-line banking and remote shopping—already partially introduced—, passing through electronic mail, remote education. Access to data banks and expert systems—expected for the not too distant future—and so on, incorporating more and more activities. The breadth and depth of this route and the eventual importance these products will have in the general composition of production will depend on social arrangements concerning income distribution.

The same can be obviously said for the technology system associated to defense and space. Its potential in terms of generation of radical innovations is enormous and its eventual importance and relative weight will depend, more than any other on political factors.

These new technology systems are the most likely to drive global growth for the decades ahead. Thus it is reasonable to expect that the most powerful and largest firms will tend to locate and concentrate in the most dynamic core areas of these systems.

NEW CONCEPTS FOR THE BEST PRACTICE IN PRODUCTION

Microelectronics based technology is particularly isomorphic. Integrated circuits are information processing systems, which are incorporated as elements of larger circuits, to form complex systems. Products based on these are systems which coordinate various sub-systems. And these products are in turn integrated into even more complex, larger systems. The organization and optimization principles applied at each of those levels are quite similar. For this reason, plant and process engineering become systems engineering. The concepts guiding incremental innovation in plant and equipment are essentially the same as those mentioned for products. In fact, the characteristics pursued in the design of capital goods are implicitly responding to the requirements of the processing and production networks that are to incorporate them.

In what follows we shall discuss some of the features characterizing the new design trajectories for plant and production process, pointing to their possible economic consequences, with special emphasis on the question of scale of production.

A. Energy and materials: saving, recycling and diversification

In general terms, the introduction of electronic equipment is expected to lead to better product quality and greater precision in process control, as well as to increases in labor productivity, in profitability and in the productivity of resources. The latter translates into materials and energy savings through various routes.

In the fabricating industries, products become smaller and design can allow narrower tolerances due to the much greater precision of computerized machine tools. Furthermore, the use of control instruments permits a reduction in waste and in the proportion of rejects, through “on-line” quality control in various points of the process. This new emphasis in the efficiency of material inputs leads to a reduction of their relative weight in the total cost. This in turn leads to the possibility of using materials which are more expensive but more precisely adapted to their specific function. As a result a growing diversification in the pattern of engineering materials consumption can be expected.

In the processing industries, electronic instruments make it easier to install energy and materials recycling systems, favoring the recovery of all by-products with possible commercial value. The “ideal” model would be the closed-loop, multi-product, no-effluent plant.

This tendency of the new model to make an increasingly rational use of material inputs appears as a factor capable of allowing the acceleration of economic growth, avoiding the threat, implicit in the continuation of the previous paradigm, of exhausting non-renewable resources. Something similar happens regarding the possibility of reducing environmental pollution levels.

B. Flexibility in plant: diversity in products

The programmable nature of microelectronics-based equipment and controls overcomes the rigidity of the old dedicated plants and establishes flexibility as best practice in plant design. The superiority of mass over batch production is brought into question and the dogma of scale economies is shaken.

This does not mean the disappearance of giant plants; much less that of giant firms. What occurs is simply a modification in the norms of production, where scale of plant becomes relatively independent of the scale of each market. With microelectronics controlled equipment, the relatively low cost of programming and effecting changes in production schedules makes it possible to reach very high levels of efficiency fabricating a wide range of different products, with frequent model changes and variable volumes. This greater scope of market coverage and the rapid adaptability to variations in demand places flexible manufacturing at a significantly higher level of economic efficiency than dedicated production. Diversity in production becomes a characteristic and a target of the new best practice model.

Moreover, using similar equipment, small and medium plants can achieve an analogous flexibility and high efficiency. Thus, high levels of productivity are no longer so dependent on economies of scale. This substantially transforms the determinants of competitiveness and redefines the question of barriers to entry. New sorts of economies are to be made: of “scope” through an optimal range of product coverage; of “location”, based on minimal distance to market and speed of response; and of “specialization” based on well targeted market niches. This could lead to a proliferation of highly competitive small and medium firms. Such a trend could take place in spite of the fact that giant firms can reap the benefits of all three sorts of economies, by controlling a vast system of production and distribution, with plants of all sizes in a variety of locations. Once diversity and segmentation substitute homogeneity as the form of market definition, optimizing coverage on the part of the giants will always leave empty spaces for initiatives at a smaller scale.

The trend towards plant flexibility and product diversity is not limited to the fabricating industries. It takes different forms depending on the characteristics of each sector. In processing plants (agro-industrial, chemical, metallurgical), flexibility translates into greater adaptability to variations in the quality of inputs and into greater ease for modifying final product specifications, eventually leading to full diversification of output.

In those service sectors that handle vast amounts of information (financial, banking, insurance) computerization has already resulted in great "product" proliferation, segmenting the market to cater even to single clients. In the particular case of financial services a redistribution of markets by firm size has occurred, which could eventually become typical for many other sectors. The giants, resulting from multiple fusions and acquisitions, have established flexible worldwide networks, covering a very vast range of services for the most dynamic sectors of the market. Small and medium firms have occupied the two extremes of the spectrum: the highly specialized niches and the routine basic low cost market segments.[17]

C. Technological dynamism: Design as an integral part of production

The new potential for flexibility extends far beyond the questions of optimal plant scales and variable output mix. It also makes possible frequent changes in the external appearance and in the technical design of products, without great losses in efficiency.

The coupling of computer-aided design and computer-aided manufacturing (CAD—CAM)[18], together with expected increases in the productivity of software development, tend to diminish the relative cost of innovation and shorten the learning curves. This turns engineering design into a capital intensive activity and makes it an integral part of the production process with a crucial role in determining productivity and competitiveness.

Under these circumstances the road is open for a fast pace of product change. This trend is further reinforced by the rapid rhythm of improvement in microelectronic components. Each new generation of chips is an incentive for redesign of products, improving their characteristics while reducing their relative cost.

Although this tendency towards shorter product life-cycles will certainly vary in intensity from branch to branch, it is likely to considerably affect managerial behavior. Engineering and R&D departments tend to establish closer and closer links between them and with the production process and begin to play a more central role not only in strategic planning but increasingly also in short and medium term programming.

This feature of the new best practice model could lead to a change in the form of oligopolistic competition. Under the previous paradigm geared to

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[17] Allen, P., Bleeke, J., Morgan, A. (1984).

[18] For an analysis of the implications of computer-aided design (CAD), see Kaplinsky, R. (1982).

mass production of identical units, every change in product implied high costs in dedicated equipment and tooling as well as high risks. Thus it was common to base competition on mere changes in appearance. In the new context, as the low cost of flexibility and dynamism is recognized in practice, the struggle for market share could increasingly take the form of rapid technical innovation with a growing segmentation of targets within the user markets. This is already happening in most branches of the electronics and information industries but it can also be observed, for example, in the automobile industry.[19] At the same time, industries, which are inevitably based on frequent model changes such as clothing[20] or printing, become amenable to adopting a continuous flow production process.

These new developments bring the fabricating industries closer to what had been a characteristic of science-based branches, such as those of the chemical industry. These, in turn, see their own potential for introducing new products further enhanced. This is due, among other things, to a reduction in the time required for research and development, thanks to ever more powerful and sophisticated microelectronics-based laboratory equipment.

Though it might seem paradoxical, this new capacity for accelerated low cost technical change could bring with it the opening of multiple spaces for dynamic, innovating small and medium firms, with quick responsiveness to market opportunities. The question is whether these will become mere test beds for high risk ventures to be taken over by the giants if successful or whether they will survive and proliferate becoming a distinctive feature of the next upswing. In any case, this latter option, the development of which would provide continuously expanding markets for the equipment, components, telecommunications and other services provided by the giants, seems a much more promising route for harmonious global growth.

Another possible consequence of the new competitive strength of technological dynamism is that mass production proper, i.e. the manufacture of standard commodities with minimum or no change, could gradually be left in the hands of small or medium firms.

D. Supply adapted to the shape of demand

Under the mass production paradigm, in which productivity and profitability depended on the growth of massive markets for identical products, pressure towards uniformity in consumption patterns was a condition of eco-

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[19] Altshuler, A. et al. (1985).

[20] Hoffman, K., Rush, H. (1984).

nomic growth. In essence it was necessary for demand to adapt to the shape of supply. The new model tends to revert this relationship. The programmability of equipment and their increasing compatibility and modularity create a new context in which diversity in final demand can multiply the opportunities for the growth of supply.

In fact, programmable capital goods are multipurpose and amenable to the most diverse configurations to suit user requirements. Furthermore, the capacity for modular expansion, which is a design target of equipment manufacturers, becomes also a rule of good design in plant engineering. Maximum plant efficiency begins to be defined by its capacity to address the specificity of the particular market environment in which it operates. Thus, systems in use could tend to be infinitely diverse, covering even the narrowest niches and the furthest corners of the market and growing modularly at the rhythm of demand.

The vehicles for achieving all this diversity are the new branches of software and systems engineering. Their task could be understood as the last phase of production of the new capital goods (where their final purpose is defined). Their activities play a double role in the expansion of production under the new paradigm. On the one hand, they allow the multiplication of investment opportunities downstream by designing the systems to cover an infinite variety of new product and service markets. On the other hand, they foster the growth of the upstream demand for equipment, components, telecommunications services and other products of the motive branches.

A NEW MODEL FOR MANAGERIAL EFFICIENCY

The diffusion of a new technological style is accompanied by a conflict-ridden trial and error process resulting in the construction of a new organizational model for the management of the firm. This process is extremely uneven and tends to spread by forced imitation under competitive pressures. The nature of the new model is shaped by the characteristics of the new technologies, in particular by those features most directly responsible for the quantum jump in productivity. In this section we shall explore some of the already visible elements of the new organizational model.

It should be noted that we are here treading much more uncertain terrain than in the techno-economic sphere. The final form taken by the organizational model at the level of the firm will be profoundly influenced by social and political factors. The general framework governing the eventual upswing will tend to favor some organizational forms to the detriment of others.

A. Systemation: The firm as an integrated network

The typical organizational model of the previous paradigm was based on a clear separation between plant and economic management. Within each, the goal was to break down every activity into its component tasks, detecting repetitive routines which could be deskilled or mechanized. It was basically an analytic model, focusing on parts and elements of the process; it led to detailed definition of tasks, posts, departments, sections, divisions and responsibilities and resulted in complex hierarchies. The new paradigm is intrinsically synthetic. It shifts the focus towards links and systems of inter-relations for global techno-economic coordination.

Although many applications of electronic equipment are generally referred to as "automation", we suggest the use of the term "Systemation" to describe the new trend towards merging all activities—managerial and productive, office and plant, design and marketing, economic and technical—into one single interactive system.[21] This term has the advantage of shifting the accent away from mere hardware and emphasizing the systemic, feedback nature of the organizational "software". We believe this to be an essential distinguishing feature between the new and the old model of firm organization.

In fact, many failures in introducing electronic equipment may be due to conceiving them as mere additions to the existing plant or office, to be incorporated with some retraining for "business as usual, hopefully better". In practice, reaping the fruits of the new technology requires a profound transformation in the internal organization of the firm and in its interconnections with markets and suppliers, tending towards a single optimized system.

This does not mean, of course, that all firm activities should be located on a single physical space. On the contrary, the power and versatility of telecommunications actually increase the degrees of freedom regarding location (allowing even the remote location of individual workers). They might in fact lead to a much wider geographical dispersion, as urban agglomerations lose their capacity to provide external economies. Nor does it imply that they would constitute a single unit. If the old corporate structure managed multi-plant, multi-country operations, the new technological infrastructure would allow the efficient management of worldwide, giant, complex and rapidly changing conglomerate structures.

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[21] An analysis of the implications of systemation for the firm (though keeping the term "automation") can be found in Kaplinsky, R. (1984).

B. "On line" adjustment of production to market demand

The concept of systemation applies beyond the frontiers of the firm and includes the possibility of establishing relatively low-cost feedback loops with the market, for acquiring information in real time. This interconnection is what gives full meaning to the potential for flexibility in output. The quickest way to convey the idea is probably through an example. Let us then look at a case in the highly volatile area of fashion.

Benneton, an Italian family firm described as one of the most successful clothing companies in Europe, is organized in a flexible network of production and distribution. At the market end it has 2500 national and international outlets, furnished with specially designed electronic cash registers which transmit on-line full information about which articles are sold, what size and color. This information is centrally received and processed for decision making at the design and production end. There, the output mix flexibility of the main production facilities is complemented by a network of 200 small firms in a sort of "putting out" system, which serves as a cushion for variations in market volume. The system reduces the response time to market changes to ten days and cuts inventory levels dramatically.[22]

This potential for reliable feedback loops with the market, could have a profound impact on management practices. It can transform production planning from a periodic "hit-or-miss" activity into a more reliable day-to-day adaptive system, tightly coupling production and markets. One of the consequences of this transformation is a change of attitude as regards inventories. From being considered a security margin required by any efficient firm, they tend now to be seen as dead weight and a prime target for cost reductions.

C. Centralization and decentralization

From what we have seen the new paradigm tends to favor both the very large and the very small. The same sorts of trends seem to appear when considering the optimal model of organizational control. To begin with, the hierarchical bureaucracies and economies of aggregation are radically questioned. The new ideal system is based on decentralized networks with local autonomy under central coordination.

In the preceding model the more complex the organization the greater the proliferation of intermediate control levels. Today, provided the adequate software, the traditional tasks of middle management can be performed by

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[22] Buxton, T. (1983).

computers. This, in itself, already "flattens" the control system bringing decisions and actions closer together. But, if this were to lead to hyper-centralization of decision-making, the main flexibility potential of the new system would be hopelessly lost. The core feature of low cost microprocessors is the capacity for providing "distributed intelligence", which, in organizational terms, means distributed decision-making. The analysis of a hardware system might help illustrate the implications. Let us look, for example, at the evolution of traffic control systems:

In electromechanical times, traffic light relay mechanisms were individually hand-set to change at prescribed intervals according to control plans drawn up at the central office, on the basis of sample counts taken by hand or instrument. By the end of the first stage of computerized traffic control, all the information was being fed into a giant computer with very complex and expensive software, provided with a giant display of the city's traffic control system, where the hyper-centralized decisions were made. Today, infinitely more flexible systems have been developed with microprocessor intelligence at each traffic light. Information on traffic flows at each intersection is collected on-line, on the spot, so each set of lights can react to demand. Further intercommunications links are provided among intersections in an area or along a main route for collective coordination, and even wider systems of information sharing between areas can be established for further interactive optimization. In this new context, the central "control" unit acquires a monitoring and coordinating role in charge of designing and evaluating the distributed intelligence network. This type of system, apart from being infinitely less costly and amenable to modular installation, is in fact far more effective and reliable than the totally centralized one.[23]

Bearing in mind the obvious limits to the analogy, it serves to make the organizational point quite clearly. A centralized decision-making system would have to be able to simulate every single possible combination of events with every single possible combination of elements and this is indeed a cumbersome and nearly impossible task. If organizations are to be diversified and flexible, to take full advantage of the new potential, they will probably tend to be based on flexible, interactive, relatively autonomous units, linked in adaptive on-line systems of coordination, under dynamic strategic management.

But, the analogy can be taken further. Because "intelligence" can be provided for single pieces of equipment, central coordination is not indispensable for efficiency in every case, and many local and niche markets, for

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[23] I owe this example to R. Suarez of EYT C.A., a Venezuelan electronics firm where a distributed system of the type described was developed.

products or services, can be covered by independent small firms or cooperative networks. And, going still further, greater worker participation, already experimented with more widely in Japan but also in some Western firms, could give better results in both human and productivity terms. All the more so because of the need for teamwork, multi-task posts and multipurpose skills. This aspect, much to our regret, is not discussed here.

Thus in organizational terms the new paradigm combines trends towards both decentralization and centralizations, towards more control and more autonomy. So, the ultimate variety of combinations can and is likely to be very wide. History in this area will be written by the social forces at play upon.

V. New technologies and new paradigm

If we accept the notion of a global transition from an energy-intensive, materials-intensive paradigm to an information-intensive one, which tends to save energy and materials, then we also have a set of criteria for assessing the diffusion prospects of new technologies in those two areas. Another set of criteria stem from the type of impact to expect from the introduction of new microelectronics equipment and of the new organizational model on the development of those two industries as well as biotechnology. Let us approach these other new technologies under the light of the new paradigm.

1. NEW ENERGY SOURCES

Energy consumption projections before the jump in oil prices were strongly exponential. It was then taken for granted that energy demand grew at least at the same rhythm as the economy. For this reason, the solution of the so-called “energy crisis” could only be seen through the development of alternative sources of supply. Conservation measures took second place, as short and medium term palliatives, while other sources came on stream.

Today, the situation has changed. Fossil fuels are once again seen as the main energy source for several decades to come. On the supply side it was seen that the provision of oil, gas and coal was strongly dependent on price levels, whereas in alternative energy sources the technological breakthroughs required for economic and massive substitution have not occurred. On the demand side, the dampening of the rhythm of growth of consumption has been little less than astonishing. In the IEA member countries, the relationship between economic growth and energy demand has been significantly altered. Before the price hike, between 1968 and 1973, a total growth of 17% in gross product was accompanied by an increase of 29% in energy consumption. Five years later, between 1978 and 1983, the same economies grew 9% while their energy consumption **decreased** 6%.[24] The scope for energy saving had been ample for a long time but, as an article in Fortune magazine put it, “energy was too cheap to worry about” and it did not pay to invest in saving it.

The conjunction of factors leading to this reduction in relative consumption is too complex to analyze here. We are however suggesting that the portion of savings directly attributable to the introduction of new technologies, until now probably small, will become the main factor in maintaining and strengthening that trend into the future.

Having arrived at a better coupling between demand and supply forecasts, both interest and research efforts have shifted to other critical areas. Should we then expect no important changes in the energy area? By no means. Simply, once the urgency which pushed the initial efforts to develop alternative energy sources has passed, the rate of diffusion of any one of them will be determined by its own capacity to be clearly competitive with the traditional sources and to be easily integrated into the prevailing energy system.

Here we shall not assess the prospects of technological breakthroughs in the various alternative sources. Instead, we will examine the manner in which the new paradigm tends to modify the patterns of energy production, distribution and consumption as well as how these new patterns affect the chances of introducing new energy sources.

In the energy sector, as in the rest of industry, information technology is transforming the methods of exploration, extraction, transport and processing. It is reducing risks and increasing precision and efficiency in each phase of activity.[25] This means that production costs in traditional fossil sources tend to be kept under control, making competitiveness more difficult for new sources.

There is, however, another trend developing in the area of electrical distribution acting in favor of diversity in sources. This trend contains what is perhaps the greatest impulse towards change in energy generation patterns.

For a long time electric utilities have been using networks to optimize supply capacity in the face of seasonal, geographic and daily variations in demand. This practice, given the versatility of electronic measurement, control and

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[24] Walker, W. (1985).

[25] For an analysis of the impact of information technology on the energy sector, see Walker, W. (1986).

supervisory instruments, has led to a simple modification with great potential consequences. Electric utilities in the U.S.A., facing growing investment costs for new generating plant, have begun to buy the excess energy generated by some of their industrial clients to feed it into the common system.[26] With this they have in fact established an interactive network.

This type of system has great potential for growth in complexity given the ease with which remote electronic control and supervisory systems permit the operation of large and complex systems. Besides, electronic meters and controls allow the setting of very adaptable price structures by type of client and time of day; the measurement and precise control of inputs and outputs at every point of the network and the calculation of selling and buying costs for each client, eventually providing him with this information on line. If this trend were to generalize a new technology system would develop in the area of energy distribution bringing forth-successive technical and organizational innovations. It would, at the same time, open ample space for source diversification, according to local comparative advantages, tending to minimize the global cost of generation, distribution and marketing.

The application of the interactive, systemic and flexible model to electricity distribution displaces the economies of scale question from the generation end, where it has been since the turn of the century, to the distribution end.[27] On the contrary, in generation equipment there is a reversal of the trend towards increasing scale and development is geared to modularity, combined generation and other means of increasing flexibility. At the same time, this system gives the erstwhile passive user an active role in the operation and development of the network. Analogous developments are occurring in gas distribution.

However, as in most things concerning this new paradigm, it is not possible to foresee the particular mix of centralization and decentralization that will eventually prevail. Linking up to a network of this kind would certainly allow large industrial users to establish their own diversified control system, optimizing energy sources according to use, calculating the best proportion of self-generation and purchasing as well as of buying and selling on the basis of relative costs. By contrast, for the great majority, options would be limited to conservation measures and perhaps to optimizing use according to price structures.

Nevertheless the road would indeed be open for a real diversification and for much greater autonomy in defining mini-energy-systems at the individ-

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[26] Business Week (1984).

[27] Walker, W. ibid.

ual, local or regional levels. These could optimize the use of the common electricity network combining it with the benefits of locally available alternative sources and pursuing the best coupling of each particular source to each particular energy use.

In our assessment, then, the impact of the diffusion of microelectronics on the energy sector is likely to be greater than the impact of new energies on the economy as a whole. By contrast with the introduction of coal for steam engines or of electricity as an energy carrier for remote and disperse electric motors or of oil for internal combustion engines, the introduction of some new energy sources for generating electricity or heat does not lead to the creation of new branches of industry nor does it induce radical changes in production equipment in the user industries. In our view new energy sources and technologies participate in the process of structural change as an additional element in the direction of greater flexibility and diversity. At the same time, energy-saving becomes an integral part of incremental innovation trajectories in both products and processes throughout the economy. A factor that could partially modify this scenario is a radical breakthrough in solar cell technology with truly dramatic cost reductions. Such an event could induce a chain of innovations associated to the massive diffusion of the direct use of solar power.

2. NEW MATERIALS

Materials science and technology laboratories have long been using electronic equipment to enhance their research capabilities and to reduce the development time of materials with ever more precisely selected properties. The diffusion of electronic equipment in industry for the design and fabrication of parts and products creates a complementary dynamics between these two spheres, facilitating the take-off of multiple chains of innovation in the area of new materials.

At first sight this would seem to contradict the characterization of the new paradigm as materials-saving. Let us begin then by a point of clarification. By materials-saving we essentially understand a trend towards increasing the productivity of natural resources. In other words, the new paradigm induces conscious efforts to take advantage of the low cost of the new information handling tools in order to minimize the quantity of material inputs required per unit of product. In the long run however there are three counter-trends which will dampen the overall rhythm of materials saving: the likely increase in the number of different products; the global increase in the production of each and the shortening of product life due to technical obsolescence.

However much the saving tendencies prevail and however much services grow in relative importance in the global product, we are not likely to witness an actual **decline** in the total use of materials at the macroeconomic level. The two most probable phenomena seem to be: a marked reduction in the **rate** of increase of materials consumption with respect to gross product (perhaps even with respect to gross industrial product) and a substantial modification in the profile or composition of materials consumption.

If we examine new materials as a whole under the light of the present paradigm change, the trend with the greatest force seems to be the one leading to a growing **diversity** in materials use. There are at least three propelling forces for innovation trajectories in that general direction: The increase in the relative cost of energy; the requirements of the microelectronic components industry and the specific demands generated by the **use** of microelectronics in products and processes.

The increase in the relative price of energy affects the cost of the majority of traditional materials. This is due to the fact that the characteristics of the previous paradigm favored the full deployment of the innovative potential in energy-intensive materials. Therefore, the rise in energy costs induces conservation measures not only in energy but also in materials. This downward pressure on demand modifies the technological and investment behavior of materials suppliers. In metals, petrochemicals, cement and paper production new trajectories of innovation are established introducing process control equipment to minimize energy use and to maximize the recycling of energy, by-products and scrap. Yet these efforts can go no further than optimizing processes and eliminating unnecessary consumption. The required transformations are energy-intensive by nature and there are limits to recovery and recycling possibilities. For these reasons the longer-term changes on the supply side might involve diverging trends for traditional and new material. On the one hand, there could be a trend towards the geographic relocation of standardized traditional materials production, in search of either comparative advantages in energy costs or savings in mineral transport costs accompanied by the greater flexibility possible by processing next to the point of extraction. On the other hand there would be a trend towards a growing diversification of production in developed countries, favoring special alloys, composite materials and, in general, deploying the range of products with greater technological appropriability and higher and less erratic prices. Thus the most powerful actors in the area of materials would have increasing interest in the diversification of the pattern of materials consumption.

The requirements of the microelectronic components industry have already led to the development of a vast supplier network for semi conductive, conductive and photosensitive materials; crystals of various types; high purity materials, processing chemicals, ceramics, resins and a growing range of specialized inputs. Doubtlessly this set of requirements constitutes a new technological system capable of generating successive radical and incremental innovations and the industries supplying the sector are poised for growth in volume and diversity with a technological dynamism parallel to that of the components industry. However, no single material is likely to experience an explosive demand, given their enormous variety and the relatively small quantities required of each. Thus, the motive industry of the new paradigm, due to its intrinsic characteristics, gives impulse to the development of a multiplicity of specialized materials.

The introduction of microelectronics in products and processes across all industries is in our opinion the phenomenon with the deepest likely influence on the pattern of materials consumption and in the direction of innovation in this field. Two developments deserve special attention: the greater degrees of freedom introduced in product design by computerized systems; the demands induced by technical change in products and production equipment.

The use of CAD-CAE (computer aided design and engineering) systems not only permits the achievement of the optimal functional and structural configuration for each product and each part but it also facilitates simulated "experiments" with a range of optional materials to select the most efficient alternative in both performance and cost terms.[28] In past practice such an optimization process would have implied prohibitive costs in testing actual prototypes. This expense was even less justifiable given the low cost of materials. The present transformation in the conditions and the economics of design is one of the factors establishing a strong complementarity between the growing capacity of R&D laboratories to create special materials and the possibility in the hands of the users to evaluate, select and specify them.[29]

In turn, the changes occurring in the functional characteristics of the products and the machines themselves tend to also change the materials demand profile. The substitution of electronic circuits for moving parts and the subsequent reduction in the size of many products displaces part of the demand for the more common engineering metals and plastics towards lighter ones as well as to those associated to the technological system around microelectronics components. At the same time, the diverse means for interfacing with the user require the development of materials which are

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[28] Mitlag, H. (1985).

[29] Queiros, S. de (1985).

sensitive to light, to touch, to sound waves, retractile materials and others with countless special characteristics for particular purposes. At the same time, radical innovations such as digital telecommunications make it possible to replace tons of metallic cables by optical fibers or satellites. Although it is difficult to forecast the actual future demand of metals for cabling when one combines the substitution trend with the probable massive growth of the network and the user base, the eventual profile is likely to be very different from that prevailing until now. And so on, in one case after another, the trend towards a greater diversification in types of materials, with a much closer coupling between specific function and selection of material is already observable in the innovation trajectories of many products. This trend is quite visible in the automobile industry.[30]

The introduction of less traditional materials also establishes feedback links with the changes in methods of production. A particularly dynamic case of interaction among interrelated innovations in products, materials and fabricating equipment is the one resulting from the introduction of ceramics as an engineering material.[31]

Summarizing then, the new paradigm creates both the technical conditions and the impulse from the demand side for a growing diversification in the pattern of materials consumption. However, as in the case of the new energy sources, new materials do not seem to be by their own weight propelling very significant transformations. The new materials do not offer, as plastics originally did, a massive range of innovation opportunities in new fabrication or molding equipment and in products to utilize them. The motivating force seems much stronger in the reverse direction.

The requirements of the new technologies associated to the use of microelectronics rejuvenate the innovation trajectories in metallurgy and polymers, give impulse to new trajectories in glass and ceramics and induce the convergence between both sets through composite materials. Thus, the competition among the various branches of industrial materials, the proliferation of alternatives and the multiplication of market niches seem a much more likely future in this field than any sort of massive displacement away from or towards any particular class of materials.

Nevertheless, the process of diversification, just as the process of adoption of the paradigm inducing it, will inevitably be slow and irregular. Thus, standardized materials are likely to maintain their overwhelming proportion of total consumption long time into the future.

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[30] Altshuler, A. et al., op. cit.

[31] U.S. Dept. of Commerce (1984).

3. BIOTECHNOLOGY

Apart from microelectronics, biotechnology is the only other clearly recognizable new technology with unquestionable revolutionary potential. The breakthrough comes with genetic engineering, which implies a quantum jump in relation to the previous development of biotechnology and transforms it qualitatively both in techniques and in range of applications.[32] The capacity to manipulate genetic information to create "new" organisms and to place the forces that guide the metabolism of life at the service of wealth production is a technological leap of unimaginable proportions.

Nevertheless, in spite of its already impressive achievements, this new technology is still in its early infancy. For this reason, in contrast with the incredible precision and degree of certainty with which experts in the area of microelectronics can forecast radical innovations and establish timeframes for introduction and diffusion, the great majority of experts in biotechnology tend to warn about the conditions of uncertainty that preside over any of their forecast. This is the difference between an embryonic paradigm and one already crystallized in its direction and in its technical and economic parameters.

If we were to force an analogy with the evolution of microelectronics, it could be said that biotechnology is at the valve phase. In other words, the applicability of the basic theoretical principles has been demonstrated and, on this basis a first set of innovations is introduced, development trajectories are established and a range of possible applications is identified. From then on technological systems of substantial economic importance develop, but they are submitted to the logic, the parameters, the imperatives and the externalities of the prevailing paradigm. This means that, in spite of its impact upon certain branches and activities, much time is likely to elapse before the revolutionary potential implicit in genetic engineering is translated into technological breakthroughs capable of drastic cost reductions and massive repercussions over the economy as a whole.

Nevertheless, every analogy has limitations and dangers and these are particularly risky in the case of historical analogies. Could one not say that at present there are certain conditions, such as the reduction of development times and the increase in R&D funds, which could significantly accelerate the evolution of that technological potential and shorten the time required to reach the equivalent of the "integrated circuit stage"? These factors do require that the door be left open for the possibility of an explosive, expansive and extensive development. We think however that there are at least

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[32] A thorough analysis of the field of biotechnology is found in Faulkner, W. (1986).

three factors playing against this possibility. In terms of the scientific knowledge base, compared with physics and chemistry, biology is a much less developed science, its object is more difficult to study and its discoveries are less generalizable. This suggests the unavoidability of relatively long periods of acquisition, systematization and testing of the required new knowledge. In techno-economic terms, bioprocesses are still in the phase of solving the basic technical problems. This means costs are still relatively high and in the majority of cases where there are alternatives bioprocesses are not competitive. Breaking the cost barriers takes a lot of time and much productive experience with which to identify the intrinsic parameters of biotechnological trajectories. For this same reason, in terms of probable investment patterns it is reasonable to expect that faced with the vast range of options related to information technology, with easily identifiable market opportunities, with proven and effective incremental trajectories and increasing externalities, investors would not massively turn towards the risky and semi-explored biotechnology route. Thus, though it will probably be central for some firms or branches, it is likely to play a secondary role in overall investment. Furthermore, the shortening of development and innovation times is in no area more evident than in microelectronics. Having said this, it must be stressed that the importance of biotechnology is bound to increase in certain points of the productive system. What we believe safe to suggest is that its evolution will be strongly marked by the determinants of the microelectronics-based paradigm.

In this overall exploratory view we are therefore interested in trying to identify the forces that could influence the evolution of biotechnology and shape the manner of its insertion in the productive fabric woven by the new paradigm.

A. Complementarity within the productive system as a whole

Seen globally, it can be said that microelectronics and biotechnology complement each other. The main direct impact of the microelectronics revolution is upon services and the fabricating industries. In both there is a radical change in the methods of production but essentially there opens up a very wide spectrum for generating radically new products. By contrast as regards agriculture, mining and the primary sector, in general, as well as in the chemical branches, the impact is concentrated in production equipment and methods. The promise of new products or of important modifications to existing ones is in these sectors offered by biotechnology. In this sense the development of biotechnology fills a void left by the constellation of information technologies.

B. Complementarity at the level of the ideal model of production

The design-production integration occurring in the new best practice model for the fabricating industries translates into research-production integration in the area of biotechnology. Its effectiveness depends upon the use of sophisticated electronics equipment in the research laboratories and in production process control. The result is again competition based on scientific and technological dynamism.

As far as the ideal model of production is concerned, industrial bioprocesses are highly compatible with the trajectories defined by the new paradigm. Bifani[33], for instance, points out the following as important advantages of biotechnology as compared to traditional chemical processes: Energy saving, given that bioreactions are based on renewable biological energy and take place at lower temperatures and pressures; less environmental damage; the possibility of smaller, simpler and less costly production facilities, and finally, greater flexibility. These features clearly coincide with those of the model based on microelectronics.

No one can predict however whether these characteristics will prevail in the medium term given the increasing control of biotechnology development by the chemical industry giants. The experience accumulated by these firms in large scale processing pushes them to insist—either by mental blockage or vested interest—in applying the old model.

A specific aspect in which the two technologies are complementary is in the increasing tendency to recycle and to reprocess effluents in the processing industries. Until now social pressures against environmental pollution have had to be taken up by governments and turned into mandatory regulations. In most cases investment for environmental protection was a net cost with zero return. As we have seen, though, the new paradigm tends to steer processing plant design towards the closed-cycle ideal, with maximum recycling and minimum effluents, in order to increase the productivity of all material and energy inputs. The possibilities offered by biotechnology for using microorganisms to filter and recover reusable or marketable by-products[34] converge with the new model. Both technologies contribute to a radical modification in the economic conditions for this type of investment turning it into a new means of increasing global profitability.

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[33] Bifani, P. (1986).

[34] For the case of the pulp and paper industry see: Science Council of Canada (1985)

C. Technological convergence: Bioelectronics

There is also a particular line of development which fuses both technologies. Research in what has been called bioelectronics directed to using living cells to make "biochips" is the object of increasing interest. There are already laboratory prototypes of memory chips with at least a hundred thousand times more storage capacity than that achievable with present chips and a considerably greater speed of operation. Another line of development is the field of biosensors for process control instrumentation. However, this type of application seems to be more directly framed within the trajectories of microelectronics itself than in what could be understood as the natural trajectories of biotechnology.[35]

D. Factors which can influence the direction of biotechnology

The possible fields of application of biotechnology are incredibly vast. Yet, any chosen application demands substantial investment in R&D. This implies that some routes will have to be followed to the detriment of others and that the choice of optional routes will depend on the priorities of the decision making agents.

Warhurst[36] has, for instance, suggested that developing countries could be interested in what she calls open-system bioprocesses as opposed to closed-systems. The former are those which take place in the natural environment and must therefore be adapted to the ecological conditions where they are made to occur. Examples are bacterial leaching of mineral ore dumps or pest control in agriculture through the manipulation of the predator cycles. The chemical industry, by contrast, would tend to favor the development of closed processes.

Even in agricultural research one can already observe a certain bias in biotechnology research priorities. An example is the development of pesticide resistant plant varieties rather than pest resistant ones. This would appear as an attempt to hybridize biotechnology with the "Green Revolution" in order to strengthen the markets of the latter.

Legislation allowing patenting is another element which, at the same time as it fosters interest in R&D investment, pushes in the direction of projects promising greater appropriability.

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[35] Naito, K. et al. (1985), pp. 46-7.

[36] Warhurst, A. (1986), especially Ch.2, where the bias taken by biotechnology in the various fields of application is examined. See also Warhurst, A. (1984).

To sum up, biotechnology fits very comfortably within the new paradigm. Its development, requiring intensive use and processing of information, expands the markets for the main branches of the new model and it plays a complementary role in technical and economic terms in several sectors. For these reasons, its expansion will be favored by the generalization of the new paradigm. However, apart from the shaping influence that microelectronics might have, the final direction eventually taken by biotechnology as a possible autonomous paradigm into the future will depend on social, economic and even geopolitical factors which are already at play.

VI. Technological transition and development prospects

The first reaction of policy makers in developing countries when confronted with such massive technological transformations is of hopelessness. It would seem that the technological gap is irrevocably widening. Yet, perhaps this is not necessarily so.

The model presented here offers a way of approaching the analysis of the pattern of technical change in a given period, its forms of evolution and interrelation and of interaction with economic, organizational and socio-institutional elements. If this framework of analysis is accepted, then discontinuity in technological evolution also leads to discontinuities in the conditions for development. Transition periods are phases of “creative destruction” not only in production facilities but also in the area of institutions and in the policies that have guided national and world development. They are periods of reassessment and innovation, of experiments and social creativity upon a new techno-economic space, the contours and main features of which are recognizable and could be used as a platform to attempt a change in direction and a leap forward.

Under these circumstances, each country is faced with two terrains for creative action. One is the participation in the construction of the new set of arrangements and institutions on the international level. The other is the redesign of the national development strategy and the institutions capable of carrying it out. Though fully conscious of the powerful influence the eventual international framework will have on development prospects, we shall only refer here to the question of reassessing national strategies.[37]

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[37] For brief comments on some of the possible scenarios at the international level, see Perez, C., op. cit., pp. 456-60.

RETHINKING THE ROUTE TO DEVELOPMENT

From what has been said no productive sector is immune to the influence of the new technologies. This implies that, into the future, most of existing plant is technically and organizationally obsolete. And with this, so are the notions and guidelines that resulted in its establishment. Hence the productive structure of each country from one end to the other must be reexamined under the light of the new conditions.

To affirm this begs the question of how to go about it. The only answer is that the new routes will necessarily result from a massive process of social creativity. The important thing is to point out that the space within which to invent them is new and different. Here we shall limit ourselves to indicating some general guidelines stemming from the features of the new paradigm. These can serve as a starting point to rethink development strategies.

We must, however, begin with a warning. As is well known the Third World is no more than a category of analysis. When trying to establish a new direction, differences in relative development are crucial. The availability of qualified human resources, for instance, can determine both the capacity to design an imaginative strategy and the possibility of successfully carrying it through.

In the present transition these differences are especially significant. The new paradigm favors flexibility, adaptation to particular conditions, integration of activities and profiting from diversity. This suggest that taking best advantage of the new paradigm is dependent upon the capacity to get the best value out of each country’s specificity. Thus, recipes should be avoided. A successful strategy in one country cannot be transferred to another. Differences in facilitating conditions as well as in restrictions demand case by case analysis. For this reason, the ideas presented here are only intended as ways of approaching the problem.

A. The systemic view

Whatever the limitations and possibilities of each country, the all-pervasive nature of the new technologies calls for using new criteria for a global reassessment of the role and prospects of every single sector of the economy, from agriculture and mining to services and for identifying every possible form of interlinkage. Given the advantages offered by integrating various activities in networks and systems, it would seem inappropriate to stick to the traditional practice of dealing separately with the primary, the industrial and the service sector. Higher efficiency and comparative advantages will more than ever depend upon interaction between activities within production complexes and between these and the internal and external markets.

The goal of integration was always present in past strategies, but, given the restrictions imposed by mass production, it was little less than impossible for small countries. The new model provides the technical means to pursue it successfully. One of the main new challenges consists in selecting ways of selectively taking advantage of this new opportunity, especially as regards possible chains of transformation on the basis of natural resources.

B. A new approach to the domestic market

One of the main headaches for developing countries under the mass production paradigm has been the incapacity of domestic markets to sustain optimal scales of production. This circumstance left two options: either to reach competitiveness with export markets or to erect high tariff barriers to compensate for high levels of idle capacity. The flexible production model, with smaller scale multi-product plants helps at least partially to overcome this old obstacle.

In this context it is important to note that the new forms of organization can, by themselves and with a minimum of new equipment, significantly raise efficiency. Moreover, experience acquired after reorganization is the best source of criteria for selecting the most adequate and truly indispensable new equipment to incorporate. This has been shown again and again in Japanese plants and is in agreement with the results of a study conducted in the UK.[38] The reorganization route can serve to revitalize and modernize certain sections of the existing industrial basis with modest investment costs.

Another opportunity stems from the flexibility offered by microelectronics-based technologies to adapt plant configuration and product design to climatic, cultural or any other type of conditions specific to a country or region. This could contribute to the demise of the traditional imitative consumption patterns. It is indeed paradoxical that the adoption of a new productive model—as foreign in origin as the previous—could result in the revalorization of local creativity and in the rescue of lost patterns of cultural identity.

Another feature of the new paradigm that can be used to advantage is its capacity to contribute towards the long desired decentralization of eco-

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[38] Dempsey, P. (1984). See also Schonberger, R. (1982).

nomic activities. The extension and modernization of telecommunications networks in each country can create favorable conditions for the geographic dispersion of public services, government functions and private—particularly banking and financial—services. This would tend to equalize externalities over the whole territory and, added to the diseconomies of aggregation appearing in most great urban centers, this feature could help to reduce the disequilibrium in geographic development patterns.

C. Leaping to the new technologies

Up to now we have discussed some of the new degrees of freedom provided by the new technologies under the assumption of attempting an intelligent use of imported equipment. It is evident however that full advantage can only be reached through a certain level of local technological capacity in equipment, software and systems design. We have already referred to the key role of technological dynamism in the new paradigm and the intermediary function performed by software and systems engineering firms in bringing the adaptive potential to practice. This means that taking true advantage of the new model requires a leap unto the new technologies.

Under prevailing notions this would seem unthinkable. Product cycle theory holds that developing countries only have access to competitive production in the maturity phase of products and processes. And this received ample confirmation in the 1960's and 1970's with the relative success of "industrial redeployment" and of some export-led industrialization strategies. Nevertheless, under the light of the model of technological evolution we have been discussing here, the process can be interpreted within a more dynamic context. A first interpretation could be that once the innovative trajectory of a product or process is exhausted, competitiveness depends upon the relative costs of the inputs and labor required for production. The corollary would be that the more mature the technologies the greater the development chances. This statement assumes, however, that the only viable option for development is traditional technology transfer. This can more or less be said to be true in the late phases of diffusion of a paradigm.

With a new paradigm though the situation is different. One could say that the more incipient a technology the greater the possibilities of autonomous entry, given a certain level of endowment in qualified human resources. The very early phases of evolution of a new technology are by definition a learning process. Previous production experience is in part useful and in part a hindrance, whereas knowledge of the sort acquired in the academic world could be indispensable. Moreover, barriers to entry in cost terms tend to be lower in the early phases than they will eventually become. This serves to explain the proliferation of small firms that characterized the initial development of the mini- and micro-computer industry as well as that of “plug-compatibles” in the 1970’s. As a technology evolves and its markets grow, acquisition of “know-how” inside firms gradually erects growing barriers to entry; some of the initial firms disappear and others rise in the ranks and remain in the race.

We have suggested that in the area of microelectronics these possibilities appear in successive waves, due to the characteristics of the design process. Today, the proliferation of small scale experiments is occurring in the software and applications areas. To the surprise of many, Latin America is participating in this phase. In some cases such as telecommunications and data processing in Brazil the impulse has come from a deliberate government strategy. In other countries firms with locally designed products have appeared spontaneously with no special government support. This is no miracle. Conditions for entering and accumulating technological capacity in equipment, software and systems design are today favorable, if the points of entry are carefully selected.

What does have to be understood is that the effort has to be sustained and concentrated. Once in the race, technological dynamism has to be maintained at the rhythm of the international frontier. This, in countries lacking a risk capital market and an adequate network of industrial services, requires a strong policy of promotion and support, capable of stimulating research and innovation and providing appropriate externalities.

Creating an appropriate framework does indeed demand a large dose of inventiveness. Yet, these new opportunities for domestic technology generation and accumulation represent, in our view, the most important phenomenon of the present transition. With a view to advantages in the longer run future it is possible to profit from these opportunities in the area of biotechnology that is still in the definition phase. It is, however, absolutely indispensable to act in the short term regarding the acquisition of technological capability in the field of applications of microelectronics.

The transition therefore opens the way to begin as of now an endogenous process of generation of technological capacity. This would constitute the focal point for pursuing a greater degree of autonomy in the use of the new potential for national goals. The selection of areas of concentration and forms of promotion has to be made on a case by case basis, within the range of the viable and according to the resources and conditions of each country. It would seem, however, that no national strategy can afford to let this opportunity pass ignored.

D. New strategies, new instruments

We are likely to encounter a wide variety of models of development due to the specific proportions of domestic generation, imitation, adaptation and imports of technology or attraction of foreign investment considered optimal by each country, including the alternative of protecting some sectors against technical change. Nevertheless, the design and implementation of any particular model under the present conditions demands direct attention to the technology question. Technological forecasting—global, by branches and by products—becomes an indispensable tool for planning. Technological assessment becomes an essential activity in development banks. The new training and knowledge requirements have to be taken into account in the plans of the educational system, and so on and so forth.

This puts into question the traditional separation between technology policy and economic policy. The two aspects become inseparable and that implies profound institutional transformations and bold innovations in policy instruments.

OBSTACLES AND OPPORTUNITIES

In developing countries, the experience of long decades of frustration has sharpened the ability to identify obstacles and limitations. The most natural attitude in the present circumstances is to simply add the new obstacles to the old. For this reason, we have considered it convenient to concentrate in pointing out some of the new opportunities in the hope of fuelling a process of renewal of development thinking.

We do not pretend there are no obstacles; we are simply suggesting that they are probably different from the previously existing ones. Nor do we pretend it is easy to face the multiple task of assimilating the impact of a global technological transformation, constructing a coherent strategy for redirecting development and inventing new institutions and instruments to carry it out. Much less do we ignore that facing the most severe manifestations of the present economic crisis is the most urgent of tasks.

Nonetheless we believe that preparation for the future cannot be postponed. Once a world upswing is unleashed, development prospects for each country will depend not only on the level of development attained in the previous wave but also in having been capable, early enough, of creating the conditions for taking best advantage of the new.

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