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Innovation, Productivity Growth, and Structural Change

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FOREWORD

This Collaborative Paper is one of a series embodying the outcomes of a workshop and conference on *Economic Structural Change: Analytical Issues*, held at IIASA in July and August of 1983. The conference and workshop formed part of the continuing IIASA program on Patterns of Economic Structural Change and Industrial Adjustment.

Structural change was interpreted very broadly: the topics covered included the nature and causes of changes in different sectors of the world economy, the relationship between international markets and national economies, and issues of organization and incentives in large economic systems.

There is a general consensus that important economic structural changes are occurring in the world economy. There are, however, several alternative approaches to measuring these changes, to modeling the process, and to devising appropriate responses in terms of policy measures and institutional redesign. Other interesting questions concern the role of the international economic system in transmitting such changes, and the merits of alternative modes of economic organization in responding to structural change. All of these issues were addressed by participants in the workshop and conference, and will be the focus of the continuation of the research program's work.

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INNOVATION, PRODUCTIVITY GROWTH, AND STRUCTURAL CHANGE

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This paper is concerned with three broad topics: first, changes in the conditions for productivity growth during the last decade; second, industrial innovation as a factor of productivity growth; and third, productivity as a factor of structural change. A considerable amount of research has been done on each of these areas, particularly through the work of IIASA's Innovation Task from 1978 to 1982. This unique team included researchers from the Soviet Union, the United States, the GDR, the FRG, Austria, Japan, and the United Kingdom, and I hope that some of its work will be continued in the new IIASA program on Economic Structural Change.

In recent times, two main processes have had a marked effect on structural change in both the world economy and also in individual national economies:

1. The radical change in the resource situation during the seventies: the most significant results of this change are an upward revaluation of natural resources and a relative devaluation of existing products and technologies.
2. The emergence of a new combination of productive forces, made up of such basic innovations as microelectronics, information technology, flexible automation, new energy options, modern biotechnology, and new materials.

Under the pressure of the altered resource situation, this new combination of basic innovations is likely to trigger off a radical innovation push in the next few years that will produce a new global economic structure with a qualitatively higher level of productivity. The revaluation of natural resources and devaluation of existing products and technologies is the reason for the current "revolution in value," to use the terminology of Karl Marx, which is deeply influencing structural change throughout the economies of the world.

Figure 1 shows the development of this "revolution in value" during the last ten years for oil, for other primary raw materials, and for manufactured goods. The increase in the relative value of natural resources is demonstrated by the movement of real prices for oil (currently the main primary energy resource, accounting for 42% of global supplies), which were ten times higher in 1983 than in 1973. (Compare, for example, the corresponding increase of only 30.5% over the entire preceding decade.) The decline in the relative value of manufactured goods and production technologies is reflected in the fact that standardized products are currently at their lowest price levels for thirty years. It is well known that today it is almost impossible for the producers of machine engineering based on traditional electronics to make any profit on the world market. On the other hand, producers of machine engineering who have been able to incorporate the achievements of modern microelectronics into their products have been rewarded with very high growth rates in both production and value added.

Table 1 shows the very high growth rates for manufactured goods that are heavily dependant on microelectronics. For the second and third generations of industrial robots, the average annual growth rate was 34% from 1972 till 1980. Average annual growth rates for other fields were 56% for computerized NC machines, 69% for computer aided design (CAD), 40% for computer aided manufacturing (CAM), and 30% for flexible manufacturing systems.

Currently, the growth of value per unit of natural resources is one hundred times higher in the newer, microelectronics-based areas of machine engineering than in traditional parts of the industry. This simultaneous revaluation of natural resources and devaluation of existing products and technologies has so far been dominant over the opposing effects of the emerging new combination of basic innovations, which will tend to restructure the world economy and increase the growth of productivity. This is the reason why productivity growth rates in all the industrial countries have been declining in recent years (see Table 2).

The present decline in productivity growth rates, which is of course not conducive to equalizing productivity levels worldwide, cannot be explained simply in terms of the absolute levels of productivity reached. Instead, we need to look for other fundamental factors that tend to produce similar effects in all countries, regardless of their level of development. From the historical point of view, we can point to the fact that the potential for increased efficiency created through the basic innovation of the forties and fifties has been largely exhausted; from the standpoint of the present there appears to have been a lack of basic innovation in recent years to launch a new wave of productivity growth. The most important growth industries of the last thirty years have been chemicals, electrical engineering, automobiles, plastics, petroleum products, and aircraft. The basic innovations that were the driving forces of productivity growth during the fifties and sixties are shown in Table 3. One of the main features of basic innovations is that production units using them are able to achieve higher productivity growth rates than those working with traditional technologies. But these growth rates begin to decline as soon as the potential for greater efficiency is absorbed. Figure 2 shows the development of the efficiencies of the main growth industries in the FRG during the fifties and sixties, and their tendency to decline in the seventies. Similar developments over this period can also be observed for the the United States, Japan, the United Kingdom, the Soviet Union, and the GDR.

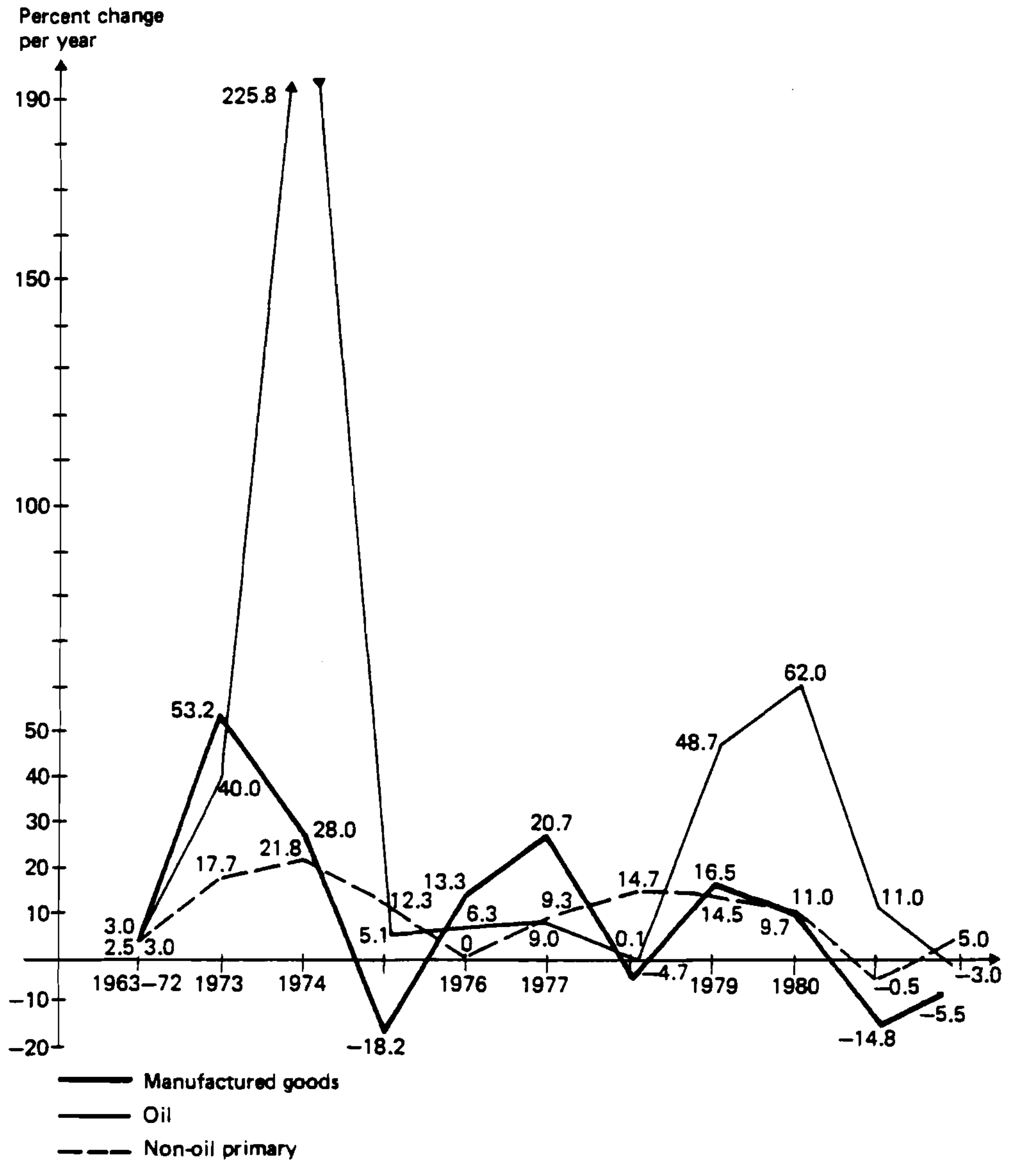

Figure 1 Price changes on the world market for manufactured goods, oil, and other primary raw materials, 1963–1982. (Source: *Financial Times*, October 11, 1982.)

Future productivity growth will depend very heavily on the ability of society to utilize new basic innovations, which will emerge over the next two decades from the following areas:

Table 1 Basic innovations of flexible automation.

Innovation	Year first commer-cialized	Length of take-off (years)	World growth rates (%)	
			1972–80	1980–90 (forecast)
NC-machine	1955	17	35	20–30
Industrial robot	1962	10	44	25–30
Computer-aided design (CAD)	1965	7	69	40–50
CNC-machine	1969	3	56	40–45
Computer-aided manufacturing (CAN, DNC)	1967	5	40	30–35
Flexible manu-facturing (FM)	1969	3	30	35–45

Table 2 Industrial productivity growth rates in major developed countries, 1963–1981.

	IPGR		Change in IPGR	Change in OGR	IPGR			
	1963–73	1973–77			1978	1979	1980	1981
Planned								
USSR	5.6	4.8	−0.8	−1.4	3.5	2.0	2.8	3.2
Poland	5.9	8.0	2.1	3.6	4.8	2.9	1.0	−10.1
GDR	5.3	5.3	0	−0.3	4.2	4.0	4.5	4.3
CSSR	5.4	5.6	0.2	−0.7	4.1	3.3	3.2	1.8
Hungary	4.6	6.3	1.7	−0.2	5.2	4.3	1.2	4.1
Bulgaria	6.7	6.7	0	−4.3	6.4	4.2	2.9	2.8
Romania	7.0	7.8	0.8	0.1	6.8	5.8	3.9	2.6
Market								
USA	2.1	1.0	−1.1	−3.5	1.8	2.0	−1.0	2.9
Japan	8.9	3.7	−5.2	−9.5	6.3	8.4	4.9	0
FRG	5.3	3.6	−1.7	−4.4	0.8	4.7	0.8	0.7
France	5.2	4.0	−1.2	−3.4	3.4	5.3	1.3	−2.4
UK	3.9	1.3	−2.6	−3.6	1.4	1.2	−3.7	5.7
Canada	3.6	0.8	−2.8	−4.4	6.2	0.4	−1.6	1.2
Italy	5.6	0.8	−4.8	−4.1	3.2	−6.3	5.0	0

Sources: *Monthly Bulletin of Statistics*, United Nations, New York, October 1982; *Statistische Jahrbücher der Mitgliedsländer des RGW*, Moscow (in Russian).

1. The electronics complex, including flexible automation, telecommunications, office automation, and computerization of all spheres of the production process.

Table 3 Basic innovations that drove productivity growth during the fifties and sixties.

Degree of impact	Industry	Innovation (year)
Complete	Plastics	Plexiglass (1935), neoprene (1931), perlon (1938), polyethylene silicone (1946), crease-resistant fabrics (1932), terylene fibers, water-resistant cellophane (1936), ball-point pens (1938)
	Petrochemical	Catalytic petrol separation, anti-knock petrol (1935)
	Aircraft engineering	Radar (1934), rockets (1935), helicopter (1930), jet engine (1941)
Heavy	Chemicals	Insulin (1922), kodachrome (1935), penicillin (1941), streptomycin (1944), detergent (1928), tungsten carbide (1926)
	Electrotechnology	Radio (1922), synthetic polarizer (1938), fluorescent lamps (1934), television (1936), tape recorder (1937), cine camera (1953)
	Automobile engineering	Power steering (1930), hydraulic clutch (1937), automatic gearbox (1938)
	Precision tool making	Giro compass (1909), zip fastener (1932)
Marginal	Polygraphic	Xerography (1950)
	Iron and steel	Continuous warm rolling (1923), continuous steel casting (1948)

2. The energy complex.
3. Modern biotechnology.
4. Appropriate technologies for the industrialization of the developing countries.
5. Social and technical innovations in the fields of human settlement, communication, health care, and relaxation.

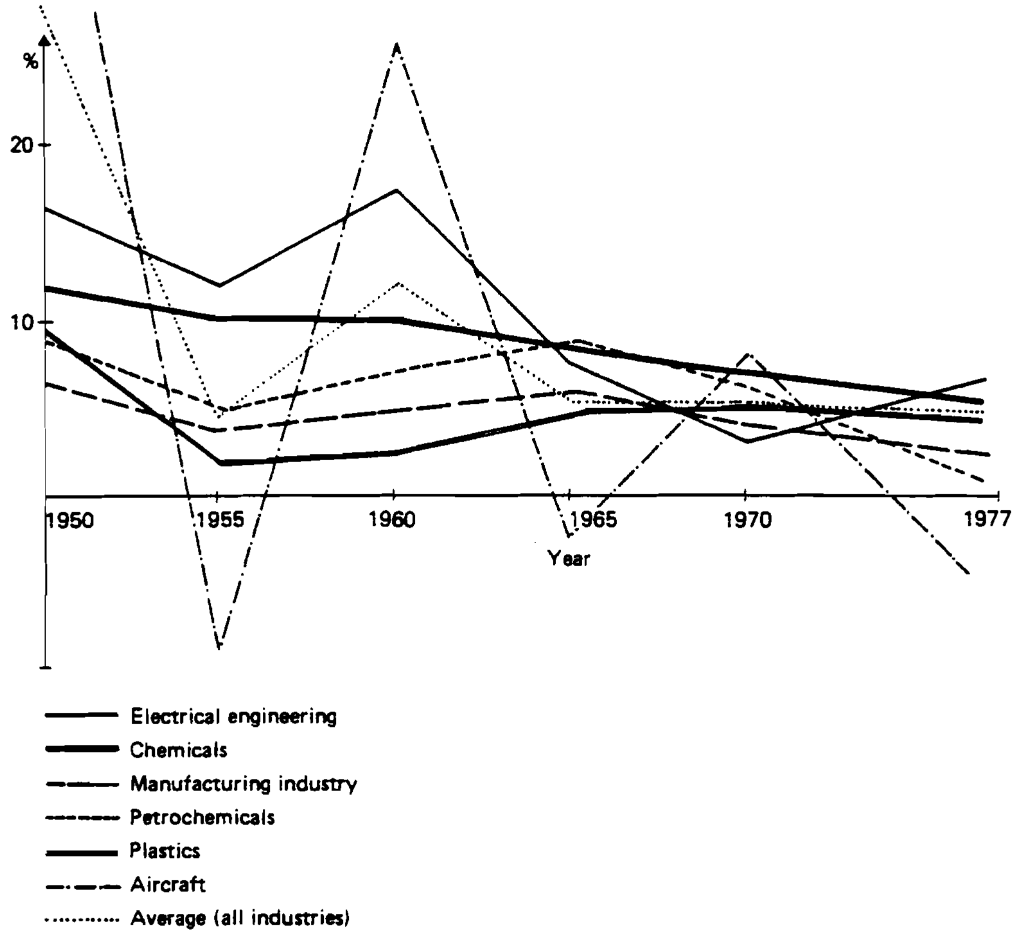

Figure 2 Labor productivity in various branches of industry in the FRG, 1950–1977.

One of the most important influences on productivity growth will be microelectronics. Figure 3 clearly shows that those industries that are closely influenced by microelectronics have significantly higher levels of productivity growth than the average.

Future productivity will depend very much on the creation of a new potential for greater efficiency through the *basic* innovation carried out now. But there are many reasons why production units show a strong tendency to follow policies of improvement and incremental innovation rather than actively supporting basic innovation. Table 4 lists some of the factors that support this attitude at the level of the individual firm.

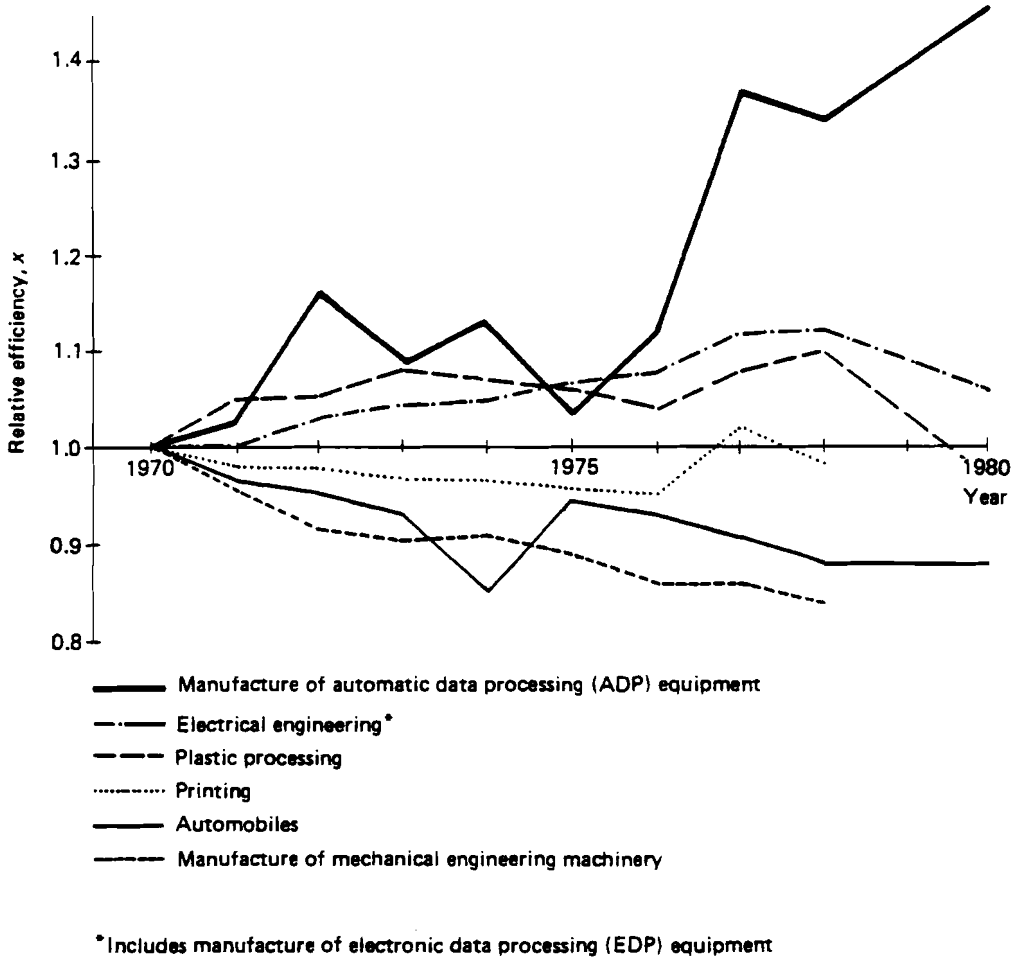

Figure 3 Relative efficiencies of various branches of industry in the FRG in terms of labor productivity, 1970–1980. (Source: Federal Bureau of Statistics and own calculations.)

However, recognizing and countering the short-run pressures on firms to pursue improvement or incremental innovation policies is only part of the solution. To achieve the right balance between improvement and basic innovation within a given production unit or national economy we must improve our understanding of the relationship between innovation and efficiency. Innovation is not a goal in itself, and it is not possible to measure the rate or importance of innovations by calculating their frequency or by identifying the input and output characteristics of a particular innovation. Average efficiency coefficients, such as labor productivity, capital coefficients, or the labor intensity of capital, are unable to reflect the impact of innovation in a clear form. We also have to bear in mind that the relative importance of the different input and output characteristics has changed during recent years.

Table 4 Implications at the company level of adopting either improvement or basic innovation strategies.

Area of impact	Implications of policy	
	Improvement	Basic technological change
Marketing	Demand relatively low, well-known, and predictable Risk of failure low Acceptance rapid Well-known marketing used	Demand high and relatively unpredictable Risk of failure high Acceptance initially slow New marketing system necessary
Production	Existing labor, skills and patterns of cooperation used to a maximum Significant risk in quality and process planning	Existing labor, skills and patterns of cooperation becoming obsolete Problems of quality, costs, and effects new and unpredictable
Research and development	Existing R&D potential used Basic research not needed R&D risk relatively predictable	Advanced R&D potential needed New research fields and disciplines needed R&D risk high and unpredictable
Management	Familiar management systems used and well-tried organizational solutions adapted	New management skills and organizational solutions needed
Society	Unpredictable problems relatively rare or nonexistent	Legal and social acceptance unpredictable

To understand the nature of the innovation process, it is important to distinguish between two kinds of efficiency:

1. *Dynamic efficiency*: the efficiency of the particular production unit that has adopted the innovation, denoted by $e(i)t$.
2. *Average efficiency*: the efficiency of the entire production field, denoted by $\tilde{e}(t)$.

We then define the relative efficiency, $x(t)$, as the ratio of the dynamic to the average efficiency

$$x(t) = \frac{e(i)t}{\tilde{e}}(t)$$

The dominance of particular types of innovation (basic, improvement, or pseudo-innovation, the roles of product and process innovations, the sorts of barriers and stimuli typically encountered, and the most appropriate management skills and tools all very much depend on how widely the innovation has been adopted and how great is the efficiency gap between the innovating production unit and the production field as a whole. With the help of the relative efficiency coefficient we can understand better the probable direction of developments in a company, an industry, or a country.

For the innovation strategy of a firm or a country, two kinds of information are decisive:

1. What is the position of the production unit concerned in the development of efficiency of the production field of which it is a part?
2. Are options available to improve or to maintain that production unit's position in its own field, or should the unit abandon the production field altogether?

To acquire such information we need to carefully investigate each different stage of the innovation cycle in order to identify appropriate strategies of growth, change, and survival. I believe that it is useful to distinguish the following five stages in the development of a production unit that has adopted a particular innovation: take-off, rapid growth, maturation, saturation, and stagnation.

Efforts are underway to confirm our hypothesis about the importance of different kinds of innovation with the help of empirical data. For the purposes of this paper, our findings concerning the "employment" and "productivity" effects of different kinds of innovation are especially interesting. These two effects have been identified with the help of data gathered by the Institut für Arbeitsmarkt und Berufsforschung, in Nürnberg, FRG. The data provide information on 2266 technological changes within 909 firms from four industrial branches (plastics, the metalwork industry, the food industry, and the wood and furniture industry) in the FRG during the period 1970–1973. By the "employment" effect of innovation we mean here the ratio between the numbers of jobs created and eliminated as a result of technological change. The "productivity" effect is the contribution of the different kinds of innovation to labor productivity growth as a result of technological change.

Figure 4 demonstrates that basic and major improvement innovations have the highest employment effect, and that they are also responsible for a high contribution to productivity growth. Within these categories, the implementation of new products had the highest single employment effect, creating 31.7 times more new positions than it eliminated. However, its contribution to labor productivity growth through technological change was a relatively low 2.4%. This is fairly typical in the take-off stage of the innovation cycle. The extension of innovations – an activity in the rapid growth stage of the innovation cycle – contributes significantly to labor productivity growth (29.6%) and also has a high employment effect (12.6 times). Major improvements in the quality of the product contribute 6.8% to labor productivity growth and create 5.9 times more jobs than they eliminate. It is important to realize that

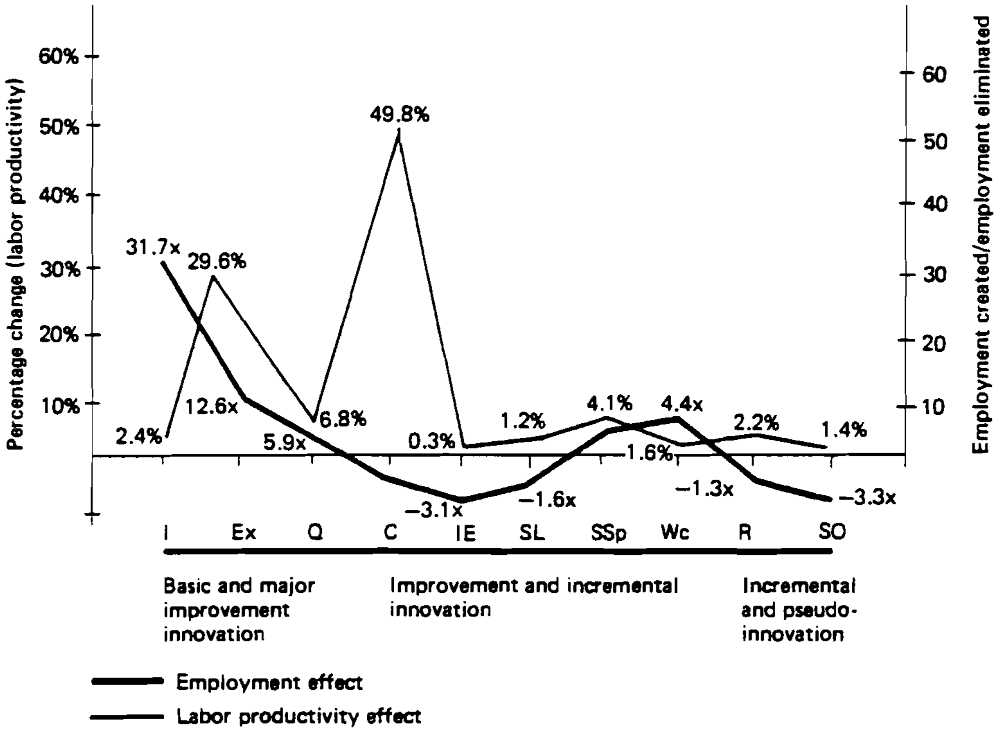

Figure 4 The employment effect and the labor productivity effect of different kinds of innovation. (I, implementation of new products; Ex, extension of capacity; Q, new quality of products; C, cost reduction innovation; IE, improvement of efficiency; SL, reduction on shortage of labor; SSp, reduction on shortage of space; Wc, improvement of working conditions; R, replacement of product equipment; SO, shortage of orders.

basic innovation does both: it creates many more jobs than any other type of technical change and it contributes significantly to productivity growth.

Improvement innovations devoted to cost reduction naturally produce the highest contribution to labor productivity growth (49.8%), but they are also the starting point from which the employment effect becomes negative. These innovations eliminate 1.4 times more jobs than they are able to create. Only in the case of improvements in working conditions and production space does the employment effect become positive again, for obvious reasons. But in other types of technical change associated with medium improvement and incremental innovation, which occur in the fourth phase of the innovation cycle (saturation), the employment and productivity effects are very low. For example, the short-term reaction to a shortage of workers has an employment effect of only -3.3 times and a productivity effect of only 1.4%.

This proves our hypothesis that a low employment effect is not so much caused by the development of labor productivity – which is what some of our colleagues have claimed up to now – as by the dominance of medium improvement and incremental innovation (at the expense of basic innovation) in economic activities. This could also explain why, at the present time, some of the industrially developed market economies are faced with both a decline in productivity growth rates and high rates of unemployment.

The main conclusion that can be drawn from our mental model of the innovation cycle is that a high degree of efficiency and production output is no insurance against future problems caused by the emergence of new technological options. In fact, a production unit that currently displays a very high degree of efficiency, a large market share, and a high degree of standardization and vertical integration may very well find it extremely difficult simultaneously to secure its future economic vitality, to search for new ways of satisfying a latent demand, or to supply an existing market with better and less expensive alternatives. Classic recent examples of sectors that have missed the right moment for change are the shipbuilding and steel industries. The main concern of the innovation policy makers of a country or a corporation should be to maintain the right mixture of business activities in the different stages of the innovation cycle. Countries or firms that concentrate on innovation activities in the maturation or saturation stages will lose, in the foreseeable future, their advantages in terms of dynamic efficiency and will run into stagnation.

One of the most important lessons from the management of innovation in all the industrialized countries is the necessity for close interdependence between government innovation policy and company strategy. Government actions to stimulate innovations have to take into account not only the way that the attitudes of production units will vary as their efficiency develops but also the adverse impacts on working conditions, environmental standards, and the health of the population that may arise from the application and diffusion of new technologies. On the other hand, the corporations themselves must improve their ability to find appropriate responses to national needs and foreseeable shortages, and to avoid not only primary but also secondary and tertiary adverse effects of the innovations they employ. This system of government-company interdependence is of major importance but is still far from perfect.

NOTES

1. Many of the ideas presented here are the result of joint work with Prof. Dr. Heinz-Dieter Haustein at IIASA and in the GDR.
2. See for example Haustein and Maier (1980, 1984), Haustein *et al.* (1981), Maier (1982), Maier and Haustein (1980), Maier and Robinson (1982), and Roman and Puett (1983).

3. "If the social capital experiences a revolution in value, it may happen that the capital of the individual capitalist succumbs to it and fails, because it cannot adapt itself to the conditions of this movement of values. The more acute and frequent such revolutions in value become, the more does the automatic movement of the now independent value operate with the elemental force of a natural process, against the foresight and calculation of the individual capitalist ... and the greater is the danger that threatens the existence of the individual capitals." (Karl Marx, *Capital, A Critique of Political Economy*, Vol. II, Moscow, 1971, pp. 108,109.)

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