Chapter 12

Some General Regularities of Techno-Economic Evolution*

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12.1 Introduction

One of the most exciting phenomena of the modern world is the fundamentally homogeneous direction of the overall techno-economic development trajectory in practically all regions of the world. The existing economic systems in different countries are collapsing one after another under the pressure of an expanding *industrial culture* and are becoming drawn into the international division of labor. Simultaneously, their economic development is influenced by the general regularities of the world techno-economic system, the rhythm of which is set by the industrially developed countries. These general regularities of long-term techno-economic development, invariant under different sociopolitical systems, are the subject of this chapter.

*We gratefully acknowledge permission to use parts of the original version of this paper which appeared in *Communist Economies*, Volume 2, No. 2 (1990),

12.2 Regularities of Technological Change

The key factor that directs the overall techno-economic development trajectory is technological change. During the last few decades the problems of technological change have been the focus of interest in economics. A new concept has evolved which views economic dynamics as an uneven and uncertain process of evolutionary development (Dosi *et al.*, 1988). From this point of view technological change is a complex interaction of various technological alternatives, carried on by competing and collaborating economic agents in similar institutional environments. The selection of techno-economic development alternatives and their implementation in technological shifts and structural changes take place as a result of learning processes (which are determined by various nonlinear feedbacks – positive and negative) that influence the dynamics of the interaction of technological and social change.

The concept of economic growth as a complex, nonlinear and uncertain process involving permanent changes, allows us to develop a new approach in studying the regularities in long-term techno-economic development and the management of technological change. Feedbacks stipulate the interaction of various elements in the socioeconomic system in the course of technological shifts and determine the directions and rates of evolution of the economy. The modeling of these feedbacks becomes a priority task of economics.

This new approach predetermines a new vision of economic structure. It is important to select a view of the economic system that can ensure the stability of its components and of interrelations between them in the process of technological change. Such a vision of economic structure assumes a corresponding choice of its primary *element.* This element should not only preserve integrity in the process of technological change, but it should be a carrier of corresponding innovations, i.e., it need not necessarily be disaggregated to describe and measure them.

The changing driving forces of the form and direction or of the overall techno-economic development trajectory have recently been summarized by Freeman and Perez (1988). In a Schumpeterian tradition, they distinguish four successive modes of growth (or *techno-economic paradigms*) since the onset of the industrial revolution. These modes of techno-economic development are driven by the growth of *leading branches* and growth sectors which involves a synergetic aggregate of key factor industries, technologies, and infrastructures.

Thus, as an element for the analysis of the overall techno-economic development we suggest a totality of technologically connected production processes preserving its unity in its evolution. Such totalities are united into a stable self-producing unity – a technological wave (TW). The latter covers a macroeconomic production cycle – from the extraction of natural resources and labor force education to final consumption.

The production sections contained in a single TW develop more or less simultaneously because of their technological interconnection. Any change in one of the elements of the TW initiates a corresponding change in other elements in the chain of production units. The broadening of each technological process is conditional on the development of the whole group of interconnected production systems.

The primary element of technological change is the innovation. The development of any technological system begins with the introduction of a basic innovation which is then followed by others. Basic innovations are usually radically different from their traditional technological surroundings. The effective functioning of a new formation can be achieved only through an adequate technological chain. The inclusion of new technological systems in traditional technological chains does not, as a rule, lead to significant technical progress, because their advantages are not always recognized. Techno-economic development takes place through the establishment of new technological chains based on clusters of technologically connected innovations which are combined in new TWs. Technological change does not proceed with the more or less smooth introduction of new technologies, the elimination of the old, and the gradual raising of the overall technological level of production. It is, in essence, a sequential process of long periods of evolutionary development of TWs, broken up by occasional revolutionary changes in the technological base of the economy through replacement of the dominant TWs. The replacement of one dominant TW by another is accompanied by the reconstruction and elimination of a large number of technological processes which form the base of the previous TW, and by the disintegration of the corresponding production links with the rapid diffusion of new technological processes and production systems.

It makes no sense to ask what is the main driving force in the genesis of each TW – technological possibilities or consumer needs – or in which sector of the economy does the original impulse for the technological breakthrough arise. Research shows that innovations and shifts in different sectors (machinery, raw materials, energy sources, construction, transport, and communications) are interdependent. They stimulate and complement each other. Radical discoveries and inventions relating to one of these sectors are not put into practice, or at the very least do not receive adequate diffusion, without the appearance of corresponding innovations in other sectors.

Each period of domination of a particular TW is characterized by a set of base technologies, a group of leading branches, a type of consumption and labor qualification, dominant energy sources, materials, and modes of transport and communications. There is a continuity between the consecutive stages of development and the corresponding TWs, i.e., the material and technical base for a particular stage emanate from the development of the previous stage. The birth of a new TW occurs within the old one, and in further development it adapts the production units that existed in the previous stage to the needs of its evolution.

The results of the research done in recent years into the long-term trends of technical and economic evolution in the industrially developed countries (see, for example, Dosi, 1983; Freeman, 1983; Grübler, 1990; Mensch, 1979; Piatier, 1984; Nakićenović, 1986; Vasko, 1987) allow us to conclude that since the first industrial revolution five technological waves have been observed, based successively on the mechanization of the textile industry (first TW), machine technologies connected with the use of the steam engine and railways (second TW), electrotechnical machinery and the electrification of the economy (third TW), comprehensive development and the use of chemicals and motor vehicles (fourth TW), and telecommunications and microelectronic technologies (fifth TW).

The evolution of each technological wave can be schematically represented by two pulsations. The first pulsation (the formation phase) takes place in an unfavorable economic and social environment which is determined by the previous technological wave (still predominating at that time). In the second stage the technological wave expands rapidly after it overcomes the social and economic barriers as a result of institutional changes. In this stage the TW becomes the main carrier of economic growth. With the exhaustion of technical improvement possibilities in the industries that constitute the predominant TW, and with the saturation of corresponding consumer needs, the predominant TW expansion becomes inefficient and the period of institutional change comes round again. The successive substitution of predominant TWs generates low-frequency variations (long waves) in world economic development.

12.3 Technological Change in Different Economic Systems

In a market economy the discontinuities of economic growth associated with the TW substitution appear empirically to have become more established, albeit interpreted from a number of different theoretical perspectives (see, for example, Delbeke, 1983; Freeman, 1983; Mensch, 1979; Vasko, 1987, among others). Such discontinuities in economic development can be explained with the help of known regularities of capital reproduction. With saturation of the corresponding type of consumption demand and exhaustion of the possibilities of further technological improvement in the life cycle of each TW, a phase of decay sets in, when the marginal efficiency of investment in that group of technologies and industries falls sharply. Further growth of national consumption and production, in addition to maintaining the profitability of the latter, requires new investment to be channeled to the radically new technologies of the next TW. The latter, as a rule, already exist in the form of inventions, R&D results, and design documentation. However, their pervasive diffusion is restricted by inadequate socioeconomic conditions: the common interests of workers (unwilling to lose their jobs and see their skills devalued), shareholders (interested in a return on capital invested in traditional TW industries), and corporations (interested in the expansion of conventional technologies). A high level of inertia in socioeconomic institutions leads to prolonged depression. During this period a large part of the available capital can find no profitable investment application and is partially lost in speculative operations. Simultaneously, the growth rates of all macroeconomic indicators decrease, including the real income of the population. It is only with the implementation of corresponding institutional changes and organizational and social innovations (it takes time to realize that they are necessary) that possibilities for the rapid growth of the new TW industries appear. Surplus capital is gradually spent, large-scale redistribution of resources takes place, and the economy embarks on a new expansion path of economic growth.

During the TW growth phase in a market economy stable circuits of resource distribution are formed, which determine the expansion of production. Private and public organizations, official regulatory bodies, and other economic institutions become connected with the technologies of the given TW. This prevents the redistribution of resources into new technologies, leading to overaccumulation of capital in traditional TW industries which are saturating. The economy enters a stage of long-term recession, characterized by low investment, underused capacity, and high unemployment. With the aggravation of social tension a search for new directions of economic activity begins. Government and corporations start to introduce social, organizational, and technological innovations, making way for the new TW.

In a world market economy the above mechanism works on a global scale. Facing falling demand in the local market, corporations start to export goods and capital, thus diffusing the corresponding technological wave throughout the world economic system. It reaches the limits of its diffusion in a number of countries, connected by intensive trade flows, more or less simultaneously, leading to worldwide overaccumulation of capital. The country that is the first to introduce the necessary social and technological innovations in order to make way for the next TW initiates a new long growth phase, frequently attaining a leading position in the world.

The substitution of technological waves in market economies is determined by the regularities in the way the capital market functions. In modern centrally planned economies there is no capital market, therefore technological wave substitution takes other forms.

Centrally planned economies are characterized by a high degree of stability in industrial relations (i.e., relations between enterprises, ministries, state authorities, etc.) and institutions that determine the flow of resources. The result of this is an inertia in technological evolution which leads to difficulties for structural change in the economy. The reasons for this great stability and inertia in centrally planned economies can be found in the regularity in the functioning of large economic organizations which form the basis for its economic mechanism.

The natural tendency of any organization to strive for stability, both internally and externally, produces an internal resistance to innovation. Any serious innovation will inevitably disrupt existing communications and management processes, which obviously results in resistance among those affected.

Usually management introduces a radical innovation only if it is necessary for its survival in a changing environment. Consequently, in a stable external environment one can hardly expect a high degree of innovative activity. The reverse side of a high degree of stability is the absence of independence. Enterprises concerned with introducing significant innovations do not as a rule have the capacity to do so independently. Decisions on important innovations are made at the top level of the economic hierarchy. The enormous scale of its *subordinate estates* and the solid management power of the ministry apparatus give a high degree of stability to its work and consequently result in a low degree of innovation.

The stability of the enterprises' economic environment under a certain ministry is complemented by a system of relevant interbranch relationships and central planning institutions. Its basic components are: the practice of planning by means of extrapolation, the allocation of capital investment according to production growth objectives, the provision of supplies to enterprises according to schedules set in advance by Gossnab (the State Supply Administration), and the preparation of plans on the basis of the *national economic need* as set by Gossnab – which in practice is a simple compilation of the orders of enterprises, usually calculated (with annual planning and a lengthy interval between putting in orders and receiving plan tasks) by proportionally increasing the orders of the previous year. Yet other components include the budget financing of capital investment plus a *soft* credit system, cost-based prices which guarantee the covering of any production costs regardless of the social utility of the resulting product, and the activity of Gosstandart (the State Standards Administration) which prevents any changes in the technology of production, whether for better or for worse. The organization of R&D also forms part of this mechanism of stable extensive production across different (unchanged) technological trajectories. The subordination of most scientific organizations to the ministries and the management of science by mass production methods promote an incremental style of technological changes.

Thus extremely stable industrial relations arose in the centrally planned economy, providing stable conditions for the extensive reproduction of existing technological processes. Its basic features were formed before the Second World War, serving as a powerful means for the rapid expansion of production typical of the third TW. Today it continues to provide unchanging flows of resources and products. The technologies of a new TW are introduced along with the old, by the formation of new branches and sub-branches, which receive resources for expanded production. As a consequence of their technological incompatibility with conventional technologies, however, the management bodies responsible for their development try as much as possible to create their own technological base. Thus, the new TW develops autonomously, but such reproduction, based on internal accumulation, proceeds extremely slowly. The expansion of the new TW requires redistribution of resources and the adaptation of conventional technologies.

This presupposes the breakdown of old technological chains and the corresponding economic information flows, which in turn is impossible without the reorganization or liquidation of many institutions serving the traditional technological systems. Until this happens the new technological structures develop parallel to the expanding reproduction of the old. With time a number of autonomous TWs form, functioning within a stable regime of expanded production.

In the system of management of the centrally planned economy there was no mechanism of automatic redistribution of resources from obsolete industries to new ones. Resources were distributed by stable circuits of industrial relations, according to the interest of ministries. For that reason development of new industries was very slow, with simultaneous excessive expansion of the established ones. The result is a specific situation of simultaneous diffusion of the consecutive and parallel existence of multiple TWs. It is followed by a number of negative consequences; overproduction of obsolete products, superfluous economic activity, the overexpansion of resource-producing industries, considerable national economic losses, and generally low efficiency of production.

12.4 Measurement of Technological Wave Substitution

In order to obtain evidence supporting the above hypotheses, we have undertaken empirical research on the formation and substitution of TWs during the last century. During this period one can see three successive TWs or techno-economic paradigms replacing their predecessors in industrialized countries (see, in particular, Freeman and Perez, 1988, for a detailed account).

The formation of the first, which we refer to here as the third TW, began in Russia in the last quarter of the 19th century, slightly later than in the leading industrialized countries. Its nucleus was electric power and electrical machinery. The diffusion of the technologies of this TW was accompanied by the mechanization of the basic technological processes and corresponding changes in the quantity and skill level of labor. The most important industrial material was steel, including rolled steel. The energy source was coal, while the main form of land transport was rail. Production was oriented toward high-volume resources, universally applicable machinery, and labor with low qualifications (by today's standards). The development of this TW was accompanied by rapid urbanization and radical changes, not only in the structure of consumer demand, but also in the lifestyle of the population.

By the beginning of the 1930s the mechanization of production, the improvement in the qualifications of the labor force, shifts in the fuel-energy balance toward liquid fuel, the growth in total energy consumption, as well as the establishment of new systems of mass communications and a new transport infrastructure (roads), created the conditions for the growth of a new (the fourth) TW in the developed market economies. Research into the rate of change in the use of traditional industrial materials, as well as the production of types of products characteristic of the third TW, shows that the technologies contained in it continued to be used in the leading market economy countries right up to the mid-1960s.

However, the basic engine of technical and economic development in the post-war years was the fourth TW. Its nucleus was the chemical industry and associated machine-tool production industries (chemical engineering) and the motor industry, which underwent further development, while road vehicles became the major mode of transport. Characteristics of this stage were the mechanization and automation of many basic technological processes, the growth in the specialization of production, and its reorientation from the use of high-volume resources and universal machinery to quality raw materials and specialized equipment. Electric power consumption grew at very high rates, while the shift in the fuel-energy balance toward oil continued until it finally replaced coal as the leading source of energy. The use of new industrial materials greatly increased, including plastics and high-quality steels. Secondary education became the norm, while the skills of the labor force and the production culture moved to qualitatively higher levels. In the mid-1970s the fourth TW reached the limits of its growth in the developed capitalist countries, which can be seen in the dynamics of the indicator (see discussion below) of its life cycle (*Figure 12.1*). At this stage in the major capitalist countries, the relative consumption of basic materials, energy sources, and non-production consumption items for this TW stabilized, while the diffusion of its basic technologies peaked. Further technical and economic development is instead connected with a new stage of technological change, based on microelectronics and telecommunication technologies (the fifth TW).

The nucleus of the fifth TW includes electronics, robotics, and microprocessor technology. This TW is characterized by computer integrated manufacturing technologies, new systems of mass communication based on computer networks and satellite links, among others.

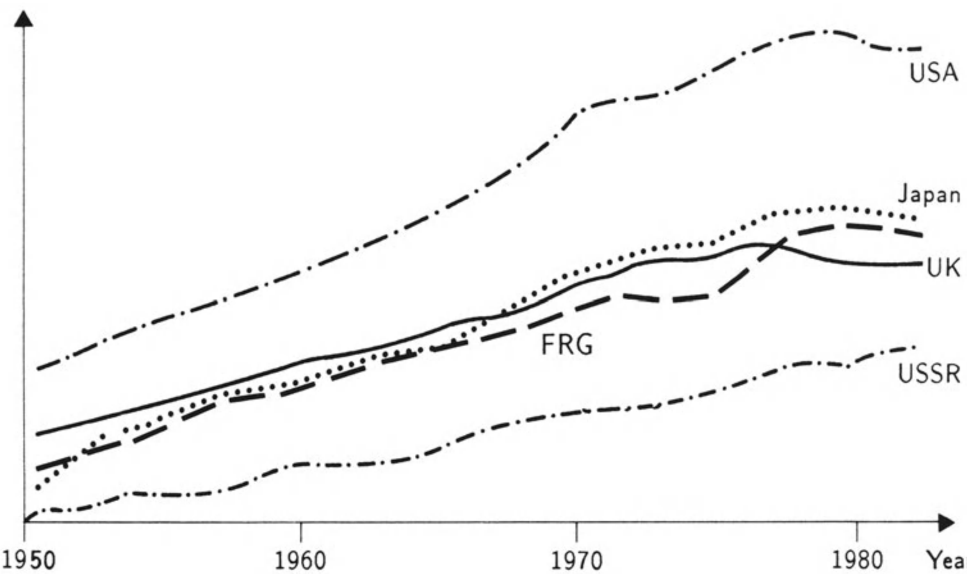

Figure 12.1. General indicator of the evolution and intensity of the fourth TW based on a two-step analysis of principal components of 50 indicators of technological change.

A conceptual analysis of the technological waves successively predominating in the technological structure of the developed countries in this century will make it possible to build systems of indicators reflecting the evolution of these waves. Work with available statistical data revealed about 50 initial indicators. They were presented as time series for the period 1951–1986, reflecting technological changes connected with the diffusion of the fourth TW in the following economies: Bulgaria, Czechoslovakia, Federal Republic of Germany (FRG), German Democratic Republic (GDR), Hungary, Japan, Poland, Romania, USSR, UK, and USA.

The information sources used in this work were publications of the UNO statistical services, as well as those of CMEA, OECD, UNESCO and other international organizations, data from national statistical sources, and separate research works. A list of the initial indicators is given in the *Tables 12.A1* to *12.A8* of the Appendix. Principal component analysis was used for aggregating a large number of initial indicators into general indicators. The justification for its use was shown by the high correlation of the initial indicators (see Appendix), reflecting a single process – the diffusion of the fourth TW.

The initial indicators used in this research reflect technological change connected with the diffusion of the fourth TW in seven economic spheres: in construction materials, the chemical industry, electric power generation, the fuel-energy complex, the agricultural complex, transportation, and final consumption. Different economic sectors are represented in the system of initial indicators by a different number of indicators. Direct application of principal component analysis to them would give, however, a distorted picture of techno-economic development in the general index, because separate economic spheres would then bear weights proportional to the number of indicators which reflect them, but not to their actual economic value. Therefore the initial data were aggregated step-by-step. First, general indicators of technological change in each economic sphere were constructed by principal component analysis (*Tables 12.A1* to *12.A7* in the Appendix), then these general indicators themselves were subject to component analysis (*Table 12.A8* in the Appendix).

The structure of the corresponding principal components is given in the Appendix. As can be seen from the coefficients of factor utilization with the first principal components, the latter not only aggregate the overwhelming majority of information contained in the initial indicators, but reflect the main direction of mutual variability of the initial indicators of techno-economic development. Therefore, they may be used as general indicators of the technical evolution of the corresponding economic spheres. Similarly, as the results of component analysis show, the principal component of the second level may be used as a general indicator of the technical evolution of the economy as a whole.

The results of the principal component analysis of the second level are presented in *Figure 12.1*. The period under consideration covers the maturity stage of the fourth TW in developed market economies and its growth stage in the USSR. The results of measurements show that the TW is more *prolonged* in a centrally planned economy in comparison with market economies: technological shifts are more even and slower. This phenomenon reflects the less intensive redistribution of resources from conventional technologies to new ones in a centrally planned economy. As a result, its technological development is more inert.

As one can see from the results of empirical research, the general direction and intensity of techno-economic development can vary depending on the peculiarities of economic relations. Despite the fact that the general direction and historical succession of technological shifts in both socialist and capitalist countries were the same, their rates, methods of realization, and manifestations were essentially different. Certain differences are also characteristic of countries within the same socioeconomic system. Thus, rates of technological change were substantially higher in Japan than in other developed capitalist countries. Thanks to an efficient national policy of long-term techno-economic development, the fourth TW life cycle was reduced to a quarter of a century, and growth in production capacities of the third TW were curtailed promptly as soon as they proved unpromising from the point of view of long-term trends in technological change. Simultaneously, at the growth stage of the fourth TW the government and corporations in Japan made great efforts to form basic industries for the fifth TW, which had been identified in the long-term forecasting of Japan's techno-economic developments. As a result, along with the growth of the industries in the fourth TW, large-scale resource redistribution into the industries of the fifth TW took place in Japan. The consequence was rapid advancement with Japan becoming one of the leaders in technological development during the process of technological wave substitution in the world economy.

In the USSR the third TW was formed during the industrialization of the 1930s. The formation of the fourth TW began in the second half of the 1950s. At this stage production units, typical of the third TW, had not yet reached their limits of diffusion and the material and technical base needed for the fourth TW had not been formed. The dynamics of the relative consumption of traditional industrial materials, the production of universal metal-cutting machinery, and a number of other indicators of the life cycle of the third TW, indicate its continued growth right up to the mid-1970s and its reproduction up to the present day in the USSR. The allocation of an enormous amount of economic resources to the continuing reproduction of the third TW resulted in an inadequate allocation of resources to the development of the fourth TW. Therefore the diffusion of its technological systems has occurred at rates and levels considerably below those demonstrated by a range of industrially developed market economies.

At present the formation of the fifth TW is beginning. Research shows a comparatively high rate of diffusion of robotics, computer-controlled machine tools, and other CIM technologies in the USSR. However, it must not be forgotten that as yet this TW is still in the initial phase of its life cycle. Therefore high rates of diffusion of technologies can be achieved without large allocations of resources, because of their insignificant weight in the technological structure and in the economy as a whole. For these high rates to be maintained in the longer term an ever-increasing redistribution will be necessary. The problems of organizing such a redistribution are apparent from the experience of the development of the fourth TW. High rates of growth at the beginning of the life cycle of the fifth TW declined sharply after expansion began. Our measurements revealed a decline in diffusion of the fifth TW-technology over that last decade in the USSR and an increase in the technological gap between the Soviet and Western economies. A qualitative analysis of the reproduction of the technological structure of the economy in the USSR, and individual calculations, indicate the parallel presence of three TWs, all at different stages of their life cycles (we refer to this phenomenon here as *technological multi-modeness*).

Technological multi-modeness is normal in periods of TW substitution. In the course of interwave interactions that take place at that time, the obsolete TW is destroyed, forming the prerequisites for the growth of the new one. Coordinated actions of government and industrial and social organizations can significantly accelerate this process and minimize social costs of technological wave substitution. However, when there are no incentives for resource redistribution from obsolete industries into new ones, the growth of the new TW may take place at the same time as the extended reproduction of the obsolete TW. If this happens, the possibilities of the new TW are restricted by the previous TW, which is still expanding and if structural policy is inadequate the parallel existence of several TWs may easily be reproduced. This is accompanied by a stratification in the economic structure.

Reproduction of each TW is autonomous. Interwave interactions are not directed at the replacement of obsolete TWs in order to meet the demands of new ones, but at the elimination of bottlenecks which restrict their simultaneous reproduction. Under these circumstances the tightest bottleneck is satisfying the demand for primary resources. Consequently, excessive efforts are concentrated in mining industries and the resource base of the economy becomes overloaded. With the prolongation of the obsolete TW, the formation of a new TW is restricted by general resource limitations – and missing links are provided through foreign trade. Owing to the deficit of high-quality resources, mass-produced resources are exported in exchange for high-quality imports. As a rule, the exports are raw materials that have undergone a low degree of processing, so that this exchange is non-equivalent and leads to an intensification in the structural crises.

One more negative consequence of *technological multi-modeness* is the stratification of the system of economic values, reflecting the peculiar structure of the economy. As a result, economic estimations cease to act as reliable reference points in making economic decisions – new technologies look inefficient in systems reflecting the conditions of the obsolete TW and economic agents turn out to be interested in the preservation of an obsolete technological structure. The reproduction of different TWs in the economy is supported by a multitude of positive feedbacks, exacerbating the losses connected with its preservation. An inadequate technical policy thus brings the economy into a permanent structural crisis with the country becoming increasingly impoverished.

12.5 International Comparisons of Techno-Economic Evolution

One can assess the technological structure of a country by comparing variations in the structural evolution of the technological and infrastructural base to the international level or to that of the leading country in a particular TW development. Below we discuss some long-term technological changes in the transport and energy systems of the USSR in comparison with a similar analysis performed for the USA (Marchetti and Nakićenović, 1979; Nakićenović, 1986 and 1987). In the case of the changing mix of transport infrastructures in the USA and USSR, the comparison shows that technological shifts in the Soviet transport infrastructure took place a quarter of a century later than in the USA. They also occurred more slowly, which is due mostly to slower curtailing of obsolete transport technologies (see Chapter 19 by Nakićenović). For instance, the slow decrease in the share of railways in the general transport infrastructure and also in intercity passenger transport are explained by the continuing reproduction of the third TW, characterized not only by active railway construction (as opposed to decommissioning in the USA), but also by a strong demand for rail transport. The high resource consumption of third TW industries means high demand for raw materials, which places great pressure on the transport system. This pressure is substantially enhanced by the demand of the fourth TW industries for oil and energy in general, and also by the fifth TW demand for imported equipment (satisfied by exporting ores and fuels). The result of this is a hypertrophied transport structure in which the role of rail transport is exceptionally high.

Comparative analysis of the structure of energy consumption in the USSR and the USA yields interesting conclusions (note that the dynamics of structural change in the US economy are close to those of the world economy). After the protracted predominance of coal in the consumption of primary energy carriers in the 1950s (compared to the peak in market dominance of coal in the USA some forty years earlier) technological shifts in the fuel-energy complex in the USSR speed up. The period from when the share of coal in primary energy consumption was at its maximum up to its replacement as the predominant energy carrier by oil took more than two decades in the USSR, compared with three-and-a-half in the USA. However, the peak market share of oil in the primary fuel mix of the USSR attained a significantly lower level than in the USA (where the market share of oil peaks above 50 percent of primary energy consumption). Even more rapid was the development of gas technology, which took only a decade and a half to become predominant in the USSR, starting from a 10 percent share in energy consumption.

The relatively rapid development of oil and gas technologies in the Soviet economy are explained by three major interrelated reasons. First, the rapid formation of the fourth TW from 1950 to 1960 caused a sharp increase in demand for oil, which had held a relatively large share in energy consumption even before (for a long period coal consumption was complemented by oil consumption – oil technology was separated from coal technology later). Second, a large share of oil consumption was a substitute for coal in industries of the third TW, the expansion of which had exerted equal pressure upon oil and coal consumption. Its predominance in the technological structure of the economy up to the period 1960–1970 also contributed to the prolongation of the coal technology life cycle. Third, the development of the fourth TW in the Soviet economy involved considerable use of imports for the production process, which in turn required the export of energy resources. This was an important incentive for the rapid expansion of oil production, and, also partially, for gas production, and this in turn influenced the structure of internal energy consumption.

The appreciation of the long-term trajectories of technology diffusion and their distinctive variations in different socioeconomic conditions makes it possible to put interstate comparisons on a more scientific basis. At the same time it is necessary to note that one must be very careful when using interstate comparisons in scientific research, and, even more, in practical economic decisions, in view of structural peculiarities and goals of techno-economic development. In particular, in the calculation of technical lags and technological gaps one must not rely on *absolute* levels of techno-economic indicators. As a rule, these values are determined not only by the level of techno-economic development but also by a number of social, geographical, political, and other factors specific to each country. What is far more important is the dynamics of such indicators and their structural evolution over time. Thus, the gap in the level of production diffusion of the fourth TW between the USA and West European countries is largely explained by geographical peculiarities such as population and consumption. More important is the almost parallel movement of the general indicator of the fourth TW development in the USA, the FRG, the UK, and Japan. This is confirmed by the synchronization of the saturation level of the given indicator (see *Figure 12.1*), despite substantial differences in the absolute value of this level. The fact that West European countries reach saturation of the given indicator only two to three years later than the USA reflects the small technological lag.

It must be noted also that, as a rule, the leading country in the development of a particular TW develops on a somewhat larger scale than the countries that follow it. This is explained by the relatively high stability of economic structures developed over a relatively long period. Such structures tend to promote the reproduction of the technologies connected with the country's earlier successes in the world market.

12.6 Economic Policy Implications

To concentrate on the absolute levels of US techno-economic indicators, as is usual in measurements of national techno-economic development, is scarcely justified. By orienting the economic policy of a country to the technological level and structure of a leading country condemns that country to permanent *lagging behind* and to the reproduction of the leading economy's development trajectory. Such an orientation does not allow the country concerned to benefit from the *advantage of the backward* in the organization of *overtaking* techno-economic development.

The *advantage of the backward* is the opportunity to use the experience of advanced countries, and forecasts for their future techno-economic development, in determining the optimal strategy for closing the technological gap. This advantage becomes most acute during the periods of large-scale structural change in the world economy connected with the substitution of overall TWs. At such a period in time the *backward* country has an opportunity to *take a short cut*, establishing the principal directions of technological shifts and concentrating resources in the key industries of a new technological wave.

The economic structure of the countries that were leading during the life cycle of the previous TW is closely connected with obsolete technologies and this leads to a high degree of sluggishness in their economic systems. Backward countries, on the other hand, find themselves in a comparatively better position, having no need to break the powerful old production machinery and to overcome the resistance of the people and organizations involved. This opens up possibilities for making a technological push with the aim of leap frogging or *surpassing without overtaking.* This was exactly how Japan made its remarkable push during the last two decades (see Freeman, 1987), followed by the new industrial countries of southeast Asia. They did not develop industries of the third and fourth TWs (and still less the second and first TWs) but put all available resources into the fifth TW.

Appendix

Indicators and factor matrices used for principal compound analysis of techno-economic change in selected market and centrally planned economies for the period 1951 to 1986.

Table 12.A1. Factor matrix for construction materials.

	Factor coefficients		
	I	II	III
Share of steel in consumption of construction materials	−0.3505	0.1739	0.0558
Share of plastics in consumption of construction materials	0.3602	−0.2342	0.0875
Share of aluminum in consumption of construction materials	0.2371	0.5553	−0.3332
Share of copper in consumption of construction materials	−0.3492	−0.0150	0.0723
Consumption of steel per unit of national income	−0.1751	0.2558	0.8396
Consumption of plastics per unit of national income	0.3540	−0.1389	0.2654
Consumption of aluminum per unit of national income	0.3214	0.3750	0.0772
Consumption of plastics per capita	0.3693	0.0014	0.0191
Consumption of steel per capita	0.2550	0.5083	0.1575
Consumption of aluminum per capita	0.3290	0.3497	−0.2574
Dispersion of factors	65%	15%	10%

Table 12.A2. Factor matrix for electric energy.

	Factor coefficients		
	I	II	III
Share of primary electric energy in consumption of energy resources	0.2338	−0.5816	0.3606
Share of electric energy in consumption of energy	0.4181	−0.2802	−0.0309
Consumption of electric energy per unit of national income	0.3861	0.2580	−0.1424
Consumption of electric energy per capita	0.3964	0.3334	−0.0770
Consumption of electric energy for lighting and household needs per capita	0.3932	0.3408	−0.1120
Consumption of fuel by combined heat and power electricity plants per unit of national income	−0.3634	0.0496	0.5329
Electricity consumption per worker in industry	0.2635	−0.5165	−0.1964
Share of atomic electricity plants in production of electric energy	0.3335	0.1411	0.6721
Dispersion of factors	59%	17%	8%

Table 12.A3. Matrix structure of energy consumption.

	Factor coefficients		
	I	II	III
Share of coal[a]	−0.4897	0.2537	0.1172
Share of oil[a]	0.4678	−0.0458	−0.2260
Share of natural gas[a]	0.3117	−0.6952	−0.0712
Share of primary energy[a]	0.3273	0.6032	−0.3277
Share of electric energy in energy consumption	0.4707	0.2376	0.0098
Share of atomic electricity plants in production of electric energy	0.3395	0.1065	0.9014
Dispersion of factors	61%	18%	10%

[a]Shares of coal, oil, natural gas, and primary energy are the shares of corresponding energy resources in the total consumption of energy resources for energy production.

Table 12.A4. Factor matrix for the chemical industry.

	Factor coefficients		
	I	II	III
Consumption of plastics per unit of national income	0.4991	0.5189	−0.5338
Consumption of synthetic fibres and yarns per unit of national income	0.4921	−0.5814	−0.5461
Consumption of plastics per capita	0.5039	0.4693	0.3570
Share of synthetic fibres and yarns in consumption of chemical fibres and yarns	0.5046	−0.4150	0.6145
Dispersion of factors	85%	8%	2%

Table 12.A5. Factor matrix for agriculture and related industries.

	Factor coefficients		
	I	II	III
Share of employees in agriculture	0.4288	0.4818	0.5827
Consumption of mineral fertilizers per 1,000 hectares of arable land	−0.4609	0.2067	0.4438
Number of tractors per 1,000 hectares of arable land	−0.3887	0.7897	−0.4261
Milk yield per cow	−0.4825	−0.2987	−0.0788
Grain harvest	−0.0685	−0.1099	0.5257
Dispersion of factors	72%	12%	9%

Table 12.A6. Factor matrix for transport.

	Factor coefficients		
	I	II	III
Length of railways	0.4198	−2.2871	0.1444
Length of roads	0.4396	−0.1151	−0.3227
Length of oil pipelines	0.4380	−0.1459	−0.3048
Length of natural gas pipelines	0.4425	−0.0075	−0.2859
Number of cars	0.2660	−0.0376	−0.8365
Share of containers in goods turnover	0.2660	0.9392	−0.0205
Dispersion of factors	83%	16%	3%

Table 12.A7. Factor matrix for private consumption.

	Factor coefficients		
	I	II	III
Consumption of national income used for non-productive consumption per capita	0.4008	0.1494	−0.2883
Consumption of energy used for lighting and household needs per capita	0.4005	−0.2324	−0.1490
Number of students per 1,000 inhabitants	0.2477	0.9136	0.1961
Number of TV sets per 100 inhabitants	0.4073	−0.0138	−0.2079
Consumption of paper per capita	0.4016	−0.1548	−0.0496
Share of employees in public services	0.3523	−0.2299	0.8794
Number of telephones per 100 inhabitants	0.4075	−0.1086	−0.1924
Dispersion of factors	80%	11%	5%

Table 12.A8. Factor matrix of the second level (seven main components of the first level).

	Factor coefficients		
	I	II	III
Construction materials	0.3295	0.3327	−0.0193
Chemical industry	0.3772	0.4648	−0.3885
Energy consumption	0.4402	0.3416	0.9000
Electric energy	0.3467	−0.3437	0.6347
Agriculture and related industries	0.0335	−0.4216	−0.1486
Private consumption	0.4749	−0.0621	−0.3239
Transport	0.4378	0.5616	−0.3026
Dispersion of factors	64%	32%	2%

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