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WITH A NEW FOREWORD BY THE AUTHOR

"One of the great seminal works of the last half century and also... the next half century."—Manuel Castells

Daniel Bell

The Coming of Post-Industrial Society

A VENTURE IN SOCIAL FORECASTING

one looks at the Soviet Union and the United States one need not depend exclusively on a principle of convergence or of inherent conflict, but one can specify the rotating axes along which the distinctions are made. In this fashion, one can avoid a single-minded determinism, such as an economic determinism or a technological determinism, in explaining social change, yet single out a primary logic within a given conceptual scheme. One forgoes causality but emphasizes significance (or in Dilthey's sense, meaning). One is able, also, to create a principle of "complementarity" in social explanation.[13]

The Dimensions of Post-Industrial Society

Analytically, society can be divided into three parts: the social structure, the polity, and the culture. The social structure comprises the economy, technology, and the occupational system. The polity regulates the distribution of power and adjudicates the conflicting claims and demands of individuals and groups. The culture is the realm of expressive symbolism and meanings. It is useful to divide society in this way because each aspect is ruled by a different axial principle. In modern Western society the axial principle of the social structure is *economizing*—a way of allocating resources according to principles of least cost, substitutability, optimization, maximization, and the like. The axial principle of the modern polity is *participation*, sometimes mobilized or controlled, sometimes demanded from below. The axial principle of the culture is the desire for the *fulfillment and enhancement of the self*. In the past, these three areas were linked by a common value system (and in bourgeois society through a common

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[13] There is an inherent risk in taking a concept derived from one field bodily into another, and the social sciences particularly have been bedeviled by such borrowing. For example, the use of the terms force and power from physics, and structure and function from biology. Complementarity was used by Niels Bohr to explain the contradictory behavior of light as wave and particle, but Bohr did feel, according to my colleague, the physicist Gerald Holton, that the principle applied to many phenomena in nature and society. This may have been the *hubris* of a great man infatuated with the discovery of a compelling principle. Since the concept is suggestive, let me say only that I use it simply as a metaphor and not as an explanatory device.

This discussion of axial structures and conceptual schemata is elaborated in my essay "Macro-Sociology and Social Change," in *Theories of Social Change: A Stocktaking*, which I have edited for the Russell Sage Foundation, to be published in 1974. A different use of the idea of conceptual schemata appears in Georges Gurvitch's *The Social Frameworks of Knowledge* (Oxford, 1971; published originally in French in 1966). Gurvitch seeks to define a succession of historical social types and the kinds of cognitive systems associated with each. To that extent he is elaborating the kind of sociology of knowledge developed by Max Scheler in his *Die Wissenformen und die Gesellschaft* (1926).

character structure). But in our times there has been an increasing disjunction of the three and, for reasons I discuss in the Coda, this will widen.

The concept of the post-industrial society deals primarily with changes *in the social structure*, the way in which the economy is being transformed and the occupational system reworked, and with the new relations between theory and empiricism, particularly science and technology. These changes can be charted, as I seek to do in this book. But I do not claim that these changes in social structure *determine* corresponding changes in the polity or the culture. Rather, the changes in social structure pose *questions* for the rest of society in three ways. First, the social structure—especially the social structure—is a structure of roles, designed to coordinate the actions of individuals to achieve specific ends. Roles segment individuals by defining limited modes of behavior appropriate to a particular position, but individuals do not always willingly accept the requirements of a role. One aspect of the post-industrial society, for example, is the increasing bureaucratization of science and the increasing specialization of intellectual work into minute parts. Yet it is not clear that individuals entering science will accept this segmentation, as did the individuals who entered the factory system a hundred and fifty years ago.

Second, changes in social structure pose "management" problems for the political system. In a society which becomes increasingly conscious of its fate, and seeks to control its own fortunes, the political order necessarily becomes paramount. Since the post-industrial society increases the importance of the technical component of knowledge, it forces the hierophants of the new society—the scientists, engineers, and technocrats—either to compete with politicians or become their allies. The relationship between the social structure and the political order thus becomes one of the chief problems of power in a post-industrial society. And, third, the new modes of life, which depend strongly on the primacy of cognitive and theoretical knowledge, inevitably challenge the tendencies of the culture, which strives for the enhancement of the self and turns increasingly antinomian and anti-institutional.

In this book, I am concerned chiefly with the social structural and political consequences of the post-industrial society. In a later work I shall deal with its relation to culture. But the heart of the endeavor is to trace the societal changes primarily within the social structure.

"Too large a generalization," Alfred North Whitehead wrote, "leads to mere barrenness. It is the large generalization, limited by a happy particularity, which is the fruitful conception."[14] It is easy—and particularly so today—to set forth an extravagant theory which, in its historical sweep, makes a striking claim to originality. But when tested eventually by reality, it turns into a caricature—viz. James Burnham's theory of the managerial revolution thirty years ago, or C. Wright Mills's conception of the power elite, or W. W. Rostow's stages of economic growth. I have tried to resist that impulse. Instead, I am dealing here with *tendencies*, and have sought to explore the meaning and consequences of those tendencies if the changes in social structure that I describe were to work themselves to their logical limits. But there is no guarantee that they will. Social tensions and social conflicts may modify a society considerably; wars and recriminations can destroy it; the tendencies may provoke a set of reactions that inhibit change. Thus I am writing what Hans Vahinger called an "as if," a fiction, a logical construction of what *could* be, against which the future social reality can be compared in order to see what intervened to change society in the direction it did take.

The concept of the post-industrial society is a large generalization. Its meaning can be more easily understood if one specifies five dimensions, or components, of the term:

1. Economic sector: the change from a goods-producing to a service economy;
2. Occupational distribution: the pre-eminence of the professional and technical class;
3. Axial principle: the centrality of theoretical knowledge as the source of innovation and of policy formulation for the society;
4. Future orientation: the control of technology and technological assessment;
5. Decision-making: the creation of a new "intellectual technology."

Creation of a service economy. About thirty years ago, Colin Clark, in his *Conditions of Economic Progress*, analytically divided the economy into three sectors—primary, secondary, and tertiary—the primary being principally agriculture; the secondary, manufacturing or industrial; and the tertiary, services. Any economy is a mixture in different proportions of each. But Clark argued that, as nations became industrialized, there was an inevitable trajectory whereby, because of sectoral differences in productivity, a larger proportion of the labor force would pass into manufacturing, and as national incomes rose, there would be a greater demand for services and a corresponding shift in that slope.

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[14] Alfred North Whitehead, *Science and the Modern World* (New York, 1960; original edition, 1925), p. 46.

By this criterion, the first and simplest characteristic of a post-industrial society is that the majority of the labor force is no longer engaged in agriculture or manufacturing but in services, which are defined, residually, as trade, finance, transport, health, recreation, research, education, and government.

Today, the overwhelming number of countries in the world (see Tables 1 and 2) are still dependent on the primary sector: agriculture, mining, fishing, forestry. These economies are based entirely on natural resources. Their productivity is low, and they are subject to wide swings of income because of the fluctuations of raw material and primary-product prices. In Africa and Asia, agrarian economies account for more than 70 percent of the labor force. In western and northern Europe, Japan, and the Soviet Union, the major portion of the labor force is engaged in industry or the manufacture of goods. The United States today is the only nation in the world in which the service sector accounts for more than half the total employment and more than half the Gross National Product. It is the first service economy, the first nation, in which the major portion of the population is engaged in neither agrarian nor industrial pursuits. Today about 60 percent of the United States labor force is engaged in services; by 1980, the figure will have risen to 70 percent.

The term "services," if used generically, risks being deceptive about the actual trends in the society. Many agrarian societies such as India have a high proportion of persons engaged in services, but of a personal sort (e.g. household servants) because labor is cheap and usually underemployed. In an industrial society different services tend to increase because of the need for auxiliary help for production, e.g. transportation and distribution. But in a post-industrial society the emphasis is on a different kind of service. If we group services as personal (retail stores, laundries, garages, beauty shops); business (banking and finance, real estate, insurance); transportation, communication and utilities; and health, education, research, and government; then it is the growth of the last category which is decisive for post-industrial society. And this is the category that represents the expansion of a new intelligentsia—in the universities, research organizations, professions, and government.

The pre-eminence of the professional and technical class. The second way of defining a post-industrial society is through the change in occupational distributions; i.e. not only *where* people work, but the *kind* of work they do. In large measure, occupation is the most important determinant of class and stratification in the society.

The onset of industrialization created a new phenomenon, the semi-skilled worker, who could be trained within a few weeks to do

TABLE 1

The World's Labor Force by Broad Economic Sector, and by Continent and Region, 1960 *

REGION	TOTAL LABOR FORCE (MILLIONS)	PERCENTAGE DISTRIBUTION BY SECTOR		
		AGRICULTURE	INDUSTRY	SERVICES
World	1,296	58	19	23
Africa	112	77	9	14
Western Africa	40	80	8	13
Eastern Africa	30	83	7	10
Middle Africa	14	86	6	8
Northern Africa	22	71	10	19
Southern Africa [a]	6	37	29	34
Northern America [a]	77	8	39	53
Latin America	71	48	20	32
Middle America (mainland)	15	56	18	26
Caribbean	8	53	18	29
Tropical South America	37	52	17	31
Temperate South America [a]	12	25	33	42
Asia	728	71	12	17
East Asia (mainland)	319	75	10	15
Japan [a]	44	33	28	39
Other East Asia	15	62	12	26
Middle South Asia	239	71	14	15
South-East Asia	90	75	8	17
South-West Asia	20	69	14	17
Europe [a]	191	28	38	34
Western Europe [a]	60	14	45	41
Northern Europe [a]	34	10	45	45
Eastern Europe [a]	49	45	31	24
Southern Europe [a]	47	41	32	27
Oceania [b]	6	23	34	43
Australia and New Zealand	5	12	40	49
Melanesia	1	85	5	10
USSR [a]	111	45	28	27

Source: *International Labour Review* (January–February, 1967); ILO estimates based on national censuses and sample surveys.

Note: Owing to independent rounding, the sum of the parts may not add up to group totals.

[a] More developed regions.

[b] Excluding Polynesia and Micronesia.

* An ILO survey for 1970 is due to be published later in the decade. In 1969, however, the OECD in Paris published a breakdown of the labor force in West Europe, by sectors, which provides for the comparisons in Table 2.

TABLE 2

Labor Force and GNP in Western Europe and United States by Sectors, 1969

COUNTRY	AGRICULTURE		INDUSTRY		SERVICES	
	PERCENT-AGE OF GNP	PERCENT-AGE OF LABOR	PERCENT-AGE OF GNP	PERCENT-AGE OF LABOR	PERCENT-AGE OF GNP	PERCENT-AGE OF LABOR
West Germany	4.1	10.6	49.7	48.0	46.2	41.4
France	7.4	16.6	47.3	40.6	45.3	42.8
Britain	3.3	3.1	45.7	47.2	51.0	49.7
Sweden	5.9	10.1	45.2	41.1	48.9	48.8
Netherlands	7.2	8.3	41.2	41.9	51.6	49.8
Italy	12.4	24.1	40.5	41.1	51.7	45.1
United States	3.0	5.2	36.6	33.7	60.4	61.1

Source: Organisation for Economic Co-operation and Development (Paris, 1969).

the simple routine operations required in machine work. Within industrial societies, the semi-skilled worker has been the single largest category in the labor force. The expansion of the service economy, with its emphasis on office work, education, and government, has naturally brought about a shift to white-collar occupations. In the United States, by 1956, the number of white-collar workers, for the first time in the history of industrial civilization, outnumbered the blue-collar workers in the occupational structure. Since then the ratio has been widening steadily; by 1970 the white-collar workers outnumbered the blue-collar by more than five to four.

But the most startling change has been the growth of professional and technical employment—jobs that usually require some college education—at a rate twice that of the average. In 1940 there were 3.9 million such persons in the society; by 1964 the number had risen to 8.6 million; and it is estimated that by 1975 there will be 13.2 million professional and technical persons, making it the second-largest of the eight occupational divisions in the country, exceeded only by the semi-skilled workers (see Table 3). One further statistical breakdown will round out the picture—the role of the scientists and engineers, who form the key group in the post-industrial society. While the growth rate of the professional and technical class as a whole has been twice that of the average labor force, the growth rate of the scientists and engineers has been triple that of the working population. By 1975 the United States may have about 550,000 scientists (natural and social scientists), as against 275,000 in 1960, and almost a million and a half engineers, compared to 800,000 in 1960. Table 4 [15] gives

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[15] In Table 3 the projected figure for the number of professional and technical persons in 1975 is given as 13.2 million and in Table 4 as 12.9 million. The discrep-

TABLE 3

Employment by Major Occupation Group, 1964, and Projected Requirements, 1975 [a]

MAJOR OCCUPATION GROUP	1964 NUMBER (IN MILLIONS)	1964 PERCENT	1975 NUMBER (IN MILLIONS)	1975 PERCENT	PERCENTAGE CHANGE, 1964–1975
Total employment	70.4	100.0	88.7	100.0	26
White-collar workers	31.1	44.2	42.8	48.3	38
Professional, technical, and kindred workers	8.6	12.2	13.2	14.9	54
Managers, officials, and proprietors, except farm	7.5	10.6	9.2	10.4	23
Clerical and kindred workers	10.7	15.2	14.6	16.5	37
Sales workers	4.5	6.3	5.8	6.5	30
Blue-collar workers	25.5	36.3	29.9	33.7	17
Craftsmen, foremen, and kindred workers	9.0	12.8	11.4	12.8	27
Operatives and kindred workers	12.9	18.4	14.8	16.7	15
Laborers, except farm and mine	3.6	5.2	3.7	4.2	b
Service workers	9.3	13.2	12.5	14.1	35
Farmers and farm managers, laborers, and foremen	4.4	6.3	3.5	3.9	—21

Source: *Technology and the American Economy*, Report of the National Commission on Technology, Automation, and Economic Progress, vol. 1 (Washington, D.C., 1966), p. 30; derived from Bureau of Labor Statistics, *America's Industrial and Occupational Manpower Requirements, 1964–1975*.

Note: Because of rounding, sums of individual items may not equal totals.

[a] Projections assume a national unemployment rate of 3 percent in 1975. The choice of 3 percent unemployment as a basis for these projections does not indicate an endorsement or even a willingness to accept that level of unemployment.

[b] Less than 3 percent.

the breakdown of the professional and technical occupations—the heart of the post-industrial society.

The primacy of theoretical knowledge. In identifying a new and emerging social system, it is not only in the extrapolated social trends, such as the creation of a service economy or the expansion of the professional and technical class, that one seeks to understand fundamental social change. Rather, it is through some specifically defin-

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ancies are due in part to the fact that the figure in Table 4 was calculated five years later, and also because different assumptions about the unemployment rate were made. I have let the figures stand to indicate the range.

TABLE 4

The Make-up of Professional and Technical Occupations, 1960 and 1975 (in thousands)

	1960	1975
Total labor force	66,680	88,660
Total professional and technical	7,475	12,925
Scientific and engineering	1,092	1,994
Engineers	810	1,450
Natural scientists	236	465
Chemists	91	175
Agricultural scientists	30	53
Geologists and geophysicists	18	29
Mathematicians	21	51
Physicists	24	58
Others	22	35
Social scientists	46	79
Economists	17	31
Statisticians and actuaries	23	36
Others	6	12
Technicians (Except medical and dental)	730	1,418
Medical and health	1,321	2,240
Physicians and surgeons	221	374
Nurses, professional	496	860
Dentists	87	125
Pharmacists	114	126
Psychologists	17	40
Technicians (Medical and dental)	141	393
Others	245	322
Teachers	1,945	3,063
Elementary	978	1,233
Secondary	603	1,160
College	206	465
Others	158	275
General	2,386	4,210
Accountants	429	660
Clergymen	200	240
Editors and reporters	100	128
Lawyers and judges	225	320
Arts and entertainment	470	774
Architects	30	45
Librarians	80	130
Social workers	105	218
Others (Airline pilots, photographers, personnel relations, etc.)	747	1,695

Source: BLS Bulletin no. 1606, "Tomorrow's Manpower Needs," vol. IV (February 1969), Appendix E, pp. 28–29.

ing characteristic of a social system, which becomes the axial principle, that one establishes a conceptual schema. Industrial society is the coordination of machines and men for the production of goods. Post-industrial society is organized around knowledge, for the purpose of social control and the directing of innovation and change; and this in turn gives rise to new social relationships and new structures which have to be managed politically.

Now, knowledge has of course been necessary in the functioning of any society. What is distinctive about the post-industrial society is the change in the character of knowledge itself. What has become decisive for the organization of decisions and the direction of change is the centrality of *theoretical* knowledge—the primacy of theory over empiricism and the codification of knowledge into abstract systems of symbols that, as in any axiomatic system, can be used to illuminate many different and varied areas of experience.

Every modern society now lives by innovation and the social control of change, and tries to anticipate the future in order to plan ahead. This commitment to social control introduces the need for planning and forecasting into society. It is the altered awareness of the nature of innovation that makes theoretical knowledge so crucial.

One can see this, first, in the changed relationship between science and technology. Almost all the major industries we still have—steel, electric power, telegraph, telephone, automobiles, aviation—were nineteenth-century industries (although steel begins in the eighteenth century and aviation in the twentieth), in that they were mainly the creation of inventors, inspired and talented tinkerers who were indifferent to science and the fundamental laws underlying their investigations. Kelly and Bessemer, who (independently) created the oxidation process that makes possible the steel converter and the mass production of steel, were unaware of their contemporary, Henry Clifton Sorby, whose work in metallurgy disclosed the true microstructure of steel. Alexander Graham Bell, inventor of the telephone, was in Clerk Maxwell's opinion a mere elocutionist who "to gain his private ends [money] has become an electrician." Edison's work on "etheric sparks," which led to the development of the electric light and generated a vast new revolution in technology, was undertaken outside the theoretical research in electromagnetism and even in hostility to it. But the further development of electrodynamics, particularly in the replacement of steam engines, could only come from engineers with formal training in mathematical physics. Edison, as one biographer has written, lacked "the power of abstraction." [16]

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[16] Matthew Josephson, *Edison* (New York, 1959), p. 361.

What might be called the first "modern" industry, because of its intricate linking of science and technology, is chemistry, since one must have a theoretical knowledge of the macromolecules one is manipulating in order to do chemical synthesis—the recombination and transformation of compounds.[17] In 1909 Walter Nerst and Fritz Haber converted nitrogen and hydrogen to produce synthetic ammonia. Working from theoretical principles first predicated by the Frenchman Henri Le Chatelier in 1888, the two German chemists provided a spectacular confirmation of Kant's dictum that there is nothing so practical as a good theory.[18] The irony, however, lies in the use of the result.

War is a technological forcing house, but modern war has yoked science to technology in a radically new way. Before World War I, every General Staff calculated that Germany would either win a quick, smashing victory or, if France could hold, the war would end quickly in a German defeat (either in the field or at the negotiating table). The reasoning was based on the simple fact that Chile was Germany's (and the world's) major source of the natural nitrates needed for fertilizer and for explosives and, in wartime, Germany's access to Chile would be cut off by the British Navy. In 1913 Germany used about 225,000 tons of nitrogen, half of which was imported. Stocks began to fall, but the Haber-Bosch process for the manufacture of synthetic ammonia developed so rapidly that by 1917 it accounted for 45 percent of Germany's production of nitrogen compounds. By the armistice Germany was almost self-sufficient in nitrogen,[19] and because she was able to hold out, the war became a protracted struggle of static trench warfare and slaughter.

In the latter sense, World War I was the very last of the "old" wars

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[17] Aviation is an interesting transition. The first inventors were tinkerers, but the field could develop only through the use of scientific principles. Langley (1891) and Zahm (1902–1903) started the new science of aerodynamics by studying the behavior of air currents over different types of airfoils. At the same time, in 1900, the Wright brothers began tinkering with gliders, and in 1903 put a gasoline-powered engine into an airplane. But further work was possible only through the development, after 1908, of experiments (such as models in wind tunnels) and mathematical calculations (such as airflows over different angles of wings) based on physical laws.

[18] See Eduard Farber, "Man Makes His Materials," in Kransberg and Pursell, eds. *Technology and Western Civilization*, vol. 2 (New York, 1967).

[19] See L. F. Haber, *The Chemical Industry, 1900–1930* (Oxford, 1971), chap. 7, pp. 198–203. As Haber writes:

> "The Haber process . . . was still largely an unknown factor when the Great War broke out. The synthesis of ammonia . . . represents one of the most important advances in industrial chemistry. . . . The process, discovered by Fritz Haber and developed industrially by Carl Bosch, was the first application of high-pressure synthesis; the technology of ammonia production, appropriately modified, was used later in the synthesis of methanol and the hydrogenation of coal to petroleum. Its influence extends to present-day techniques of oil refining and use of cracker gases from refining operations for further synthesis." Ibid., p. 90.

of human civilization. But with the new role of science it was also the first of the "new" wars. The eventual symbolic fusion of science and war was, of course, in World War II the atom bomb. It was a demonstration, as Gerald Holton has written, "that a chain of operations, starting in a scientific laboratory, can result in an event of the scale and suddenness of a mythological occurrence." Since the end of World War II the extraordinary development of scientific technology has led to hydrogen bombs, distant-early-warning networks coordinated in real time through computer systems, intercontinental ballistics missiles, and, in Vietnam, the beginning of an "automated" battlefield through the use of large-scale electronic sensing devices and computer-controlled retaliatory strikes. War, too, has now come under the "terrible" dominion of science, and the shape of war, like all other human activity, has been drastically changed.

In a less direct but equally important way, the changing relation between theory and empiricism is reflected in the formulation of government policy, particularly in the management of the economy. During the Great Depression of the 1930s, almost every government floundered about and had no notion of what to do with any confidence. In Germany in 1930, the socialist economists who determined government policy insisted that the depression would have to "run its course," meaning that the "overproduction" which caused it, by their Marxist reasoning, would be sopped up. In England, there was a similar sense of hopelessness. Tom Jones, a confidant of Stanley Baldwin and a member of the Unemployment Assistance Board, noted in a letter to Abraham Flexner on March 1, 1934: "On the home front we have favourable if slight evidence of improved trade, but nothing that will make any dent in the unemployment figures. It is slowly but surely being realized by more and more that the great majority of these will never work again, and people like Lindsay of Balliol, T.J., and that ilk, are facing up to big and permanent developments of these occupational and training centres."[20]

In the United States, Franklin D. Roosevelt tinkered with a wide variety of programs. Through the National Recovery Administration he set up an elaborate price-fixing and regulative set of codes which resembled a corporate state. On the advice of George Warren, he manipulated the gold content of the dollar in order to raise the price level. To do something for the idle, he began a large campaign of public works. Few of these policies derived from any comprehensive theory about economic recovery; there was none at hand. As Rexford Tugwell, one of Roosevelt's economic advisors, later observed, Roosevelt simply was trying one "magical formula" after another in the hope of finding some combination that would get the economy moving.[21]

It was largely through the joining of theory and policy that a better understanding of economic management was achieved. Keynes provided the theoretical justification for the intervention of government into the economy as the means of bridging the gap between saving and investment.[22] The work of Kuznets, Hicks, and others in macro-economics gave government policy a firm framework through the creation of a system of national economic accounts—the aggregations of economic data and the fitting of such components as investment and consumption into product accounts and income accounts—so that one could measure the level of economic activity and decide which sectors needed government intervention.

The other major revolution in economics has been the attempted use of an increasingly rigorous, mathematically formalized body of economic theory, derived from the general equilibrium theory of Walras and developed in the last three decades by Leontief, Tinbergen, Frisch, and Samuelson[23] for policy purposes. In the past, these concepts and tools—production functions, consumption functions, time preferences, and discounting—though powerful as abstractions were remote from empirical content because there was no appropriate quantitative data for testing and applying this body of theory.[24]

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[20] Thomas Jones, *A Diary with Letters* (New York, 1954), p. 125. Lindsay is A. D. Lindsay, Master of Balliol College for twenty-five years until 1949. T. J. is an ironic reference by Jones to himself.

[21] See Rexford G. Tugwell, *The Democratic Roosevelt* (New York, 1957), chap. 15, esp. pp. 312–313.

[22] The Keynesian revolution in economics actually occurred after most of the economies had recovered from the depression even though many policies, particularly so-called unbalanced budgets or deficit financing, were adopted by trial-and-error and had "Keynesian" effects. The most self-conscious effort to use the new economics was in Sweden, where the socialist finance minister, Ernest Wigforss, broke away from Marxist thinking and, on the advice of the economists Erik Lindahl and Gunnar Myrdal, pursued an active fiscal and public-works policy which was Keynesian before Keynes, i.e. before the publication of Keynes' *General Theory* in 1936.

[23] Thirty years ago few, if any, graduate schools taught mathematical economics. The turning point, probably, was the publication of Paul Samuelson's *Foundations of Economic Analysis* in 1947, which presented a mathematically formalized version of neoclassical economics. Today, no one can work in economic theory without a solid grounding in mathematics.

[24] It is striking that during the depression there was no real measure of the extent of unemployment because of the confusion over a conceptual definition and the lack of sample survey techniques to make quick counts; the government relied on the 1930 census and some estimates from manufacturing establishments. In 1921, when President Harding called a conference of experts to discuss the unemployment that accompanied the postwar depression, estimates ranged widely and the final figure published was decided, literally, by majority vote. The confusions about who should be counted, or what constituted the "labor force," continued through the 1930s and a settled set of definitions and figures emerged only in the 1940s. Nor were there, of course, the Gross National Product and national-income accounts to give a view of

The development of modern economics, in this respect, has been possible because of the computer. Computers have provided the bridge between the body of formal theory and the large data bases of recent years; out of this has come modern econometrics and the policy orientation of economics.[25] One major area has been the models of interdependencies among industries such as the input-output matrices developed by Wassily Leontieff, which simplify the general equilibrium system of Walras and show, empirically, the transactions between industries, or sectors, or regions. The input-output matrix of the American economy is a grid of 81 industries, from Footwear and other Leather Products (1) to Scrap, Used, and Secondhand Goods (81) grouped into the productive, distributive, and service sectors of the economy. A dollar-flow table shows the distribution of the output of any one industry to each (or any) of the other 80 sectors. The input-output matrix shows the mix and proportions of inputs (from each or several industries) which go into a specific unit of output (in dollar value or physical production terms). An inverse matrix shows the indirect demand generated by a product as well as the direct demand. Thus, one can trace the effect of the final consumer demand say for automobiles on the amount (or value) of iron ore, even though the automobile industry buys no iron ore directly. Or one can see what proportion of iron ore, as a raw material, goes into such final products as autos, ships, buildings, and the like. In this way, one can chart the changes in the nature of final demands in terms of the differential effects on each sector of the economy.[26] Input-output tables are now the basic tools for national economic planning and they have been applied in regional planning, through computerized models, to test the effect on trade of changes in population distributions.

The large econometric models of the economy, such as the Brookings model discussed earlier, allow one to do economic forecasting, while the existence of such computer models now enables economists to do policy "experiments," such as the work of Fromm and Taubman in simulating eight different combinations of fiscal and monetary policy for the period 1960–1962, in order to see which policy might have been the most effective.[27] With these tools one can test different theories to see whether it is now possible to do "fine tuning" of the economy.

It would be technocratic to assume that the managing of an economy is only a technical offshoot of a theoretical model. The overriding considerations are political, and set the frames of decision. Yet the economic models indicate the boundaries of constraint within which one can operate, and they can specify the consequences of alternative political choices.[28] The crucial point is that economic policy formulations, though not an exact art, now derive from theory, and often must find justification in theory. The fact that a Nixon administration in 1972 could casually accept the concept of a "full employment budget," which sets a level of government expenditures *as if* there were full utilization of resources (thus automatically accepting deficit financing) is itself a measure of the degree of economic sophistication that government has acquired in the past thirty years.

The joining of science, technology, and economics in recent years is symbolized by the phrase "research and development" (R & D). Out of this have come the science-based industries (computers, electronics, optics, polymers) which increasingly dominate the manufacturing sector of the society and which provide the lead, in product cycles, for the advanced industrial societies. But these science-based industries, unlike industries which arose in the nineteenth century, are primarily dependent on theoretical work prior to production.

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the economy as a whole. This came into public-policy use only in 1945. (I am indebted to an unpublished dissertation at MIT by Judith de Neufville, on social indicators, for the illustration on unemployment statistics.)

[25] Charles Wolf, Jr., and John H. Enns have provided a comprehensive review of these developments in their paper "Computers and Economics," Rand Paper P-4724. I am indebted to them for a number of illustrations.

[26] Mathematically speaking, an input-output matrix represents a set of simultaneous linear equations—in this case 81 equations with 81 variables which are solved by matrix algebra. See Wassily Leontieff, *The Structure of the American Economy: Theoretical and Empirical Explorations in Input-Output Analysis* (New York, 1953). Ironically, when the Bureau of Labor Statistics tried to set up an input-output grid for the American economy in 1949, it was opposed by business on the ground that it was a tool for socialism, and the money was initially denied.

[27] Their conclusions: that the largest impact on real GNP came from increases in government nondurable and construction expenditures. Income-tax cuts were less of a stimulant than increase in expenditures. Gary Fromm and Paul Taubman, *Policy Simulations with an Econometric Model* (Brookings Institution, Washington, D.C., 1968), cited in Wolf and Enns, op. cit.

[28] With modern economic tools, Robert M. Solow argues, an administration can, within limits, get the measure of economic activity it wants, for the level of government spending can redress the deficits of private spending and step up economic activity. But in so doing, an administration has to choose between inflation or full employment; this dilemma seems to be built into the market structure of capitalist economies. An administration has to make a trade-off—and this is a political choice. Democrats have preferred full employment and inflation, Republicans price stability and slow economic growth.

In the last few years, however, there has been the new phenomenon—simultaneous high unemployment and high inflation. For reasons that are not clear, unemployment no longer "disciplines" an economy into bringing prices down, either because of substantial welfare cushions (e.g. unemployment insurance), wage-push pressure in organized industries, or the persistent expectation of price rises that discounts inflation.

The two turning points in modern economic policy were President Kennedy's tax cut in 1964, which canonized Keynesian principles in economic policy, and President Nixon's imposition of wage and price controls in 1971. Though mandatory controls were relaxed in 1973, the option to use them now remains.

The computer would not exist without the work in solid-state physics initiated forty years ago by Felix Bloch. The laser came directly out of I.I. Rabi's research thirty years ago on molecular optical beams. (One can say, without being overly facile, that U.S. Steel is the paradigmatic corporation of the first third of the twentieth century, General Motors of the second third of the century, and IBM of the final third. The contrasting attitudes of the corporations toward research and development are a measure of these changes.)

What is true of technology and economics is true, albeit differentially, of all modes of knowledge: the advances in a field become increasingly dependent on the primacy of theoretical work, which codifies what is known and points the way to empirical confirmation. In effect, theoretical knowledge increasingly becomes the strategic resource, the axial principle, of a society. And the university, research organizations, and intellectual institutions, where theoretical knowledge is codified and enriched, become the axial structures of the emergent society.

The planning of technology. With the new modes of technological forecasting, my fourth criterion, the post-industrial societies may be able to reach a new dimension of societal change, the planning and control of technological growth.

Modern industrial economies became possible when societies were able to create new institutional mechanisms to build up savings (through banks, insurance companies, equity capital through the stock market, and government levies, i.e. loans or taxes) and to use this money for investment. The ability consistently to re-invest annually at least 10 percent of GNP became the basis of what W.W. Rostow has called the "take-off" point for economic growth. But a modern society, in order to avoid stagnation or "maturity" (however that vague word is defined), has had to open up new technological frontiers in order to maintain productivity and higher standards of living. If societies become more dependent on technology and new innovation, then a hazardous "indeterminacy" is introduced into the system. (Marx argued that a capitalist economy had to expand or die. Later Marxists, such as Lenin or Rosa Luxemburg, assumed that such expansion necessarily had to be geographical; hence the theory of imperialism. But the greater measure of expansion has been capital-intensive or technological.) Without new technology, how can growth be maintained? The development of new forecasting and "mapping techniques" makes possible a novel phase in economic history—the conscious, planned advance of technological change, and therefore the reduction of indeterminacy about the economic future. (Whether this can actually be done is a pregnant question, discussed in Chapter 3.)

But technological advance, as we have learned, has deleterious side

effects, with second-order and third-order consequences that are often overlooked and certainly unintended. The increasing use of cheap fertilizers was one of the elements that created the revolution in agricultural productivity, but the run-off of nitrates into the rivers has been one of the worst sources of pollution. The introduction of DDT as a pesticide saved many crops, but also destroyed wildlife and birds. In automobiles, the gasoline engine was more effective than steam, but it has smogged the air. The point is that the introduction of technology was uncontrolled, and its initiators were interested only in single-order effects.

Yet none of this has to be. The mechanisms of control are available as well. As a number of studies by a panel of the National Academy of Science has shown, if these technologies had been "assessed" before they were introduced, alternative technologies or arrangements could have been considered. As the study group reported:

> The panel believes that in some cases an injection of the broadened criteria urged here might have led, or might in the future lead, to the selection or encouragement of different technologies or at least modified ones—functional alternatives with lower "social costs" (though not necessarily lower total costs). For example, bioenvironmental rather than primarily chemical devices might have been used to control agricultural pests, or there might have been design alternatives to the purely chemical means of enhancing engine efficiency, or mass transit alternatives to further reliance upon the private automobile.[29]

Technology assessment is feasible. What it requires is a political mechanism that will allow such studies to be made and set up criteria for the regulation of new technologies.[30] (This question is elaborated in Chapter 4.)

The rise of a new intellectual technology. "The greatest invention

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[29] *Technology: Processes of Assessment and Choice*, Report of the National Academy of Sciences, U.S. House of Representatives, Committee on Science and Astronautics, July 1969.

[30] To further the idea of technology assessment, the National Academy of Engineering undertook three studies in developing fields, that of computer-assisted instruction and instructional television; subsonic aircraft noise; and multiphasic screening in health diagnosis. The study concluded that technology assessment was feasible, and outlined the costs and scope of the necessary studies. In the case of technological teaching aids, the study considered eighteen different impacts they might have. In the case of noise, they examined the costs and consequences of five alternative strategies, from relocating airports or soundproofing nearby homes to modifying the airplanes or their flight patterns. See *A Study of Technology Assessment*, Report of the Committee on Public Engineering Policy, National Academy of Engineering, July 1969.

The idea of "technology assessment" grew largely out of studies made by the House Science and Astronautics Committee, and in 1967 a bill was introduced in the House by Congressman Daddario for a Technology Assessment Board. The bill was passed in 1972 and the Congress, not the Executive, is charged with setting up a Technology Assessment Office.

of the nineteenth century," Alfred North Whitehead wrote, "was the invention of the method of invention. A new method entered into life. In order to understand our epoch, we can neglect all the details of change, such as railways, telegraphs, radios, spinning machines, synthetic dyes. We must concentrate on the method itself; that is the real novelty, which has broken up the foundations of the old civilization." [31]

In the same spirit, one can say that the methodological promise of the second half of the twentieth century is the management of organized complexity (the complexity of large organizations and systems, the complexity of theory with a large number of variables), the identification and implementation of strategies for rational choice in games against nature and games between persons, and the development of a new intellectual technology which, by the end of the century, may be as salient in human affairs as machine technology has been for the past century and a half.

In the eighteenth and nineteenth centuries, scientists learned how to handle two-variable problems: the relationship of force to distance in objects, of pressure and volume in gases, of current versus voltage in electricity. With some minor extensions to three or four variables, these are the bedrock for most modern technology. Such *objects* as telephones, radio, automobile, airplane, and turbine are, as Warren Weaver puts it, problems of "complex simplicity." [32] Most of the models of nineteenth- and early-twentieth-century social science paralleled these simple interdependencies: capital and labor (as fixed and variable capital in the Marxist system; as production functions in neo-classical economics), supply and demand, balance of power, balance of trade. As closed, opposed systems, to use Albert Wohlstetter's formulation, they are analytically most attractive, and they simplify a complex world.

In the progression of science, the next problems dealt with were not those of a small number of interdependent variables, but the ordering of gross numbers: the motion of molecules in statistical mechanics, the rates of life expectancies in actuarial tables, the distribution of heredities in population genetics. In the social sciences, these became the problems of the "average man"—the distributions of intelligence, the rates of social mobility, and the like. These are, in Warren Weaver's term, problems of "disorganized complexity," but their solutions were made possible by notable advances in probability theory and statistics which could specify the results in chance terms.

The major intellectual and sociological problems of the post-industrial society are, to continue Weaver's metaphor, those of "organized complexity"—the management of large-scale systems, with large numbers of interacting variables, which have to be coordinated to achieve specific goals. It is the *hubris* of the modern systems theorist that the techniques for managing these systems are now available.

Since 1940, there has been a remarkable efflorescence of new fields whose results apply to problems of organized complexity: information theory, cybernetics, decision theory, game theory, utility theory, stochastic processes. From these have come specific techniques, such as linear programming, statistical decision theory, Markov chain applications, Monte Carlo randomizing, and minimax solutions, which are used to predict alternative optimal outcomes of different choices in strategy situations. Behind all this is the development in mathematics of what Jagit Singh calls "comprehensive numeracy." [33] Average properties, linear relationships, and no feedback, are simplifications used earlier to make mathematics manually tractable. The calculus is superbly suited to problems of a few variables and rates of change. But the problems of organized complexity have to be described in probabilities—the calculable consequences of alternative choices, which introduce constraints either of conflict or cooperation—and to solve them one must go beyond classical mathematics. Since 1940, the advances in probability theory (once intuitive and now rigorous and axiomatic), sophisticated set theory, and game and decision theory have made further advances in application theoretically possible.

I have called the applications of these new developments "intellectual technology" for two reasons. Technology, as Harvey Brooks defines it, "is the use of scientific knowledge to specify ways of doing things in a *reproducible* manner." [34] In this sense, the organization of a hospital or an international trade system is a *social* technology, as the automobile or a numerically controlled tool is a *machine* technology. An *intellectual* technology is the substitution of algorithms (problem-solving rules) for intuitive judgments. These algorithms may be embodied in an automatic machine or a computer program or a set of instructions based on some statistical or mathematical for-

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[31] *Science and the Modern World*, p. 141.

[32] Warren Weaver, "Science and Complexity," in *The Scientists Speak*, ed. Warren Weaver (New York, 1947). I am indebted to a former special student at Columbia, Norman Lee, for this citation and for a number of other suggestions in this section.

[33] Jagit Singh, *Great Ideas of Operations Research* (New York, 1968).

[34] Harvey Brooks, "Technology and the Ecological Crisis," lecture given at Amherst, May 9, 1971, p. 13 from unpublished text, emphasis added. For an application of these views, see the reports of two committees chaired by Professor Brooks, *Technology, Processes of Assessment and Choice*, Report of the National Academy of Science, published by the Committee on Science and Astronauticism, U.S. House of Representatives, July 1969; and, *Science Growth and Society*, OECD (Paris, 1971).

mula; the statistical and logical techniques that are used in dealing with "organized complexity" are efforts to formalize a set of decision rules. The second reason is that without the computer, the new mathematical tools would have been primarily of intellectual interest, or used, in Anatol Rappoport's phrase, with "very low resolving power." The chain of multiple calculations that can be readily made, the multivariate analyses that keep track of the detailed interactions of many variables, the simultaneous solution of several hundred equations—these feats which are the foundation of comprehensive numeracy—are possible only with a tool of intellectual *technology*, the computer.

What is distinctive about the new intellectual technology is its effort to define rational action and to identify the means of achieving it. All situations involve constraints (costs, for example) and contrasting alternatives. And all action takes place under conditions of certainty, risk, or uncertainty. Certainty exists when the constraints are fixed and known. Risk means that a set of possible outcomes is known and the probabilities for each outcome can be stated. Uncertainty is the case when the set of possible outcomes can be stipulated, but the probabilities are completely unknown. Further, situations can be defined as "games against nature," in which the constraints are environmental, or "games between persons," in which each person's course of action is necessarily shaped by the reciprocal judgments of the others' intentions.[35] In all these situations, the desirable action is a

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[35] Most of the day-to-day problems in economics and management involve decision-making under conditions of certainty; i.e. the constraints are known: These are such problems as proportions of product mixes under known assumptions of cost and price, production scheduling by size, network paths, and the like. Since the objectives are clear (the most efficient routing, or the best profit yield from a product mix), the problems are largely mathematical and can be solved by such techniques as linear programming. The theory of linear programming derives from a 1937 paper by John von Neumann on the general equilibrium of a uniformly expanding closed economy. Many of the computational procedures were developed by the Soviet economist L.V. Kantorovich, whose work was ignored by the regime until Stalin's death. Similar techniques were devised in the late 1940s by the Rand mathematician G.B. Dantzig, in his simplex method. The practical application of linear programming had to await the development of the electronic computer and its ability (in some transportation problems, for example) to handle 3200 equations and 600,000 variables in sequence. Robert Dorfman has applied linear programming to the theory of the firm, and Dorfman, Samuelson and Solow used it in 1958 in an inter-industry model of the economy to allow for substitutability of supply and a criterion function that allows a choice of solutions for different objectives within a specified sector of final demand.

Criteria for decision-making under conditions of uncertainty were introduced by the Columbia mathematical statistician Abraham Wald in 1939. It specifies a "maximin" criterion in which one is guided by an expectation of the worst outcome. Leonid Hurwicz and L.J. Savage have developed other strategies, such as Savage's charmingly named "criteria of regret," whose subjective probabilities may cause one to increase or decrease a risk.

strategy that leads to the optimal or "best" solution; i.e. one which either maximizes the outcome or, depending upon the assessment of the risks and uncertainties, tries to minimize the losses. Rationality can be defined as judging, between two alternatives, which one is capable of yielding that preferred outcome.[36]

Intellectual technology makes its most ambitious claims in systems analysis. A system, in this sense, is any set of reciprocal relationships in which a variation in the character (or numerical value) of one of the elements will have determinate—and possibly measurable—consequences for all the others in the system. A human organism is a determinate system; a work-group whose members are engaged in specialized tasks for a common objective is a goal-setting system; a pattern of bombers and bases forms a variable system; the economy as a whole is a loose system.

The problem of the number of variables has been a crucial factor in the burgeoning fields of systems analysis for military or business decisions. In the design of an airplane, say, a single performance parameter (speed, or distance, or capacity) cannot be the measure of the intrinsic worth of a design, since these are all interrelated. Charles J. Hitch has used this to illustrate the problems of systems analysis for bombers. "Suppose we ruthlessly simplify aircraft characteristics to three—speed, range, altitude. What else do we have to consider in measuring the effectiveness of the bombers of 1965? At least the following: the formation they will use, their flight path to target, the base system, the target system, the bombs, and the enemy defenses. This may not sound like many parameters (in fact, it is far fewer than

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Game theory has a long history but the decisive turn occurred in a 1928 paper of John von Neumann which provided a mathematical proof of a general minimax strategy for a two-person game. The 1944 book by von Neumann and Morgenstern, *Theory of Games and Economic Behavior* (Princeton), extended the theory of games with more than two persons and applied the theorem to economic behavior. The strategy proposed by von Neumann and Morgenstern—that of minimax, or the minimization of maximum loss—is defined as the rational course under conditions of uncertainty.

Games-and-decision theory was given an enormous boost during World War II, when its use was called "operations research." There was, for example, the "duel" between the airplane and the submarine. The former had to figure out the "best" search pattern for air patrol of a given area; the other had to find the best escape pattern when under surveillance. Mathematicians in the Anti-Submarine Warfare Operations Research Group, using a 1928 paper of von Neumann, figured out a tactical answer.

The game-theory idea has been widely applied—sometimes as metaphor, sometimes to specify numerical values for possible outcomes—in bargaining and conflict situations. See Thomas C. Schelling, *The Strategy of Conflict* (Cambridge, Mass., 1960).

[36] R. Duncan Luce and Howard Raiffa, *Games and Decisions* (New York, 1957). My discussion of rationality is adapted from the definition on p. 50; that of risk, certainty, and uncertainty from p. 13.

would be necessary) but if we go no higher than ten, and if we let each parameter take only two alternative values, we already have 2^{10} cases to calculate and compare (2^{10} 1000). If we let each parameter take four alternative values we have 4^{10} cases (4^{10} 1,000,000)."[37] The choice of a new kind of bomber system was thus not simply a question one could leave to the "old" air force generals. It had to be computed in terms of cost-effectiveness on the weighing of these many variables.

The crucial point is the argument of Jay Forrester and others, that the nature of complex systems is "counterintuitive." A complex system, they insist, involves the interaction of too many variables for the mind to hold in correct order simultaneously. Or, as Forrester also suggests, intuitive judgments respond to immediate cause-and-effect relations which are characteristic of simpler systems, whereas in complex systems the actual causes may be deeply hidden or remote in time or, more often, may lie in the very structure (i.e. pattern) of the system itself, which is not immediately recognizable. For this reason, one has to use algorithms, rather than intuitive judgments, in making decisions.[38]

The cause-and-effect deception is illustrated in Forrester's computer simulation model of how a central city first grows, then stagnates and decays. The model is composed of three major sectors, each containing three elements. The business sector has new, mature, and declining industries; the housing sector has premium, worker, and underemployed housing; and the population sector holds managerial-professionals, laborers, and underemployed. These nine elements are linked first with twenty-two modes of interaction (e.g. different kinds of migrations) and then with the outside world through multiplier functions. The whole, however, is a closed, dynamic system which models the life-history of the city. At first the vacant land fills up, different elements readjust, an equilibrium is attained, then stagnation develops as industries die and taxes increase. The sequence runs over a period of 250 years.

From this model, Forrester has drawn a number of policy conclusions. He argues that increased low-income housing in the central city has the negative effects of bringing in more low-income people, decreasing the tax base, and discouraging new industry. Job-training programs have the undesirable consequence of taking trained workers out of the city. None of this surprises Forrester because, as he points out, the direct approach is to say that if there is a need for more homes, build more housing, whereas the more difficult and complex approach would be to try to change the job patterns and population balances. In this sense, the policies which are wrong are the immediate cause-and-effect judgments, whereas the better policies would be the "counter-intuitive ones."

The decision-making logic which follows systems analysis is clear. In the case of Rand and the Air Force, it led to the installation of technocrats in the Defense Department, the creation of the Program Planning Budget Systems (PPBS), which was responsible in large measure for the realignment of strategic and tactical programs, and the imposition of cost-effectiveness criteria in the choice of weapons systems. In Forrester's illustration, it would lead to the substitution of economic rather than political judgments in the crucial policy decisions of city life.

The goal of the new intellectual technology is, neither more nor less, to realize a social alchemist's dream: the dream of "ordering" the mass society. In this society today, millions of persons daily make billions of decisions about what to buy, how many children to have, whom to vote for, what job to take, and the like. Any single choice may be as unpredictable as the quantum atom responding erratically to the measuring instrument, yet the aggregate patterns could be charted as neatly as the geometer triangulates the height and the horizon. If the computer is the tool, then decision theory is its master. Just as Pascal sought to play dice with God, and the physiocrats attempted to draw an economic grid that would array all exchanges among men, so the decision theorists seek their own *tableau entier*—the compass of rationality, the "best" solution to the choices perplexing men.

That this dream—as utopian, in its way, as the dreams of a perfect commonwealth—has faltered is laid, on the part of its believers, to the human resistance to rationality. But it may also be due to the very idea of rationality which guides the enterprise—the definition of function without a justification of reason. This, too, is a theme I explore in these essays.

The History of an Idea

No idea ever emerges full-blown from the head of Jove, or a secondary muse, and the five dimensions which coalesced in the concept of the post-industrial society (its intellectual antecedents are sketched in

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[37] See Charles J. Hitch, "Analysis for Air Force Decisions," in *Analysis for Military Decisions: the Rand Lectures on Systems Analysis*, ed. E. S. Quade (Chicago, 1964). His illustration is conjectural. A more relevant but much more complicated illustration is Quade's case history, in the same volume, on the selection and use of strategic air bases.

[38] Jay W. Forrester, *Urban Dynamics* (Cambridge, Mass., 1969), pp. 10–11.