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TECHNICAL CHANGE AND CAPITAL FORMATION

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1. *Acts of Skill and Insight*

THE STUDY of technical change in the economy has been hindered by the failure of students to treat effectively the kinds of novelty that are a normal and continuous consequence of the skilled activities of engineers and technicians and those that are related to acts of insight and the process of invention. In the history of the sciences and technology, primary emphasis has fallen upon the process of invention and, all too frequently, upon selected items in the process as a whole. In the administration of the economy, however, acts of skill have played a commanding part in the diffusion of new technical processes both by fields and by geographic areas.

Many presume that the diffusion of technical knowledge and the applications of known techniques are imitative acts devoid of novelty. Tarde's sharp distinction between imitation and invention is hardly more than a broad generalization of attitudes that have been widely held over long periods of time.[1] But these interpretations rest upon concepts of knowledge, skill, and invention that fail to recognize the pervasiveness of novelty in our behavior. They are inconsistent with the concept of emergent novelty that is rapidly developing in the biological and psychological fields.

The distinction between acts of skill and inventions is suggestively drawn by Gestalt psychology. Novelty is to be found in the more complex acts of skill, but it is of a lower order than at the level of invention. As long as action remains within the limits of an act of skill, the insight required is within the capacity of a trained individual and can be performed at will at any time. At the level of invention, however, the act of insight can be achieved only by superior persons under special constellations of circumstance. Such acts of insight frequently emerge in the course of performing acts of skill, though characteristically the act of insight is induced by the conscious perception of an unsatisfactory gap in knowledge or mode

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[1] Michael M. Davis, "Gabriel Tarde: An Essay in Sociological Theory," thesis, Columbia University, 1906, pp. 52 and 56-61.

of action.[2] The principles underlying the distinction are clear, but application to particular cases is difficult, because it is not easy to know whether even a specific individual actually performed the act as and when he chose. Common usage reflects the difficulty of making rigorous classifications of activities that involve any elements of novelty.

This problem of boundaries between acts of skill and inventions has a long history and is an underlying feature of the laws granting monopoly privileges for the introduction of new industries and new processes. Special privileges were at first granted to favorites of the rulers in nearly all European states, but opposition developed and it became customary to base the privileges on some element of novelty. Despite emphasis upon the idea of invention, privileges were given for introducing new trades and processes that were admittedly not inventions. Although this development followed similar lines in several major jurisdictions, it will be enough for our present purpose to confine our attention to English law. A principle first stated by counsel in 1598 was embodied in the important section of the Statute of Monopolies (1624) which became the basis of the patent system in England. This authorized the issue of "letters patents and grants of privilege for the term of fourteen years, or under, to be made of the sole working or making of any manner of new manufactures within this realm, to the true and first inventor or inventors of such manufactures."[3] Until the middle of the nineteenth century, judicial decisions emphasized the phrase "new manufactures within this realm." The device or process needed only to be new in England; and it did not have to be an invention. As late as 1803 Lord Ellenborough stated the issue sharply. "There are common elementary materials to work with in machinery, but it is the adoption of those materials to the execution of any particular purpose, that constitutes the invention; and if the application of them be new, if the combination in its nature be essentially new, if it be productive of a new end, and beneficial to the public, it is that species of invention which, protected by the King's Patent, ought to continue to the person the sole right of vending."[4]

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[2] Wolfgang Köhler, *Gestalt Psychology*, Horace Liveright, 1929, pp. 371-394; Kurt Koffka, *Principles of Gestalt Psychology*, London, Routledge, 1935, pp. 382, 628-631, and 641-646; and A. T. Welford, *Skill and Age: An Experimental Approach*, Oxford, 1951, pp. 11-27.

[3] Harold G. Fox, *Monopolies and Patents*, University of Toronto Press, 1947, p. 219.

[4] *Ibid.*, p. 229.

The Constitution of the United States did not permit the issue of a patent for the introduction of a device or process developed abroad by a person other than the person introducing the process in the United States. But improvements that should be classed as the work of a skilled mechanic were not excluded either by the statute or by the earlier case decisions. This trend was reversed in 1850 by the decision in *Hotchkiss* v. *Greenwood*. The doctrine was laid down that "unless more ingenuity and skill in applying the old method . . . were required . . . than were possessed by an ordinary mechanic acquainted with the business, there was an absence of that degree of skill and ingenuity which constitute essential elements of every invention."[5] This doctrine was adopted both in the United States and in England. The British statute of 1932 explicitly excluded any obvious development of existing knowledge; and the Supreme Court of the United States in 1941 took the position that the new device "must reveal the flash of creative genius, not merely the skill of the calling."[6]

It is tempting to fill in the literary background for this identification of invention with the work of genius. As early as the seventeenth century many scientists and inventors were becoming self-conscious about the recognition of the priority of their achievement, for they felt that this constituted their claim to fame. Huygens took pains to state very carefully the relation of his work on the pendulum to the work of Galileo. Newton was offended by Leibnitz's publications on the calculus without the acknowledgements that he felt to be due him.[7]

We cannot give space to this problem, but it is important to recognize the danger of this identification of invention with an act of genius. It leads toward an undue emphasis upon a relatively small number of acts which are presented without due regard to the conditions which made them possible, and to a concept of change at infrequent intervals in units of great magnitude, although the simplest effort of analysis makes it clear that acts of insight are numerous, pervasive, and of very small magnitudes. The analysis of behavior, and most particularly of social action, becomes confused and misleading if the transcendental point of view is not carefully and consistently distinguished from the empirical.

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[5] *Ibid.*, p. 245. [6] *Ibid.*, pp. 239-240 and 247.

[7] Edgar Zilsel, *Die Entstehung des Geniebegriffes*, Tübingen, J. C. B. Mohr, 1926; Nathaniel D. M. Hirsh, *Genius and Creative Intelligence*, Sci-Art Publishers, 1931, esp. pp. 277-317; and Wilhelm Lange-Eichbaum, *The Problem of Genius*, London, Routledge, 1931, pp. 6-7.

All modes of action can be reduced to three categories: innate activities, acts of skill, and inventive acts of insight. The broader descriptions of these categories are clearly formulated in recent research in biology and Gestalt psychology, but so much work remains to be done that definitions of boundaries must be treated tentatively and the interweaving of different types of activity sketched with caution.

Innate activities are unlearned modes of action that develop as responses to the structure of the organism or the biochemical processes that control its functions. Current research and analysis present interpretations of these activities that differ in many important respects from the older concepts of instinct.[8] Acts of skill include all learned activities whether the process of learning is an achievement of an isolated adult individual or a response to instruction by other individuals of the same or different species of organisms. Inventive acts of insight are unlearned activities that result in new organizations of prior knowledge and experience. In this meaning the concept was introduced by Köhler in his study of apes (1917). It has been further developed by Koffka, but it is still incompletely generalized. It is not recognized by those who do not accept the general positions of Gestalt psychology.

Biologists now find grounds for presuming the existence of learning and acts of skill among wide arrays of subhuman organisms, especially among the social insects and many higher mammals. Psychologists recognize the presence of some acts of insight among subhuman organisms, but the basis of inference presents many special problems and results are uncertain. The importance of this new analysis for the social sciences lies in the superiority of these techniques for the study of the boundary between acts of skill and acts of insight at the higher levels in technology and economic administration.

Generalization of the concept of an act of skill leads to its extension to fields of conceptual activity involving interpretations of codes, rules for group behavior, and the execution of policies for individual or group activity. Inventive acts of insight occur in all these conceptual fields. Social activity involves an interweaving of acts of skill with interspersed acts of insight. No particular field

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[8] Nikolaas Tinbergen, *The Study of Instinct*, Oxford, Clarendon Press, 1951; *Comparative Psychology*, Calvin P. Stone, editor, 3rd ed., Prentice-Hall, 1951; William Morton Wheeler, *The Social Insects*, London, Routledge, 1928; and Conroy Lloyd Morgan, *The Criminal Mind*, Longmans, 1930.

should be presumed to involve a single type of action. The term "innovator," as applied by Schumpeter to the entrepreneur, suggests a kind of differentiation from inventors in the technical fields that is likely to be misleading. Executives, like technicians, must be presumed to perform many acts of skill, and likewise to achieve many acts of insight and invention.

Legal doctrines in the field of patent law suggest the more important gradations of novelty that may be found in administration and engineering. The concept of the act of skill presents three choices for testing the relation of existing knowledge to an improvement. We may take as a measure the achievement of any person trained in the field, that of a superior person with general interests and training, or that of a superior person with special interests and training. The inventive act of insight emerges only under special conditions of a different kind. These conditions cannot be controlled at will. The new perception or novel synthesis is produced by some special constellation of circumstances that invites or requires a special response. Although in a particular instance the act of insight may not involve an essentially different response to circumstance from what we find in an act of skill, the conditions which precipitate the act of insight are not regularly recurrent. In the act of skill there are forms of recurring action which fall within a definable range of variation; and, over time, it is presumed that action will be necessary throughout the whole range of variables. Novelties emerge, but within limits which are defined by the possible changes in conditions. From time to time the performance of an act of skill may result in a new observation of the properties of materials or a new perception of relationships or a new mode of action. Acts of insight thus occur in the normal course of the exercise of skills.

Since acts of skill are so directly related to an established technique of action and to organized systems of knowledge, the individual act of novelty is often ignored. Acts of insight, especially at high levels, are likely to become the focus of all our attention, so that we are prone to ignore individual acts of novelty in long sequences of action which can best be described as processes of invention. Uncritical observation of behavior is likely to give too little stress to elements of novelty in acts of skill, and to present inventive acts of insight as completely unconditioned, isolated actions.

In a formal theory of invention, according to the general principles of Gestalt analysis, it is possible to recognize four distinctive steps in the process of invention: the perception of an unsatisfactory pattern, the setting of the stage, the primary act of insight, and critical revision and development. Acts of insight occur at each step if major elements of novelty are involved.[9] The first and last steps in the process commonly involve close relationships with acts of skill. New problems emerge, because some inadequacy of existing knowledge or of current modes of action is perceived. Existing skills are seen to be inadequate. Some measure of failure in the performance of an act of skill touches off a sequence of invention. If stage-setting is deliberately undertaken by systematic experimentation, acts of skill enter at this stage also, but not too clearly. After the major act of insight has occurred, critical revision and development involve a very intimate interweaving of minor acts of insight and acts of skill performed at high levels by persons of special training.

The work of Frank Julian Sprague upon electric traction affords two striking illustrations of the development of new techniques which at the final stages were performed under contracts with sharply restricted terminal dates. Both contracts were designed to demonstrate the possibility of extending to allied fields equipment that was already in use in narrower fields. At that time they were incidental to the activities of an established business, and costs were treated as promotional expenses.[10] The trolley system at Richmond, Virginia had to submit to rigorous tests before a fixed date, as did the multiple-unit system for rapid transit service, first installed at Chicago. Neither dateline was actually met. By making financial concessions, an extension of time was obtained for the Richmond contract. A preliminary test for the system of multiple control was carried out one day after the date specified, and a full test made ten days later. The delays were due partly to illness and partly to mechanical problems and not to new acts of insight or inventions which occurred after the contracts were signed. The substantive inventions preceded the making of the contracts. In terms of the process of invention, the work that held up the contract was work of critical revision. In professional terminology, it was engineering work; the psychologist would classify it as the exercise of a series of acts of skill. They involved a combination of activities in the fields of technology and entrepreneurship.

These instances also serve to demonstrate the need of much in-

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[9] Abbott Payson Usher, *A History of Mechanical Inventions*, McGraw-Hill, 1929, Chap. II; rev. ed., 1954, Chap. IV.

[10] Harold C. Passer, *The Electrical Manufacturers, 1875-1900*, Harvard University Press, 1953, pp. 241-243 and 271-273.

vention after the decisive demonstration of a new technique. Supplementary inventions of tertiary rank were necessary to secure full efficiency, and further secondary inventions were ultimately made. The quality of this work is usually ignored in descriptions of the application of the technique, except in accounts dominated by professional interest in technical detail. Practical application of a new technique does not mean that the process of invention has come to an end. But, in general, it is true that, as development proceeds, acts of skill become increasingly important.

There is no difference in the general character of the behavior of entrepreneurs and technologists. Entrepreneurs and executive directors invent new concepts of social ends and new procedures in social action. They discover new meanings in motivations and new modes of reconciling authority with individual freedom. But these acts of insight are dispersed through a highly diversified array of acts of skill which are often incorrectly classified because they are generalized to a greater degree than acts of skill in the fields commonly regarded as skilled and professional.

In considering the history of science and technology, the acts of insight and the processes of cumulative synthesis that can best be identified with invention are obviously more important than the acts of skill which are performed in the current applications of knowledge to individual and social needs. It is dangerous, however, to presume that the performance of acts of skill does not require abilities of a high order. At lower levels of action mere competence may suffice for much of the activity in the field. At higher levels—in the fields of art and the professions, and in leadership of large groups—mere competence has a narrowly limited value. Virtuosity in performance becames an essential requirement. Accomplishment with such distinction is possible only to small numbers of individuals, and, even if no major acts of insight are involved in their activity, their achievements are no less important to the social life of the group than the achievements of inventors. At the higher levels, however, acts of skill and insight are so completely interwoven that we cannot easily distinguish them.

2. *Primary Inventions and Discoveries*

The concept of a process of invention requires a notion of a sequence of acts of insight which leads to a cumulative synthesis of many items which were originally independent. Strictly speaking, each act of insight is an achievement of novelty of the highest order. Practically, we characterize as an invention only some concept or device that represents a substantial synthesis of old knowledge with new acts of insight. Common usage, however, does not require us to assume that an invention is practical. In fact, there has been a strong tendency to stress the outstanding importance of discoveries of new properties and relationships, and of new devices for producing motion when they are merely laboratory models or small devices for entertainment or mystification. These attitudes are well grounded, and this distinction between the working model or demonstration and the commercially useful machine is especially important for the history of technology since 1600. New scientific concepts have emerged, new devices have been invented, but practical application has been long deferred.

Transcendentalists and romantic individualists have commonly sought a single inventor in each sequence of achievement. Insofar as emphasis has been placed on sheer priority, the scientist is ranked ahead of the engineer, the achievement of a new principle counted as the true invention, and the practical application of the principle treated as a mere unimpeded act of skill achievable by any competent technician. There has been, thus, a large group who wish to credit Galileo with the "invention" of the pendulum clock because he perceived the bare principles involved, though no complete clock movement was produced during his lifetime. The work of Huygens has been treated as the explicit achievement of the discoveries and inventions of Galileo. In general, there has been a tendency to emphasize the scientific achievement if there is any single principle definite enough to seem to imply all the subsequent steps in the sequence. In the history of the steam engine the attempts to give primary credit to the early work have not successfully challenged the common appraisal of Watt's work.

This search for the unique inventor is naïve and ill grounded. All the items specified and many other acts of insight are an integral part of the history of the steam engine. Even if we accept the unduly restricted common meaning of the word invention, there were many inventions and a large number of acts of insight which are entirely ignored by the lay public though fully appreciated by engineers who have any interest in history. Emphasis upon the achievements below the level of practical use must not lead to an underestimate of the high degree of originality involved in practical applications of the general principle.

The scientific and technical achievements below the level of practical commercial use fall into several broad categories that do not lend themselves to comprehensive enumeration in detail. In the field of pure science we can recognize easily the discoveries of new properties of materials, the perception of new relationships expressed as principles or laws, the invention of apparatus for the observation and measurement of natural phenomena. Above this level of generality we find laboratory models and demonstrations which lead directly from primary principles to applications. Otto von Guericke's work on air pressure affords a conspicuous illustration of this phase of scientific work. The primary principles had been worked out by Torricelli and Pascal, but Guericke invented an air pump by which he could produce a significant vacuum. Guericke's work was important both for the development of the atmospheric engine of Newcomen and for the establishment of a technique of experimentation which, with improvements, enabled Boyle to carry the analysis of pressure in gases to the formulation of the famous laws.[11]

If we wish to complete the survey of work below the level of general commercial use, we must include the production of new objects of luxurious consumption. The development of technology has been profoundly influenced by the desire to produce articles of superior quality and special character for ritualistic use and for consumption by dignitaries of church and state outside the limits of explicit ceremonial use. Under such circumstances considerations of cost have been ignored and processes and products developed to gratify the desire to achieve distinction. In the early history of metallurgy, glass-making, and textile production, the development of luxury items was an important factor in invention. In the modern period the development of clocks and watches illustrates the importance of ritualistic and luxury demand. The mechanical clock was clearly developed in response to the ritualistic needs of the larger ecclesiastical establishments. Water clocks were not a convenient means of maintaining the schedule of services. Even a crude mechanical clock was superior; it was more accurate and required less attention. With improvements in craftsmanship, clocks and watches became an outstanding item of luxury consumption. In

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[11] Blaise Pascal, *The Physical Treatises of Pascal: The Equilibrium of Liquids and the Weight of the Mass of the Air*, trans. I. H. B. and A. G. H. Spiers, Columbia University Press, 1937, pp. xv-xx, survey of whole episode. The appendices contain selections from the works of Galileo and Torricelli. Hans Schimank, *Otto von Guericke, Burgermeister von Magdeburg*, Magdeburg, Stadt Magdeburg, 1936, pp. 37-55.

many instances the accuracy of the movement was subordinated to the decoration of the case. But these crafts became the basis of work in light engineering which laid a secure foundation for the heavy-duty power engineering that became important in the eighteenth century.

There is thus a broad field of activity in which costs have been subordinated to the achievement of novelties in science and in the production of luxuries. Activities in this field have fallen somewhat outside any economic calculus. In the early modern period much of the work of scientist-inventors was associated with gainful professional work, especially in the fields of art and engineering. Painting, sculpture, architecture, and general engineering were not sharply specialized occupations. Much experimental work was done in the shops or studios, so that science, invention, and practice of the arts went hand in hand. The universities also created opportunities for science and invention. In the seventeenth century Galileo and Newton were the most distinguished representatives of the universities, though they were not alone. Boyle, Huygens, and Otto von Guericke were the most distinguished men who had personal wealth to use for their work. Patronage of the wealthy and of chiefs of state was of course a further source of finance for work in primary science and invention.

The sixteenth, seventeenth, and early eighteenth centuries were more notable for the accomplishments in science and primary invention than for achievements that added conspicuously to the productivity of industry and agriculture. However, the foundations were laid for the great technical achievments that followed directly upon the development of power engineering that stems from Watt. In the nineteenth century, basic work in the field of electricity was accomplished in a period in which practical achievements lay in the fields of mechanical and civil engineering. It is, therefore, important to recognize the necessity of this underlying work in science and primary invention. In general, the financing of such work came from sources which were essentially the same as in the sixteenth and seventeenth centuries; but the external features were somewhat different.

Since the beginning of the nineteenth century the research programs of the major universities have undergone a remarkable development. The private laboratory has given place to organized laboratory instruction in the universities, and research has become a recognized duty. General university functions have been expanded by the establishment of special research centers in the universities supported by public funds or private endowment, or both. Direct governmental support of basic research has a longer history in the agricultural field than elsewhere, but the importance of public provision for primary research is increasing in other fields. Even if political pressures require state-supported research to give much time to secondary research of immediate interest, the larger organizations will doubtless contribute much to basic research and primary invention.

The research organizations of many corporations today provide a certain amount of free time for the personal projects and interests of the research worker. In some corporations, too, the general program of the staff includes many basic or primary problems not expected to yield immediate commercial results.[12]

3. *Secondary Inventions and New Investment*

In order to clarify distinctions between different types of invention, they may be classified as primary, secondary, and tertiary. Underlying inventions not carried to a stage of general commercial use may be classified as primary inventions. Inventions which open up a new practical use may best be considered as secondary inventions, whatever their importance. Any invention which extends a known principle to a new field of use should be so classified. The noncondensing engine and the locomotive should thus be treated as distinct secondary inventions, despite the utilization of some of the principles of the Watt condensing engine. Improvements in a given device which do not clearly extend the field of use can be classed as tertiary inventions. They are not to be ignored, but they stand in a different position in the sequence of technical change, and they have different consequences for the economy. Such inventions may increase the efficiency of the secondary invention or add to its convenience and safe operation; but they remain subordinate in importance if they do not extend the field of use.

In the field of secondary invention the associations and problems of the inventor are profoundly changed. Contacts with science are weakened and contacts with business assume commanding importance. When functions are not fully specialized, the inventor acts as

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[12] J. D. Bernal, *The Social Function of Science*, London, Routledge, 1939, pp. 35-70, 126-154 and 261-291; Charles E. K. Mees, *The Organization of Industrial Scientific Research*, McGraw-Hill, 1950, pp. 5-16 and 51-149; and Paul Freedman, *The Principles of Scientific Research*, Public Affairs Press, 1950.

an entrepreneur; this stage is characterized by the inventor-entrepreneur just as the first stage is characterized by the scientist-inventor. These differences in the activities of inventive types were clearly present in Schumpeter's mind, but the problems cannot be adequately analyzed in terms of his categories of invention and innovation. All activities at the stage of secondary invention involve close interweaving of acts of skill, acts of insight, and inventions. In enterprises which take a lead in the introduction of new inventions and processes, both inventors and administrators are engaged in inventive work of commanding importance. They also achieve great virtuosity in the performance of the associated acts of skill. Schumpeter underestimated the degree of novelty involved in these acts of skill—of both the engineers and technicians and the administrative staff of the enterprise.

The character of the choices to be made and their relation to the financing of the enterprise can be appreciated best if we concentrate attention on particular examples. Three cases are especially significant: the development of the locomotive, the development of interchangeable-part processes of manufacture, and the introduction of the Bessemer process in the iron and steel industry. All three cases exhibit the importance of a period in which technical achievements were imperfect. The early locomotives did not compete decisively with horsepower. Whitney's methods of production were at first limited in scope and used elementary techniques; but though not fully developed for thirty or more years they were commandingly successful from the start. The Bessemer process, in its early form, was restricted to particular ores. The failure to understand these limitations at the outset led to such great disappointment that the whole procedure for the introduction of the process had to be changed.

In histories of these inventions these critical periods of difficulty are frequently ignored or underemphasized. Full analysis is clearly necessary in order to understand the process of investment in new industries. If good judgment is exercised, risks of loss do not exceed the risks in established industries. The beginnings of commercial application precede the full accomplishment of the secondary invention. In many instances even the major invention remains to be achieved; in other cases the process of critical revision is conspicuously incomplete. The implications of Schumpeter's analysis suggest the opposite order of development: the completion of the secondary invention is represented as preceding the entrepreneurial work on application.

If we study the history of the locomotive with a dominant interest in engineering detail, we find three important steps in the achievement: the Pen-y-darran locomotive of Trevithick, 1804; the *Royal George*, built by Timothy Hackworth in 1826; and the *Rocket*, built by Robert Stephenson & Co. in 1829. Trevithick's engine was impractical because its steam capacity was low and it was too heavy for the cast iron rails then in use. Hackworth's *Royal George* was an effective heavy-duty freight locomotive decisively superior to horses, but it was not suitable for passenger service and needed much improvement in details. The *Rocket* was the first locomotive in which all essential features were incorporated in a mature form, and definitely the first locomotive designed to operate at high speeds on rails. It is an oversimplification to stress any single one of these steps as the controlling secondary invention. The vocabulary of common speech does not supply convenient words to express an achievement spread over time in a number of steps. The best we can do is to use the plural form "secondary inventions."

The problems of new investment have been dominated by the multiplicity of steps involved at this stage and by the relatively small magnitudes of improvements necessary to justify the expenditures. Trevithick's locomotives were incidental to his work on the high-pressure engine as a stationary source of power. The expenses incurred in making the model and in demonstrations of the road locomotive (1798-1802) were covered by the income from the engineering work that was Trevithick's primary concern. The demonstration at Pen-y-darran was financed by Homfray, the mine-owner for whom Trevithick had built a number of stationary engines. The engine itself was built to work a hammer, so that the special expenditure was restricted to the adaptation of the engine to operation on the tram line at the mine. The test was not intended to open up an application of steam power to the transport work of the mine.[13] Although demonstrations of the locomotive on rails were made at London in 1808, Trevithick did not himself, or through associates, develop any project for the systematic operation of a tram line by steam locomotives. His work, however, inspired the projects in the northeastern coal fields which began with Blenkinsop's work at the Middleton Colliery, three miles south of Leeds (1812).

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[13] H. W. Dickinson and Arthur Tetley, *Richard Trevithick: The Engineer and the Man*, Cambridge University Press, 1934, pp. 42-65.

These locomotives were largely the work of Matthew Murray, but royalties were paid to Trevithick for the use of his patents. Blenkinsop added a rack rail, so that this application of steam has been frequently regarded as a diversion of attention from the basic pattern of steam traction. The toothed wheel, however, was not intended to make up for lack of adhesion in a smooth rail; it was a naïve and relatively simple driving mechanism which was good enough to remain in operation for many years around the collieries.[14] These applications, therefore, were in no sense failures.

A locomotive sent to the Royal Iron Foundry in Berlin for the mines at Gleiwitz could not be put into operation because of the opposition of the local engineers and workers. There was similar resistance to the use of a locomotive in the colliery at Saarbrücken.[15] It may be that these engines failed to achieve all the potentialities that other inventors realized, but they were good enough to compete directly with horses. There are a few statements about the costs and the performances of these engines, but they are not detailed enough to inspire much confidence. Fully loaded, speeds were about 2.5 miles per hour. With light loads, 10 miles per hour was claimed.

The development of the mature type of locomotive and of the civil engineering work on the line was accomplished by Hedley and George Stephenson on the tram lines operated by the Wylam, Killingworth, and Hetton Collieries and the famous Stockton & Darlington Railroad, which was a colliery line with supplemental common-carrier functions. All this highly novel work was accomplished in the course of the systematic operation of transport service at these collieries. Use on a restricted scale, but with success, led to a great enlargement of the scale of operation and to a commanding technical superiority over alternative modes of transportation. It is easy to overlook the fact that the early achievements in the restricted field were of material value.

The Stockton & Darlington and the Liverpool & Manchester Railroad represent two successive enlargements of the application of the locomotive. The Stockton & Darlington was an alternative to a canal. It offered common-carrier service, but the company leased the right to operate passenger service to contractors who put horse-drawn coaches on the line. Freight service was operated by locomo-

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[14] C. F. Dendy Marshall, *Early British Locomotives*, London, Locomotive Publishing, 1939, pp. 19-30.

[15] *Ibid.*, p. 34, and C. F. Dendy Marshall, *Two Essays*, London, Locomotive Publishing, 1928, pp. 19-21.

tives on level stretches and by cable haulage on two inclines. No feature of the project was at that time new, though it did involve a longer line than the colliery tram lines. The Liverpool & Manchester project was an alternative to a line operated by cables and stationary engines. It was planned to offer both freight and passenger service. Passenger service had not previously been attempted on rails, but a number of steam coaches were in operation on highways out of London and the potentialities of the locomotive were understood though still underestimated. Speeds of 15 to 20 miles per hour were presumed to be achievable. The conditions for the Rainhill competition prescribed a speed of not less than 10 miles per hour. The *Rocket* averaged 15 miles per hour, and ran for a time at a rate of 29 miles per hour. After the accident to Huskisson, the *Northumbrian* of similar design ran 15 miles at a rate of 36 miles per hour. Fifteen or sixteen years later the *Rocket* ran 4 miles in four and one-half minutes, or at a rate of 53 miles per hour.[16]

The Liverpool & Manchester project marked the culmination of eighteen years of work in the application of the steam locomotive to tram lines. Under progressively exacting conditions of use, both the locomotive and the civil engineering work were greatly improved. Wrought iron rails of improved design replaced the cast iron rails used at Pen-y-darran for Trevithick's demonstration. The locomotive had greater steam capacity, and the differentiation between the freight and the passenger locomotive was understood. The technique had been carried to a point at which it could be used for a generalized system of inland transport. The work of these critical years involved the cooperation of engineers as skilled technicians and as inventors, and of businessmen as colliery managers seeking means of expanding transport services for which the supply of horses was becoming a limiting factor. Novelties were emerging at many levels and in many forms but under conditions which made losses unlikely, though the magnitude of the gains was uncertain. The new technique could be used if it was not less productive than the current alternative. As long as the scale of operations remained small, the dangers of losses were also small. Overoptimism was not likely to develop until the whole group of secondary inventions had been completed, and work began for the generalization of the new

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[16] Samuel Smiles, *The Life of George Stephenson and of His Son Robert Stephenson*, Harper, 1868, pp. 325 and 327n.; and Clement E. Stretton, *The Locomotive Engine and Its Development*, London, Lockwood, 1896, p. 36.

technique in the economy as a whole. The railway crisis started in England in 1845.

The general pattern observed in the development of the locomotive and the railroad may be seen also in the history of Eli Whitney's manufacture of muskets on the principle of interchangeable parts. The idea itself was not new. The Swedish engineer Christopher Polhem had perceived the general elements of such a system of manufacture, though he had not attempted to work within the field of precision mechanisms. Work on firearms on such a system had been tried in France but had not been pushed to conspicuous and decisive accomplishment.

The significance of Whitney's work lay not only in the bare idea, but also in the progressive mechanization of the process with machine tools capable of great precision. The actual manufacture of muskets passed through several stages. The first contracts were executed by filing the parts of the lock to conform to patterns or jigs. The parts were worked out in soft metal, subsequently tempered and hardened. At first, only the locks were made on an interchangeable-part system. Later the stocks were shaped on pattern-turning lathes which reduced the amount of hand labor to a minor fraction of the prior requirements. The lock mechanism, too, was manufactured by methods which reduced handwork and increased the degree of precision achieved. This was accomplished by developing the technique of die stamping for some parts, and by the development of the milling machine to supplant the laborious processes of filing. These activities covered about twenty years. There was thus a group of interrelated secondary inventions, all of which were essential to the mature accomplishment, though commercial success was assured when the new procedure had not been carried beyond its most elementary form.[17]

The array of machine tools ultimately developed were not implicit in or even suggested by the system of jig filing that was first used. The new tools were independent inventions of great merit and importance whose earlier history and background lay in the field of lathes, which worked originally in wood and soft metals below the level of precision required by the system of interchangeable-parts manufacture.

The complexity of the stage of early secondary invention is illustrated also by the history of the refining processes in the iron and

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[17] Jeanette Mirsky and Allan Nevins, *The World of Eli Whitney*, Macmillan, 1952, pp. 128-146 and 177-205.

steel industries. The transition from an industry dominated by malleable iron to one dominated by steel was brought about by the improvement of refining processes, so that a larger scale of production could be achieved at lower costs. The development was begun by the introduction of the Bessemer converter. By means of intense internal combustion, this device decarburized the cast iron coming from the blast furnace. The treatment of the charge of the converter required about twenty minutes. Puddling, the process then in use, required eight or ten hours to treat a much smaller charge and used highly skilled labor.

When Bessemer's process was announced it was immediately recognized as a potentially controlling factor in the industry. Bessemer proposed to lease the right to use the process on a royalty basis. As soon as attempts were made to apply the process, however, serious difficulties appeared. Much of the iron produced was brittle and poor, its quality far below any standard required in the industry. Bessemer was convinced of the truth of his claims, but careful analysis finally revealed the fact that the process could be used only in the treatment of iron that was free from phosphorus. Many of the ores then in use contained more phosphorus than was allowable if the new process was to be used. Bessemer now found it necessary to join some ironmasters in the organization of a company to apply the process to suitable ores.[18]

Conditions in the iron and steel trades became very complex. The new process was directed to new fields in the market, and the older firms and older processes of production were able to maintain themselves for an interval; but conditions were very unstable, and the value of ores was profoundly affected by the selectivity of the Bessemer process. Balanced use of ores was ultimately made possible by two new secondary inventions: the open hearth process provided a method of refining that was effectively competitive with the Bessemer process commercially and happily suited to an array of ores that could not be treated by the Bessemer process. Neither of these processes was adapted to ores containing much phosphorus, though the open hearth was more tolerant of phosphorus than the Bessemer process. This difficulty was overcome by two chemists, Thomas and Gilchrist. They devised a basic lining for the refining furnaces which removed the phosphorus by a chemical reaction. With the two refining processes and the use of basic linings when

[18] Sir Henry Bessemer, *Autobiography*, London, Offices of *Engineering*, 1905, pp. 155-177.

required by the ores, it became possible to treat the whole array of commercially important ores. The transformation of the industry thus required all three of these secondary inventions. The full accomplishment took place between 1854, when the Bessemer process was announced, and 1878, when the basic lining of the furnaces was achieved by Thomas and Gilchrist.

The introduction of secondary inventions is profitable from a very early stage once capitalist methods of production have reached a point at which monopoly power can be achieved even for short periods of time. The inventor-entrepreneur cannot secure profit unless the introduction of the device or process can be controlled through patent privileges, secrecy, or dependence upon small numbers of specially trained workmen. The textile inventions of the eighteenth century, Whitney's cotton gin, and Oliver Evans' mechanization of flour-milling afford characteristic illustrations of the weakness of the position of the inventor when the machines can be built by any craftsman without drawings or detailed specifications. When machine-building becomes a fully specialized occupation in any given field, new devices can be controlled and protected even without a patent system, though patent privileges are of undoubted social value in creating property rights to invention.

The development of the use of power in transport and manufacture is also an important condition. Increases in the scale of manufacture through the use of power or through the opening of wider markets give new significance to monopoly. The great watchmakers of France and England in the eighteenth century made outstanding contributions to their craft and to the whole field of mechanical engineering. But their most distinguished inventions merely gave them prestige in a craft which at best enabled them to sell their products to distinguished customers willing to ignore the costs of objects of luxury and ostentation. The work of the Dollands in the optical field is perhaps even more striking, because telescopes and microscopes appealed almost exclusively to wealthy amateurs with little serious interest in science. Work on the chronometer was stimulated by the prizes offered in France and England for a means of determining longitude at sea.

The characteristic phenomena of capital formation as we know them since 1800 are clearly attributable to the precision working of iron and steel and the developments in the related field of general power engineering. The textile inventions of the eighteenth century would have had a different and more restricted application if it had not become possible to supplant the machines of wood and soft metals with well-designed machines of iron and steel.

4. *The Spatial Diffusion of New Techniques*

When the first cycle of secondary inventions is complete, or even well launched, the diffusion of the new technique throughout the economy presents a new set of problems. At this stage new acts of insight and new inventions are somewhat obscured because such a large part of the total task can be achieved by acts of skill. Furthermore, no particular invention is necessary at any given time to make the process or activity commercially effective. Delays incidental to positive invention cease to be of immediate consequence; improvements that are achievable are desirable, but they merely increase the profit derived from a process that is already profitable. There is thus some justification for the overemphasis so commonly placed upon particular inventions in the first cycle of secondary invention; but, though understandable, these judgments are misleading.

The usual treatment of Watt's inventions gives too little credit to Newcomen and to the engineers who developed the high-pressure engine. In the textile series the stress on the earliest forms of the inventions is excessive. With the caprice characteristic of incomplete analysis, the importance of the work of the Darbys in the iron industry is ordinarily understated, but the emphasis upon puddling and rolling and upon the steel-making processes in the nineteenth century is sound. The history of the iron industry is perhaps the clearest instance of a succession of secondary inventions whose independence and importance are rarely questioned.

The acts of skill which dominate the spatial diffusion of new techniques appear both in the field of technology and in the field of economic administration. The process of development discloses new characteristics which are most effectively described if we distinguish between meliorative effects and the cumulative accumulation of knowledge, on the one hand, and growth as a quantitative and adaptive phenomenon, on the other. Once the point of secondary invention is reached the scale of the economy and its productivity are affected. These results can be observed in the growth of population and in the changes and net increases in consumption.

Approached from this point of view, the process of growth in the economy is a resultant of the array of accelerating factors represented by technical changes and the decelerating or limiting factors of scarcity of resources. Older concepts of change assumed the intermittent occurrence of particular changes in an essentially stable economy. A mature concept of the process of invention requires us to conceive of changes as essentially continuous in units of small magnitude. Discontinuities are not felt as such because the magnitudes are small. The substantial continuity of the process of growth is clear in the records of the iron and steel industry and in the field of power engineering. When products of specialized use are involved, the case is not as clear. Illustrative material is afforded by the history of the petroleum industry and by the development of heavier-than-air flight. The statistics of the production of illuminating oils are interesting when the whale oils and mineral oils are combined in one series for a substantial period. Adequate analysis of the records, however, would require more space than is here available.

There is enough statistical material to show that growth in the economy proceeds at varying rates: at accelerating rates up to the inflection point; at decelerating rates beyond it. In some fields growth may occur as a continuous process of deceleration, as presumed by Raymond Pearl, but such rigorous conditions are not characteristic of the biological processes in individual organisms or of human economies. It is not possible at this time, with the data available, to identify a specific mathematical formula with the process of social growth. The records we have now, however, are consistent with the suggestions made by R. A. Lehfeldt in 1916. He pointed out that the integral of the normal curve affords a satisfactory formula for much statistical material if we use the logarithms of the items. The formula expresses a cycle of orderly growth between two limiting magnitudes at varying rates of change.[19] The framework of the curve does not quite fit the facts of social life, because major technical changes displace the upper asymptote and release new potentialities of growth. The upper asymptote of the preceding cycle is passed and becomes the lower asymptote of the next cycle. Even with good statistical material, the records of actual growth would not conform to the formula in portions of the curve close to the asymptotes implicit in the major portion of the record.

The production of pig iron in Great Britain in the eighteenth and nineteenth centuries exhibits as much conformity to the integral

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[19] R. A. Lehfeldt, "The Normal Law of Progress," *Journal of the Royal Statistical Society*, Vol. LXXIX, 1916, pp. 329-332.

of the normal curve as the quality of our statistical material would warrant us to expect. The magnitude of the growth is most vividly reflected in the figures for per capita consumption: 1735, 15 pounds; 1800, 26 pounds; 1830, 77 pounds; 1890, 303 pounds. The record discloses a relatively smooth curve despite the major inventions that were required to make this development possible.[20] It seems strange that there is no evidence of more discontinuity. Some might take the position that the whole development was implicit in the application of coal and coke to iron-making. A better explanation is that the occurrence of inventions and acts of insight does not stand outside the formula of probability. Favorable constellations of events occur as a matter of chance. Over a large field and long periods of time, the emergence of novelty may well conform to the formula of probability. The normal curve may thus be related to all the arrays of phenomena involved in the process of growth.

If these inferences are justifiable, we have means of studying the rate of capital formation in economies undergoing technical change. Even if the statistical record of capital is inadequate, sampling methods will give an indication of the changing relations between product and capital, so that inferences can be drawn from the records of production.

The organic quality of the process of growth has important bearings upon the financial operations underlying new investment. It is not necessary to assume that the funds are deflected from older channels by the higher bids in new industries and undertakings. The credit resources available are sufficient to make the new investments largely dependent upon the expectations of gain in the new activity. New techniques of production affect the value of resources so directly that technological change is reflected in increases in the physical quantity and in the value of basic resources. New techniques of transportation affect site values and the values of agricultural and mineral lands that would otherwise be inaccessible to markets. These facts are obvious, but the timing of these changes in values is sometimes inadequately analyzed.

Analysis must be considered from two points of view: that of the statistician and that of the entrepreneur. The statistician may legitimately regard the change in value as implicit in the substantial accomplishment of the secondary inventions. Changes in the coal and iron resources of Great Britain would, therefore, date from the

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[20] Witt Bowden, Michael Karpovich, and Abbott Payson Usher, *An Economic History of Europe since 1750*, American Book, 1937, pp. 384-385.

successful work of the Darbys with coke. All these resources would have been revalued at least after 1735. Any survey of physical resources may legitimately distinguish between potential and actual resources. If technical and market conditions do not justify current utilization, particular deposits should be classified as potential. If workable at current costs, resources are actual. In a region whose resources are significantly known, the stocks available from the statistical point of view commonly provide for long periods. Primary minerals are available as "actual" resources for intervals of 300 to 500 years; and potential resources in mineralized areas extend in many instances to 1,000 years.

The entrepreneur must deal with shorter time spans and more immediate market relationships. He is primarily concerned with close analysis of actual resources, though potential resources may be of great moment if the technical or transportation problems admit of some change in technique that would bring the resources into the current cost structure in the industry. The entrepreneur considers three categories of resources: resources that are actual but not proven by detailed surveys, proven resources, and currently developed resources. The time span for entrepreneurial activity would rarely exceed twenty-five years, though acquisitions of title to prospective ores may well be carried further. The essential feature of the situation lies in the emergence of material values well in advance of current exploitation. These values can properly support a structure of long-time loans, and with good judgment should involve no greater risk than in a supposedly established industry. The long-time value structure in the old industry is not insulated against change. The development of petroleum as a primary fuel, for example, has had an adverse effect on the values of coal properties.

The influence of new techniques of transport upon land values is more complex than the effects of technical change on particular fixed resources. Changes in transportation affect site values for all classes of sites, but most particularly for the first-, second-, and third-class urban units. These sites increase in size proportionately to the population within a given area and an expansion of their market areas.[21] The internal structure of the urban units is effected both by local facilities for transport and by techniques of house construction.

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[21] George Kingsley Zipf, *Human Behavior and the Principle of Least Effort*, Addison-Wesley, 1949, pp. 374-383.

Both mineral lands and agricultural land are sensitive to the market connections that are a function of transport costs. Improvements in transportation, therefore, affect all the values of the land and fixed resources of the economy. The application of power to land transport has completely transformed the world economy. Before the development of the railroad the world economy was in effect the maritime fringe of the great continents. The interiors were open only to the extent that some form of water transport was available, and, as a consequence, contacts with the deeper interiors were very restricted. The railroad opened all these interiors to world markets, and today the emergence of a truly global economy is painfully evident. Its substantial emergence can perhaps be dated as early as 1878, when wheat from the prairies of the United States entered the European markets with such devastating effect.

No problems of technical diffusion and expansion are as complex as the agrarian dislocations created by the introduction of new transport facilities extending the areas devoted to particular crops. Such areas of cultivation bear no significant relation to the development of demand for the product. The extension of the sugar culture to the New World presents a complex episode of this type that cannot be accurately analyzed because of the inadequacy of our statistical material. On the other hand, the expansion of wheat culture in the prairie regions of the United States, Russia, and Australia can be studied in detail. Large portions of these areas were suitable only to wheat culture, as the rainfall pattern was unfavorable to general farming. Beyond the margins of wheat culture, specialized grazing became important.

Competition with these frontier producing areas was disastrous to the established agricultural areas in Europe dependent upon general farming; both mixed and cereal farming areas suffered, though the latter were more severely affected than the former. Wheat prices fell, even in relation to other commodities. Since nonhuman uses could be brought into the market only at prices that were unremunerative to growers, primary reliance lay in the expansion of human consumption. Over the period of fifty-five years studied by Malenbaum, acreage expanded in excess of the requirements for human consumption. In the decade 1929-1939, this excess acreage averaged 35 million acres per year.[22]

[22] Wilfred Malenbaum, "Equilibrating Tendencies in the World Wheat Market," thesis, Harvard University, 1941. Cf. especially the author's summary of conclusions. Substantially the same analysis was published subsequently by

The problem of maintaining equilibrium in the spatial economy appears in a special form in the construction of the railroad network. In Great Britain, public policy became committed at an early date to a principle of requiring presumptive evidence of cost recovery as a condition for the grant of a charter. In France and in the United States it was recognized that some railroad construction could advisedly be authorized even if there were no prospect of recovering all the costs immediately—or perhaps even ultimately. The grounds for this position are different in different circumstances. Some areas of France were provided with more service than they could themselves support in order to avoid losses from major displacement of population in such areas. In the United States it was presumed that losses would be temporary, but this optimism has not always been justified, though the operation of the network in the United States has been affected by a pattern of ownership that results in the segregation of strong and weak lines.

The diffusion of new techniques throughout the world economy is certainly not a smooth process that admits of the continuous maintenance of equilibrium conditions. The difficulties come from many sources: the magnitude of the units of investment, the length of the time intervals needed to produce effective responses in the economy, the number of different regions affected by a single change in technology, and the divergent influences upon particular kinds of resources or activities. Coal deposits and coal-mining have been profoundly affected by the development of petroleum as a major fuel and by large-scale hydroelectric installations. Furthermore, the demand for coal in transportation has been influenced by the development of pipeline transport of oil and gas, and by long-distance transmission of electricity. Economy in the use of coal was recognized as an undoubted necessity as late as 1920; but when the changes came, the magnitudes of the reductions in demand could not be absorbed without drastic reorganization of the industry.

For all these reasons it is desirable to think of these spatial problems as growth problems. All such changes are not necessarily positive and advantageous. Even the most important technical advances affect adversely many activities and even entire regions.

The time intervals involved in the general process of technical advance are certainly much longer than current economic literature

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him as *The World Wheat Economy, 1885-1939*, Harvard University Press, 1953.

is ready to recognize. Some broad entrepreneurial policy decisions most certainly recognize intervals of twenty-five to thirty years, but the technical changes themselves do not disclose all their influence within such intervals. The development of the mineral economy reaches maturity with the development of petroleum and a generalized system for the distribution and use of energy in the form of electricity. The beginning of the change can be dated from the Newcomen engine and Darby's use of coal and coke, in the years 1708-1712. A period of more than 200 years must, therefore, be considered. With long time intervals the achievement of equilibrium becomes more difficult.

5. *Technology and Centralized Administration*

It is tempting to presume that centralized administration might achieve a more adequate equilibrium in the economy than has been achieved in the past. Analysis of technical change certainly creates the presumption that important increases in the size of administrative units are likely to emerge as a consequence of changes in the techniques of communication. Increased speed of communication, new techniques of collecting and organizing information, and larger-scale units of production all lead us to presume that administrative units will become larger both in private and in public administration. Comprehensive control of the economy from some highly centralized policy committee raises a different issue. The precise form of the central authority is perhaps less important than the concept of the direction of investment in terms of statistical aggregates. If we assume that these aggregates can become the sole basis of primary economic policy, the economy must be a closed organic system.

The organic concept of the state and of the economy has exerted a powerful influence upon the social sciences since the early nineteenth century. No problem presents more sharply the issues between idealistic and empirical interpretations of history and of social structure. Idealists assert that the social structure is a closely knit and comprehensive whole. Empiricists hold that society consists of a loosely related array of structures, none of which is comprehensive. Individual elements may belong to more than one structure, and the parts may be combined in different ways in different periods of history. To the empiricist the wholes possess less vitality than their parts—though the parts cannot function except in some broader structure.

We therefore face a significant issue of analysis when we consider the aggregative records of an economy: Do these aggregates indicate the presence of an organic whole that can be directly administered as a comprehensive entity? The idealist assumes that society is such a monolithic whole. However, a concept of emergent novelty and a theory of invention presented as cumulative synthesis are inconsistent with such a position. We should think of the events in our social life as a relatively large number of systems of events, some of which have contacts with each other; some of them, however, are positively opposed to each other. It is possible to show readily that many of these systems of events have no genetic relationship; though, over long periods of time, events which have not been related in the past converge toward a new synthesis. This pluralistic concept does not exclude the concept of organic structure, but it attributes organic relationships to smaller units and presumes that these relationships are created by social process. The organic wholes recognized by the empiricist are never comprehensive.

The statistical universes which are found in social life disclose systems of order that can be analyzed in terms of probability. We must think of these aggregates merely as representations of arrays of events disclosing a multiplicity of causes which afford no clues to the degrees or degree of interdependence or independence. The empiricist thinks of them as statistical aggregates which reflect large numbers of individual items. In the field of investment, multiplicity is manifested as a large number of separate judgments—judgments about the values of resources and new materials, about costs of production and of marketing, and about consumer responses to different price policies. Even in fields dominated by well-organized markets, values are not independent of individual judgments; they do not come to the entrepreneur from the outside as a final fact. He is concerned with a future that is not fully calculable, so that even in the best market economy individual judgment must be exercised. The market registers an array of judgments; it does not make judgments.

Centralization of fiscal and monetary authority can serve usefully in guiding many of the value judgments to be made, but fiscal and monetary policies do not make independent judgments unnecessary. Wise policies can direct the process of investment, but they cannot change the primary character of the process as a summation of individual items proceeding upward from a large number of separate decisions. It is not necessary to assume that all decisions are made by entrepreneurs charged with the administration of independent corporations operated on a profit basis. Government corporations or departments may also be making judgments about investment in which cost factors may be given primary importance or subordinated to other social interests. The form of the process would not be altered by the introduction of new criteria for decisions as long as it is recognized that many independent decisions are being made.

The fully administered economy may seem to achieve unity, but this is not necessarily the case. Are the totals for the comprehensive plan aggregates of items that have been added together or are they allocations of funds that are divided after the total has been determined by a judgment of a central executive officer? No final answer can safely be given to such a question. In the past, concentration of authority has frequently been carried beyond the limits of the actual and effective making of executive decisions. Orders that emanate from the highest levels of authority are actually based on information and texts that are collected and prepared by lower levels of the bureaucratic hierarchy. Since the operation of bureaucracies is capricious, it is dangerous to generalize about the effective limits of the authority of central executive officers. Practical limits of centralization are determined by techniques of communication. We may now recognize the desirability of a much greater concentration of administrative power than was possible before the introduction of the telegraph and telephone, but even after all these developments, and with ancillary inventions in electrical tabulation, it is probable that important limitations to centralization should be recognized. If there is to be any innovation, there must be opportunity for independent judgments about the use of time and of uncommitted funds. Novel achievements emerge most freely beyond the limits of the pressures of convention and authority. The existence of many different authorities is the ultimate safeguard of the individual and the basis for the continuity of the process of invention in all its forms and fields. Major innovations in technology would probably encounter more resistance in an authoritarian society than in a society without full concentration of control over property and choice of occupation.

The adaptation of social and economic administration to changing circumstances will probably be quicker and more successful in a society without full centralization. But social and economic structures will undoubtedly function even if centralization is carried beyond the point of full efficiency.