Chapter 6

A Theory of Economic Systems, Part 1:

The Categories and Stages of Production

The theory of economic systems as developed in the next three chapters will be used as the foundation for the theories and hypotheses concerning the rise and decline of Great Powers. The central focus will be on the dynamics of production and the technologies of production. The general theory of systems will be used in order to analyze the processes, in particular, of production, and to construct theories of economic, production, and capital systems. In this way, theories and hypotheses concerning the rise and decline of Great Powers will be constructed, it is hoped, that will have greater explanatory power than those theories reviewed in chapters two and three.

Defining the Economic System

In the previous chapter, the domain of material social reality was divided into two mutually exclusive domains, the political and the economic. The political domain was assumed to be the sphere of space, and the economic domain was assumed to encompass matter and energy. Both political and economic phenomena involve the procession of time. Therefore, the domain of political systems involves the social experience of space through time, while the domain of economic systems encompasses the social experience of matter and energy through time.

In a previous chapter I proposed that a system can usually be divided into two subsystems, a generative subsystem and an allocative subsystem. The generative subsystem *produces* output, while the allocative subsystem *distributes* that output among the units of the system. In the case of the economic system, the generative subsystem involves in the generation of forms of matter/energy, and the allocative system distributes those forms of matter/energy (I will usually use the term *system* when referring to both complete systems and subsystems).

Only cosmological processes such as supernovas or stars generate different types of atoms, and except for the nuclear energy industry, energy is not created by humans. Instead, humans (and all life) *transform* one configuration of matter/energy into another configuration during processes of production.

In making an automobile, for instance, many transformations occur. The iron molecules that exist in iron ore are extracted by blast furnaces, using massive amounts of coking coal. The resulting array of iron molecules are not created; instead, iron's naturally occurring form as part of rock is transformed into something more useful, smelted iron. The smelted iron is then treated in steel-producing machinery, generally using electrical energy, by adding various kinds of molecules to its structure, including carbon and chromium. The resulting steel is output in the form of certain shapes, such as slabs or rolls of sheet metal. These intermediate steel goods are then transformed by a large metal-forming machine tool into the shape of the hood of a car, for example, during which time the machine tool uses an electric motor. The final automobile includes thousands of pieces that began as completely different configurations of matter and energy, moved through various intermediary states, and finally became parts of an automobile after being put together on an assembly line.

Thus, in an economic system, matter/energy is transformed from one configuration to another through time. While the original matter and energy still exist – according the laws of thermodynamics, energy does not spontaneously disappear or appear – the *structure* of the element, such as the slab of steel or the hood of the car, is made to change. The *substance* of the element may change, such as the change from iron to steel. All of these processes involve two inputs: *energy*, such as the coking coal or electricity in the example above; and the *design*, or *information*, needed to guide the transformations that occur within the economic system.

As seen in the example above, the economic system uses part of its own output to transform one configuration of matter/energy into another configuration. The economic system uses production technologies such as the blast furnace, steel-making machinery, and metal-forming equipment. Thus, the full definition of the economic system should be the following:

> The economic system transforms one set of configurations of matter/energy into a different set, through time, using certain previously produced configurations called production technologies. A configuration has a certain structure composed of a certain set of substances. Production technologies transform the structure and substance of a configuration, and generate the forms of energy and information processing needed to effect this transformation. The economic system then allocates these configurations, called goods and services.

This definition is useful for investigating the phenomenon of the long-term causes of growth because *production* is the focus of the definition. Allocation is important in the process of production as well, but the term "economic growth" describes the increase of the output of goods and services, which is a function of production. My definition of an economic system has three major implications for the nature of economic systems: 1) production is the central activity in an economic system; 2) there are several *categories* of production within an economic system; and 3) there are several *stages* of production within an economic system.

The first implication of my definition is that the economic system is based on the capability to produce goods and services. Neoclassical economists refer to this capability, in the most general sense, as *capital*; as shown in Chapter 3, capital has always been a problematic concept in economics because capital cannot be considered exogenous, or outside of, the economic system, and because production has not been a central concern in neoclassical economics. Neoclassical economic thinking tends to bypass this problem by focusing on other concepts. Instead of ignoring capital, my definition proposed above places capital at the center of the functioning of the economic system.

Distribution is also critical; both production and distribution are necessary functions within an economy. For the purposes of this study, however, I am claiming that production is more important than distribution.

As Friedrich List wrote, "*The causes of wealth* are something totally different from wealth itself. A person may possess wealth, i.e. exchangeable value; if, however, he does not possess the power of producing objects of more value than he consumes, he will become poorer. A person may be poor; if he, however, possesses the power of producing a larger amount of valuable articles than he consumes, he becomes rich.

"*The power of producing wealth* is therefore infinitely more important than *wealth itself*", and "this is still more the case with entire nations (who cannot live out of mere rentals) than with private individuals" (List 1885, 133, emphasis in original). Further, "the forces of production are the tree on which wealth grows, and…the tree which bears the fruit is of greater value than the fruit itself" (List 1885, 46).

Capital, or the means of production, constitutes the "power of producing wealth", or "the power to create wealth", the title of this dissertation. The means of production are used in the generation of output in the economic system. The generative subsystem of the economic system will be referred to as the *production system*. The production system is synonymous with the term *the means of production*.

Manufacturing, plus some utilities, mining, and construction, compose what I am referring to as the production system. Many authors have written about the importance of production, usually in terms of manufacturing, or more specifically, machinery. Most have only asserted that manufacturing is very important without constructing an argument to support the claim. Like the definitions of Great Power and the explanations of technological change reviewed earlier, the assertions concerning the importance of manufacturing and machinery have been ad hoc, not based on a theoretical framework.

For instance, A DRI study simply stated that “beginning with our industrial revolution shortly before the Civil War, the growth of manufacturing industry has been the principal vehicle of U.S. economic growth” (Eckstein et al. 1984, 1), and further, “without a strongly advancing manufacturing industry, the U.S. economy is hardly likely to maintain its progress in the decades ahead” (Eckstein et al. 1984, 4), although no justification is given for this statement. Eric Green states that “a country cannot expect to be a world economic power unless it nourishes the industrial network on which national power is based” (Green 1996, 37). John Wilkinson argued that economists should refocus their efforts onto the problems of production (Wilkinson 1983).

In the early 1800’s, Freidrich List proclaimed the advantages of manufacture: “The sciences and industry in combination have produced that great material power which in the new state of society has replaced with tenfold benefits the slave labor of ancient times, and which is destined to exercise on the condition of the masses, on the civilization of barbarous countries, on the peopling of uninhabited lands, and on the power of the nations of primitive culture, such an immeasurable influence – namely the *power of machinery*”. Further, “the power of machinery, combined with the perfection of transport facilities in modern times, affords to the manufacturing State an immense superiority over the mere agricultural state" (List 1885, 201, italics in original).

Thus, machinery in particular, has been seen as a critical technological capability. John Hobson, who provided much of Lenin's argument for a theory of imperialism, conceived of "The Evolution of Capitalism" as "A study of machine production", (the title and subtitle, respectively, of his book). He claimed that "the chief material factor in the evolution of Capitalism is machinery. The growing quantity and complexity of machinery applied to purposes of manufacture and conveyance, and to the extractive industries, is the great special fact in the narrative of the expansion of modern industry" (Hobson 1902, 5-6).

The German economic historian W.G. Hoffman noted that the "process of economic growth which has been fostered by the increasing use of capital goods and improved techniques of production has affected all sectors of the world's national economies" (Hoffman 1958, 1). In addition, "the expansion of a modern industrial country is generally characterized by a continual increase in the output of manufactured goods which is closely associated with a steady expansion in the volume of capital goods available in the economy" (Hoffman 1958, 31). The term "capital goods" covers both production machinery and the output of that machinery, and Hoffman was one of the few economists who studied the global capital goods industries thoroughly.

In a massive study on mechanization, published in 1934 for the National Bureau of Economic Research, F.C. Mills introduces the volume with the remark that "the machine has been the foremost factor making for economic and social change in the western world during the past hundred and fifty years", and after listing some of the changes, says that "all this is commonplace enough. That the machine has worked great changes in human life is no discovery of the past few years. For more than a century social observers have commented on the progress of machine industry" (Jerome 1934, xxi). Unfortunately, the rest of the study is content to simply describe the levels of mechanization, without trying to prove what, at the time, was obvious to most observers. The same is true of the other writers quoted in this section – they may have been correct about the importance of machinery, but there is no theoretical framework presented to help support their assertions.

Perhaps Thomas Carlyle brought the effects of production technology to their poetic extreme: "…He can use Tools, can devise Tools : with these the granite mountain melts into light dust before him ; he kneads glowing iron as if it were soft paste ; seas are his smooth highway, winds and fire his unwearying steeds. Nowhere do you find him without Tools; without Tools he is nothing, with Tools he is all" (quoted in Vowles and Vowles 1931, 1).

Unlike the previous authors, Alfred Chandler, the business historian, has constructed a useful framework for understanding production. Chandler asserts that "in production an increase in output for a given input of labor, capital, and materials was achieved technologically in three ways: the development of more efficient machinery and equipment, the use of higher quality raw materials, and an intensified application of energy". Further, "Mass production industries can then be defined as those in which technological and organizational innovation created a high rate of throughput and therefore permitted a small working force to produce a massive output" (Chandler 1977, 241). In addition, "In modern mass production, as in modern mass distribution and modern transportation and communications, economies resulted more from speed than from size. It was…the velocity of throughput and the resulting increase in volume that permitted economies that lowered costs and increased output per worker and per machine…Central to obtaining economies of speed were the development of new machinery, better raw materials, and intensified application of energy, followed by the creation of organizational designs and procedures to coordinate and control the new high-volume flows through several processes of production" (Chandler 1977, 244).

Chandler's focus on speed suggests a definition for productive power, or production capabilities. As explained in the previous chapter, power in the physical sense measures the speed at which a particular mass moves a particular distance. Chandler implies that the power of a production system is its ability to process and output a certain quantity of goods in a certain period of time. As Chandler states, "…the two decisive figures in determining costs and profits were (and still are) rated capacity and throughput, or the amount actually processed within a specified time period" (Chandler 1990, 24).

Speed is an important dimension of industrialization, according to the economist and historian of technology Nathan Rosenberg: "Industrialization, quite simply, requires the development of highly specialized kinds of skills and knowledge which are essential to the solution of the technical problems involved in machine production. In all of this there is an essential learning process and, historically, much of this learning took place within the confines of a small number of firms engaged in machine production. Furthermore, the rapidity of industrialization was substantially determined by the speed with which technical knowledge was diffused from its point of origin to other sectors of the economy where such knowledge had practical applications" (Rosenberg 1972, 97).

Thus, a production system which is becoming more powerful would be experiencing an acceleration of output along with a rapid diffusion of innovation throughout the economic system. A relatively powerful economy would be able to produce a relatively large amount of goods and services in a particular period of time, and improvements in these capabilities would move through the entire economic system at great speed.

The first implication of my definition of an economic system, therefore, is that for the purposes of ascertaining national rise and decline, it is useful to conceive of production as the most important activity in an economic system. In addition, productive power can be defined as the capability to generate a certain quantity and quality of goods and services in a certain period of time, and the capability to diffuse a certain set of innovations throughout an economic system in a particular period of time.

CATEGORIES OF PRODUCTION

The second implication of my definition of an economic system is that there are categories of production which consist of the creation of structure and substance, the generation of forms of energy, and the processing of information . Categories of production are the kinds of processes that people must use in order to produce goods and services.

Unlike the neoclassical world-view, production as defined here is not a homogeneous process. Neither is production viewed as an infinitely decomposable process. By restricting processes of production to four categories, production can be modeled in such a way as to capture its most important aspects while remaining comprehensible.

An element, such as a configuration of matter/energy, is also a system; it is itself composed of elements, or substance, and has a structure. An element, in order to be changed from one configuration of matter/energy to another, must undergo a change in structure and/or a change in substance. Thus, a transformation involves the change of two systemic aspects of an element: the structure of the element must change; and the nature of the element, in terms of its substance, must change.

There are certain categories of production technology that are used to effect these changes of structure and substance. To use the previous example of the production of an automobile, a metal-forming machine will change the shape, or structure, of a piece of steel so that it is usable as the hood of a car. This kind of production will be defined as *structural production*, since it involves the change from one structure to another. The metal-forming machine tool is defined as a piece of *structural production machinery*. In the example of automobile production, the steel-making machinery changes iron to steel; this kind of production will be defined as *material production*, since it involves the change from one type of material to another. The steel-making machinery is defined as a type of *material production machinery*.

There are many types of production machinery that are used in each category of production. In the automobile example, for instance, the blast furnace was used as another type of material production machinery, in order to transform iron ore into smelted iron. The assembly line is an example of another kind of structural production machinery. The process of assembling the car is an example of structural production because the assembly process creates a new system, called an automobile, by putting together the various car parts into a particular structure.

Thus, two categories of production are structural and material production. In order for these forms of production to take place, however, two other categories of production are required, energy-converting production and informational production.

The third category of production involves energy. In order for change of any kind to occur in the world of material reality, energy must be converted from one form to another. Any movement not involving momentum requires force, and this force requires the conversion of energy. Iron ore does not spontaneously change substance to smelted iron, and a metal-forming machine tool does not magically bend steel to form the hood of an automobile. A force must be applied, and this force must be manifested as a type of energy conversion, in the form of coking coal (and other energy sources) for a blast furnace, an electrical lance producing heat in a steel crucible, or the electrical-to-mechanical energy conversion of an electric motor in a machine tool. Thus, *energy-converting production* is accomplished using *energy-converting production machinery*, such as an electric lance or an electric motor.

Often, energy comes from a machine outside the factory, as in the case of electricity. In this case, production machinery is still being used to generate a form of electricity or other energy. The spatial placement of the production machinery is not as important as the fact that it is being used to generate something for application in the factory, or more generally, for application at a production site (which includes construction sites, mines, and farms).

In this study, transportation will be categorized as energy-converting production. The main activity which takes place in transportation is movement from one point in space to another, and this movement always involves, first and foremost, the conversion of energy. One of the ways in which energy is manifested is in the form of movement; work, as was explained in the discussion of physical power, is a measure of the distance an object moves. Moving an object from one position in space to another, a task which transportation machinery achieves, is a manifestation of work in a mechanical sense. Besides the components such as wheels, hulls, and wings which are used to effect this movement, forms of transportation are defined by association with their energy source, whether automobiles with an internal combustion engine or jets with a turbine engine.

Transportation does not generally involve a change in the substance or structure of an object. A machine shop is used to fabricate parts for a car; a ship is then used to transport the parts to a car factory in another country. The ship is changing the position of the parts in space, but the structure and substance of the parts stay the same.

Within a factory, certain kinds of machinery called *materials handling equipment* are used to move unfinished items from one piece of structural or material production machinery to another. On the one hand, these classes of machinery could be considered as transportation equipment, since they do not, themselves, change the substance or structure of the objects, just as the ship does not change the car parts. On the other hand, materials handling equipment can be classified as being part of the process of the generation of structure, as in the case of an assembly line, or as part of the process of the generation of substance, as in the case of an overhead rail used to transport a bucket of molten steel in a steel factory. To some extent, the exact boundaries of the categories of production are arbitrary, and I will consider materials handling equipment to be types of structural or materials production machinery, not energy-converting machinery. Once machinery is used on the outside of the factory, such as in the case of a cargo ship or truck, however, I will consider such machinery to be energy-conversion production machinery.

Transportation, as well as other energy-converting production, can be part of the final output of the production system. That is, energy-converting production is not always in the service of structural and material production, but may be part of final production itself, such as airline travel. Energy is also manifested in the change in the movement of molecules that occurs in heating or cooling, which may be used both for production (as in a blast furnace) or in final production (as in a kitchen oven). Finally, energy is manifested in the generation of light and other forms of electromagnetic energy (such as radio and TV broadcast); I will categorize light as a form of energy-conversion, but the rest of the electromagnetic wavelengths will be part of the domain of the next category of production, information.

The fourth category of production involves information. In order for production of any kind to take place, there must be a preexisting design which must be generated by a person or a group of people. This design will specify the process of production to be taken to create the desired object, and expresses the system as a whole. The design is used to help bring together all of the other categories of production -- structural, material, and energy-converting -- *through time*, in order to create a new set of configurations of matter/energy. In the automobile example, engineers create the designs and fabrication processes which are then carried out by operating managers and production workers. Computers and process instruments are used to help coordinate and monitor automobile production.

This production of a system as a whole does not involve, itself, any material manifestation, which is created by changing the structure and/or substance of the new element using the application of energy. Instead, the production of the system as a whole involves the processing of *information* (using, of course, production machinery). The fourth and final category of production is therefore *informational production*, and involves the use of *information production technologies*, such as computers for design or instrumentation for monitoring the production process.

In the realm of biology, information production technologies can be found at the cellular level. The biologist Mahlon Hoagland explains that "life's information – the 'ideas' governing how it operates – is encoded in genes, which are, in turn, decoded by machinery that manufactures parts that work together to make a living creature. Like the computer that builds itself, the process follows a loop: Information needs machinery, which needs information"(Hoagland and Dodson 1995, 81).

Human production involves designs, not genes. For example, in the automobile example, engineers, using either a drafting table and tools or a computer-aided design station, produce blueprints for various car parts, and specifications for the kinds of materials to be used in those parts. Other engineers specify the series of steps that must be taken, through time, to put the car together. Skilled production workers and operational managers receive the blueprints and use them to construct the parts of the car. Quality control personnel, as well as the production workers and foremen, use gauges and other industrial instruments to obtain information on how the production process is progressing, and to determine to what extent the original designs are being fulfilled.

Information production, like energy-converting production, may also be a part of final production, not just a way to change structure and substance. Media such as books and other printed matter, radio, and TV, or communications technologies such as the telephone and internet, involve the generation of information which is desired in its own right.

The definition of the economic system thus implies a four-fold division of categories of production: structural, material, energy-converting, and informational. Each category of production requires a set of production technologies. In the industrial era, the vast majority of these production technologies are types of machinery, and thus I will usually refer to production technologies as production machinery.

This four-fold categorization is simple enough to be comprehensible but complex enough to characterize the different functions that must be performed by the generative subsystem of an economic system. Each category of production can be seen as a function within the generative system. Thus, each category of production can be seen as an element of the economic system, each element serving a separate function. The set of these functions describes one aspect of the functional differentiation of the structure of the generative subsystem of the economic system.

This generative subsystem of the economic system will be labeled the *production system*. The allocative system, which distributes the output of the production system, will be labeled the *distribution system*. The following diagram shows the structure of the economic system as it has been elaborated up to this point:

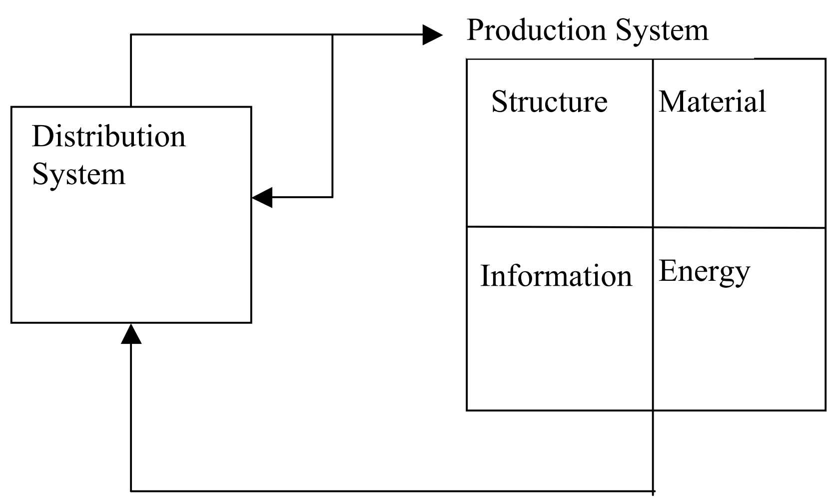

Fig. 22. Categories of production and economic system.

The economic system is composed of two subsystems, the distribution subsystem and the production subsystem (I will usually refer to these as systems, not subsystems). The production system, at this point in the argument, is composed of four elements, each of which has a function or purpose within the system of production. The output of the production system is received by the distribution system, which then allocates the output to the four elements of the production system and back to the distribution system.

One advantage of this categorization is that the categories emanate from the theory of systems. The production categories can be mapped to the categories used to describe a system.

First, the structural production function can be mapped to the structural level of the system. Just as a system is characterized by the organization of its parts, any produced good has been put together from a set of parts which themselves have been structured in a particular way (in the systems theory, the systems level includes structure and the domain of the system).

Second, the material, or substance, production function can be mapped to the elemental view of the system. The elements are the substance of the system, as the structure is the arrangement of the elements of the system. Similarly, the production elements, such as the steel molecules in a sheet of steel, are the substance while the structure, such as the shape of the sheet of steel as the hood of a car, is the arrangement of the steel crystals.

Third, the function of energy conversion can be mapped to the level of processes of change in the theory of a system. Energy conversion is required to effect change, just as positive and negative feedback processes change systems.

Finally, the information or design function is analogous to the system as a whole. The system encompasses the elemental, process, and structural levels. In the same way, the information function knits together the structural, material, and energy-converting functions of production.

The following diagram shows the mapping:

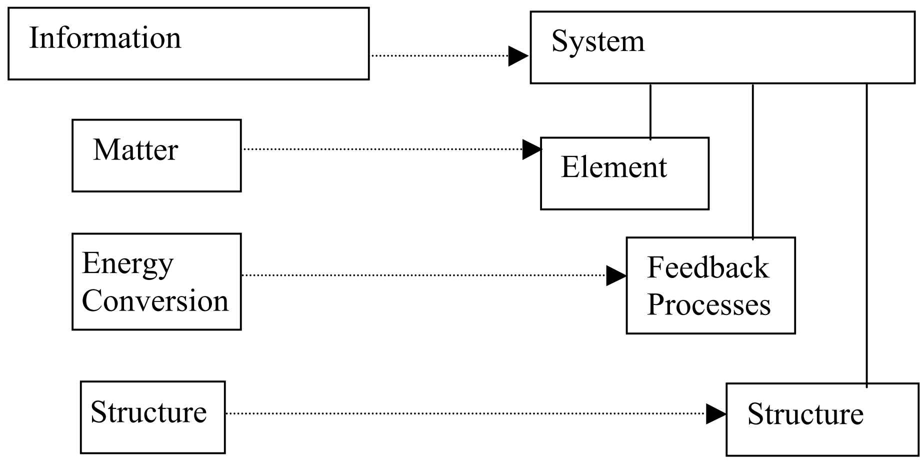

Fig. 23. Mapping categories of production to xystems.

The boxes on the left of figure 23 represent the production categories, and the boxes on the right represent the systems categories, while the dotted arrows represent mapping from the production to the systems categories. In a general system, there is a hierarchy among the elements, as shown on the right-hand side of the diagram. The categories of production conceptually divide all aspects of production among themselves, but do not imply any hierarchical ordering. Thus, my four categories are not ad hoc, but are based on my general theory of systems.

Since the categories of production map to the aspects of a system, then a production machine is also a system. A production machine, first, is made of parts, which consist of certain materials; second, it is put together in a certain structure; third, it relies on the production of forms of energy, usually in the form of a motor or engine; and finally, a production machine encompasses a design which puts together substance, structure, and energy, and it may also contain within itself the ability to gather information and change its actions accordingly.

Production is a mutually symbiotic interaction of the four functions specified above. Each category of production is necessary in order for the other categories of production to take place; none could exist without the others.

Since the functioning of one element is contingent on the functioning of the other elements, a negative feedback process occurs. Growth of the production system as a whole will be constrained unless all four categories of production are growing in some sort of balanced way. When one element attempts to grow beyond the capabilities of the other elements, the growth of the one element is stopped, restrained, or even reversed. The necessity of balanced growth leads to a kind of stability of the relative size of each functional sector.

Improvement in the techniques and quantity of production in one category reverberate to the other categories of production. *There is a positive feedback process of technological change among the four categories of production*; this is the first hypothesis about economic systems. This process is one in which an improvement in one category will cause improvement in other categories, and the improvement in the other categories will then lead to improvement in the first category, and so on.

Many scholars have offered similar lists of categories of machinery as being important for technological innovation, economic growth, and historically, the commencing of the Industrial Revolution. In none of these discussions of categories, however, is a theoretical framework proposed that would justify the inclusion of particular categories, as I have done. The lists are ad hoc.

For example, Bertrand Gille devised a diagram of the interrelation of technologies that existed at the beginning of the industrial revolution. The following is a reproduction, from Chesnais (Chesnais 1981, 55):

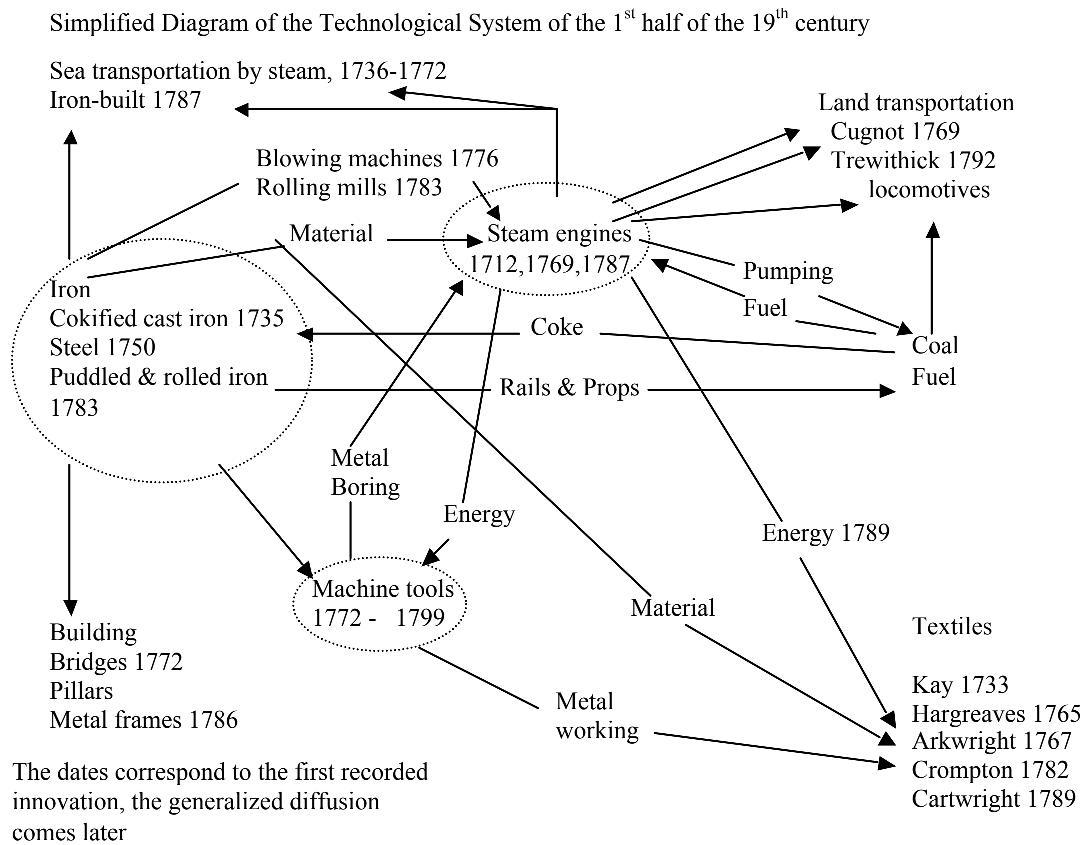

Fig. 24. Gille's structure of production.

I have added the dotted circles, to show the material production machinery, in the case of iron and steel technologies, energy-converting production technology, in the case of steam engines, and structural production technology, in the case of machine tools. There are many positive feedback loops in this schema – for instance, from machine tools through metal boring to steam engines, and back through energy-conversion to machine tools.

Chesnais, building on this work of Gille, claims that "each system has particular nodes from which one can trace the development of strong influences on the course of technological development in many sectors, industries or branches other than those where the original innovations appeared. Innovations at the central point in the system will induce a chain of innovations at other points of the industrial system. Some of these are complementary to the initial one and, when they occur, have feedback effects and help the new 'technology system' establish its hold over wide areas of industrial … production. The principal nodes in technology, around which the most important clustering of a systemic type takes place, have always been located in the capital goods and in the intermediate product industries: machine tools, electric and electronic equipment, and the various branches of the chemical industry." (Chesnais 1981, 55-56)

For Robert Brady, several production technologies are needed in modern manufacturing, most of which can be fit into my categories, as I indicate in parentheses: "low-cost metal" (material); "machine tools" (structural), "low-cost bulk overland-freight facilities" (energy-converting); "the ability to reduce friction", e.g., lubricants and bearings (structural); machinery which "is powered by an indefinitely flexible motive force", e.g., engines and motors (energy-converting); "systems of interchangeable parts" (structural); "automatic-control devices" (informational); and "feedback control" (informational), all depending, according to Brady, on standardization, which involves informational production (Brady 1961, 108-109).

Victor S. Clark stated that for the period from the Civil War to World War I, "the great expansion of manufacturing and its concentration in large establishments are due to the wider use of power and the improvement of machinery…Throughout the period covered by this volume, therefore, the manufacture of iron and steel was the nation's key industry, by which the progress, prosperity, and developmental tendencies of manufacturing in general were determined and illustrated" (Clark 1949, 351).

Shepard Clough notes that "in the expansion of industry during the years between 1875 and 1914 so many important innovations were made that designating the most strategic is exceedingly difficult. Yet there is little doubt that among the very important changes was the introduction of ways of making steel which permitted an enormous expansion in the output of this product as well as a dramatic reduction in price… Furthermore, cheap steel revolutionized the use of tools. It made possible great feats of drilling into the earth's crust in search of new riches". He also lists other building materials and mechanical engineering innovations, such as machine tools, as being most strategic, and entitled a section, as is common in histories of this era, "New sources of power" (Clough 1968, 400-407). Similarly, Rosenberg identifies as "the major components of industrial change" in the nineteenth century, "the substitution of machinery for handicraft skills, the widespread application of new power sources to industry and transportation, and the massive utilization of iron (and later steel)" (Rosenberg 1972, 59).

For David S. Landes, "the heart of the Industrial Revolution was an interrelated succession of technological changes. The material advances took place in three areas: (1) there was a substitution of mechanical devices for human skills; (2) inanimate power – in particular, steam – took the place of human and animal strength; (3) there was a marked improvement in the getting and working of raw materials, especially in what are now known as the metallurgical and chemical industries" (Landes 1969, 1).

In general, according to the economic historian Pollard, "the essential core of the process described here was technological, consisting of a better way of producing things or the production of new things" (Pollard 1982, v). Another economic historian, W. Paul Strassmann, also claimed that "at the heart of an industrial revolution are new machines, new processes, and new materials that transfigure the economic landscape" (Strassman 1959, 1). In particular, "Industrialization depends on metallurgy, power, and machine tools" (Strassman 1959, 117).

The historian of science A. Rupert Hall asserted that "modern technology seems to spring from four major roots, which I define in the order of their historical importance: the reorganization of labor, the use of machines in manufacture, the exploitation of man-made materials, and the application of new sources of energy. Each of these roots extends far back beyond the modern historical period" (Hall 1962, 501). By "reorganization", Hall seems to mean mainly factory organization, and his "machinery" is roughly synonymous with my use of "structural" machinery. However, Hall, like the other historians quoted, does not offer a reason for choosing these categories.

For the technological historian S. Lilley, "if the telegraph and telephone changed the world by making possible instantaneous communication over the whole globe, possibilities just as revolutionary were implied in the transmission of power by electricity" (Lilley 1965, 120). After discussing these information and energy technologies, in his next chapter he focuses on "three very important aspects of machines: the materials from which they are made and the tools and methods used in making them" (Lilley 1965, 142), concluding that "the lathe, with its many variant forms, is the most important of the machine tools and the possibility of most of the nineteenth-century advances was closely tied up with its development into a robust machine of high precision" (Lilley 1965, 147; see also Robert Woodbury's book on lathes, Woodbury 1961).

The business historian Alfred Chandler claims that "modern business enterprise, as defined throughout this study, was the organizational response to fundamental changes in processes of production and distribution made possible by the availability of new sources of energy and by the increasing application of scientific knowledge to industrial technology" (Chandler 1977, 376). He identifies structural, material, and energy-converting production technologies as key to this transformation. The factory managers "concentrated on three types of technological innovation to help expand further the volume of throughput: sustained development of multipurpose machine tools, improvement of metals in cutting tools to increase the speed at which machines worked, and increasing application of power to move materials more swiftly from one stage of production the next. All three intensified the use of energy and increased the amount of capital required in the processes of production" (Chandler 1977, 279).

Understanding the Industrial Revolution and the "second industrial revolution" of electricity and steel is important because all economies since the nineteenth century have depended on the base laid down by these eras of production innovation. The technologies created then have not disappeared today. There have been constant innovations in the basic industrial technologies, yet they have not received the same attention that other technologies, such as computers, have received. Social scientists should not judge the importance of a technology on the column inches a technology receives in magazines and newspapers. This study is an attempt to construct a more objective, theoretical basis for understanding the role of various technologies.

Aristotle, in a way, proposed a set of categories of production that were based on a theoretical framework. His categorization may serve as a useful way to understand many other scholars' categories. In the book *Physics*, he states that "the point of our investigation is to acquire knowledge, and a prerequisite for knowing anything is understanding *why* it is as it is – in other words, grasping its primary cause" (Aristotle 1996, 38-39, emphasis in original). Asking "why something is as it is", is equivalent to asking how something came to be as it is, and Aristotle is clearly interested in this process of change. His next sentence reads, "Obviously, then, this is what we have to do in the case of coming to be and ceasing to be, and natural change in general" (Aristotle 1996, 39). For something as mundane as goods and services which are the output of a system of production, then, Aristotle's inquiry is relevant – how did the goods and services come to be as they are? In other words, one way of phrasing his question, "Why is it as it is?", is to ask, "How was it produced?"

In the context of production, his answer makes more sense than he is usually given credit for. Aristotle proposes four types of "causes", but only one, philosophers tell us, is what we think of as a "cause", at least in the way "cause" has been discussed since Hume (see Bunge 1979, 31-33). Aristotle's "causes" are not really causes in the modern sense, but categories of production, or more generally, categories of coming into being.

Aristotle states that "one way in which the word 'cause' is used is for that from which a thing is made and continues to be made – for example, the bronze of the statue" (Aristotle 1996, 39) This corresponds to one of my proposed categories of production, material production, consisting of the substance of a produced object.

Aristotle continues, "A second way in which the word is used is for the form or pattern…", corresponding to structure as defined in the chapter on systems (Chapter 4). This concept is similar to my structural category of production.

Aristotle's third type of cause is the one that survives to this day: "A third way in which the word is used is for the original source of change or rest. For example, a deviser of a plan is a cause, a father causes a child, and in general a producer causes a product and a changer causes a change" (Aristotle 1996, 39). In terms of a generative system as I have described it, Aristotle is describing a generator, or the "source of change", as he puts it. Production machinery is the "producer that causes a product".

However, I have said that *all* of the categories of production include generators. Thus, there is a generator of material and a generator of form, or structure. For Aristotle, there are the categories of substance and form, and a separate category for the generator. I am claiming that it is more useful, in understanding production in an economy, to conceive of a generator for the material *and* a generator for the structural aspects of production. There is no generator separate from form or substance.

Thus, change is a part of the material category and the structural category, instead of being a separate part of production. Several of the quoted scholars use Aristotle's method of categorization. Often, steel and sources of energy, for instance, are listed as important categories, while machinery is then put in a separate category. But machinery is part of *all* categories of production.

In order to make any change, in the Newtonian mechanical world, a force must be produced. This is Newton's answer to Aristotle: force is the "changer" that "causes a change" in the simplified model that Newton proposed. In Einstein's reformulation of Newton's categories, energy replaced force as the producer of change. Similarly, I propose that energy-conversion be the third cause of "why something is as it is". Again, a "producer" or machine is necessary in order to "cause" this kind of change.

Aristotle's most controversial "cause" was his final one: "A fourth way in which the word is used is for the end. This is what something is for, as health, for example, may be what walking is for" (Aristotle 1996, 39), in other words, there is a purpose to everything. In chapter 8 of book 2 (Aristotle 1996, 50-53), he uses this reasoning to reject the possibility that animals are the way they are because of "accident". Animals are the way they are, Aristotle reasons, because of the implementation of a consciously planned design. This idea is counter to Darwin's conception of evolution. Although evolution does not occur "by accident", since adaptations succeed because they are congruous with their environment, Darwin was able to show that there can be a design without a designer, or a "blind watchmaker", as Richard Dawkins titled his book (Dawkins 1996). However, both Aristotle and Darwin are discussing the same problem: design.

Aristotle's fourth category can therefore be conceived as the category of *design*, although we now know that, because of DNA, design can be "accidental" in the sense of not having been consciously created. I have characterized the fourth category of production as the production of information, which includes the storage, processing, and propagation of design. Machinery is used for information processing.

Many authors, such as Chandler, give causal priority to management and organization, or to computer technology, which can be seen as variations on the theme of design. But for the purposes of understanding the technological change which leads to growth, it is more useful to focus on all four categories of production – material, structural, energy-converting, and informational – simultaneously. All four categories constitute a proper list of "causes" of "why it is as it is". The approach used here is therefore multicausal, as opposed to a monocausal explanation of technological change.

Authors often claim that a single category of production is central to industrial society. It may be claimed that energy is the center of industrial life (see Smil 1999 for a guide to energy), or that we live in an age of steel (for recent surveys of materials, see

Amato1997 and Sass 1998). It may be asserted that the computer has led to another industrial revolution (for a recent survey of information technologies, see Lebow 1995). Some scholars declare that transportation technology shapes history (for a good history of transportation technology, see Hugill 1993). Machines which shape and structure goods, such as machine tools, are not usually classed with these same technologies (with the occasional exception of the assembly line). This study will consider all four categories of production to be of similar importance, and I will discuss the importance of structural technologies such as machine tools in more depth in the next section.

Thus, the second implication of my definition of an economic system is that the processes of production can be usefully divided into four categories. In order for an economic system to grow, the technologies of all four categories of production must grow in a balanced way. Furthermore, innovations in any one category reverberate throughout the other categories as well, setting up a virtuous cycle of technological advance.

STAGES OF PRODUCTION

The first implication of my definition of economic systems is that production is central to the functioning of economic systems. The second implication is that there are four categories of production. This section explains the third implication, that there are stages of production.

As was claimed in the chapter on systems, in constructing a theory of a particular system, one needs to specify an ordering principle for placing functions along a particular dimension. In the case of categories of production, there is no ordering in the sense of a series of numbers; the categories of production constitute an unordered set. The ordering principle is that the elements are part of a set of functions, or functional set.

My definition of economic systems implies, in addition to categories, *stages* of production. While categories of production comprise simultaneous processes, stages constitute the sequences of different kinds of production necessary to produce goods and services.

Two stages of production are the production machinery stage and the production stage. First, production machinery is created, and second, the production machinery is used to generate final goods and services. This sequence is a model of the economy at a very high level of abstraction. In the real world, there are very long sequences and cycles involving production machinery, output, production machinery, output, etc.

For instance, one such simplified sequence was given above in the description of the production of an automobile, and is shown here in diagrammed form:

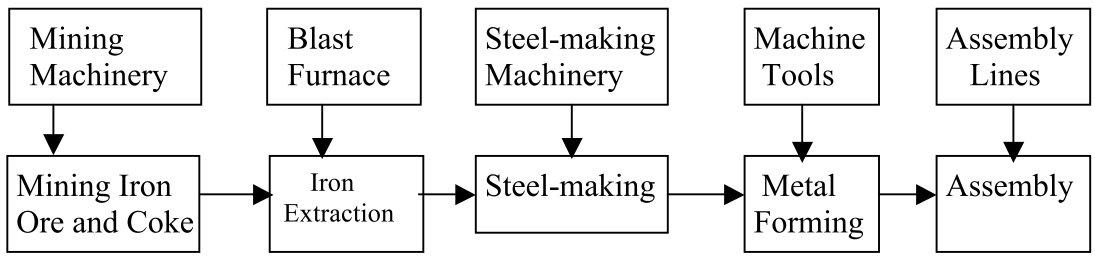

Fig. 25. Automobile production and production machinery.

The production machinery in this case consists of the mining machinery, the blast furnaces, the steel-making machinery, the machine tools, and the assembly lines. All of these classes of machinery must be produced before they can be used. The stage at which these machines are built I am calling the *production machinery stage* of the sequence of production. Once these machines are constructed, they are then used in the *production stage* to produce, in the automobile example, the iron ore, coke, steel, metal parts, as intermediate goods, and then the automobiles, as final goods.

At all times all stages of the sequence are active. That is, in the case of the automobile, there are always blast furnaces, steel crucibles, metal-forming machine tools, and assembly lines in operation. This process is referred to as *pipelining*: something is always in the production pipeline. In order to claim that production machinery is produced before final goods are produced, I must abstract from reality, and observe that in production, the generator must exist before the final output exists.

The generator *causes* the output to exist. The existence of a cause assumes a sequence in time, that is, the effect of the cause occurs *after* the cause. In the case of production, production technology causes the provision of goods and services; therefore, production technology exists prior to the goods and services.

The production system is a generative system, which includes a sequence and a functional differentiation. Along one dimension of functional differentiation, as explained in the previous section, there exist categories of production. Along a second dimension, we have a sequence of production composed of stages. The first stage *produces* production machinery, and second stage *uses* production machinery to produce goods and services.

This sequence corresponds to the general generative systemic structure of a generator and output, as proposed in the chapter on systems. There is another possible stage in such sequences, the metagenerator stage. That is, there is a stage that must exist in order to generate the generator.

Such a stage exists in all human societies. Humans are unique in being able to use tools to make tools. Many other animals make tools. For instance, chimpanzees strip leaves from a twig and use them to capture termites, or they find appropriate rocks with which to crush shelled nuts. Since the earliest humans, predating our species *homo sapiens*, "metagenerator" stones have been selected for use in order to create various stone-based cutting tools; certain "hammer" stones were used to produce tools. But these hammer stones were not a reproductive technology. That is, the stones used to make stone cutters were not used to make more stone metagenerators.

Similarly, there have been various simple technologies for creating fires, and fires were (and still are) used both as energy-converting production technologies and material production technologies. But these devices, such as setting a spark using flint, could not be used to help create more flints.

With the development of iron technologies, however, a reproductive aspect appeared in human technology. It was now possible to use an iron hammer to help create another iron hammer.

The industrial revolution created the production technologies which enabled human production systems to become fully reproductive. *It is because of the ability of the metagenerative production machinery to be mutually causative and reproductive that economic output has increased exponentially since the advent of the Industrial Revolution*; this is the second hypothesis about economic systems. By using the systems theory as developed in this study, it is possible to give a formal definition of the Industrial Revolution: the Industrial Revolution was *a change in the structure of the system of production from containing a partially reproductive metagenerator to a fully reproductive metagenerator*.

Carrol Pursell has summarized the interactive nature of the metagenerative technologies of the industrial revolution:

> The increasing availability of cheap iron, both cast and wrought, made it possible to move from the wood technology of time immemorial to modern iron technology. This was not a simple progression from one development to another. Immediate and critical feedback reinforced the change and made it irreversible through a ratchet effect. The use of coke had, for example, made iron cheaper and available in larger quantities. As a result, it became economically feasible to use steam engines in many more industries. When John Wilkinson, who cast the iron cylinders for Boulton and Watt's great engines, installed one to power his blast furnace, the increased blast further improved the quality, quantity, and cheapness of iron that he then used in improved engines. The steam engines were widely used to drain coal mines, and this application made coal cheaper and more readily accessible. This in turn encouraged the greater use of steam engines that drew on coal for fuel. And so it went….The rolling mill developed by Cort offers another case in point…Another example can be taken from the extremely important field of machine tools. To be most useful, iron had to be worked into useful shapes. The only machines that could possibly accomplish this were themselves made of iron. Thus each improvement in metallurgy made it easier to cut and work iron, and this in turn made it possible to produce more and better iron products…(Pursell 1995, 56-58: for similar quotes, see [Rosenberg 1982, 246] and [Strassman 1959, 206-208]).

This trend of mutually causative metagenerative technology has continued throughout the last two centuries. Because of the development of steel, the construction of electricity-generating turbines was enabled. With ample electricity, fine steels were created by using electric lances. In addition, electricity allowed for an increased productivity and precision in the use of machine tools, which in turn created the opportunity for the development of better steel-producing and electricity-producing technologies.

More recently, the expansion in power and use of computers has led to breathless descriptions of the present era as ushering in a “new economy” or as being the most important period of technological innovation in history. By using my theory of production, however, it is possible to understand the present period of technological change: the *informational production technologies* have caught up with the structural, material, and energy-conversion technologies.

The metagenerator for all computer-based technologies is a set of machinery called semiconductor-making equipment. These technologies, which are based most fundamentally on optical technology, are used to create the semiconductors that are then inserted into most pieces of equipment today, including production machinery. An improvement in semiconductor-making equipment leads to more powerful semiconductors, which are then used to create better semiconductor-making equipment. Before the advent of the transistor, vacuum tubes were not used in the construction of vacuum-tube producing equipment; the information production technologies were not used to reproduce themselves. Semiconductor-making machinery, like machine tools, help to reproduce themselves.

These reproductive metagenerative technologies can be labeled *reproduction machinery*, to focus attention on the ability of these classes of machinery, collectively, to cause exponential growth of output. This exponential growth is the result of two kinds of positive feedback. First, the technologies help each other; there is mutually causation, and an amplification of innovation. This is a general feature of the four categories of production, as explained in the previous section.

Second, reproductive machines can collectively reproduce themselves. This positive feedback process is particular to the reproductive stage of production, as opposed to the mutually causative aspect of the categories of production. Since machinery can produce output much faster than humans can produce the same output by hand, the total production emanating from reproductive machines can expand explosively. The reproduction machinery industries contain great productive power.

We can see this self-production in several technologies. Machine tools produce the metal pieces that are used in all machinery. This means that machine tools make the parts for making more machine tools.

The reproductive potential of reproductive technologies, furthermore, can be most easily observed within the machine tool industry, although machine tools are not the only kinds of machinery which help to reproduce themselves. Many scholars have written about the importance of machine tools and the more general category of metal-working technology. These scholars have also noted the way in which machine tools create the machines which create goods and services, without setting this insight into a general theoretical framework, as I am attempting here.

For example, a long-time editor of the trade journal *American Machinist*, not surprisingly, believed that "machine tools are the foundation for almost all manufacturing." He goes on to back up this assertion: "Once we leave the work of artisans behind, virtually every man-made device is produced either by machine tools or by machines and equipment produced by machine tools. Thus an automobile is an assembly of metal parts made by machine tools, plastic parts produced by machines made by machine tools, fabric processed on textile machines made by machine tools, rubber processed and molded by equipment made on machine tools, and glass processed by equipment produced by machine tools…Machine tools have often been called the only machines that can reproduce themselves" (Ashburn 1988, 19).

According to Corcoran, "It is said that machine tools are the master tools, the tools that make tools. Virtually every product is built on a machine tool or on a machine made by a machine tool. Accordingly, technological change within the machine tools industry translates into technological change in manufacturing processes themselves" (Corcoran 1990, 227). The economic historian Habakkuk (1967, 105) states that "A large part of American industrial progress in the nineteenth century was due to the rapidity of technical advance in machine tools". In a well-known article entitled "Do machines make history?" Robert Heilbroner states that "until a metal-working technology was established – indeed, until an embryonic machine-tool industry had taken root – an industrial technology was impossible to create" (Heilbroner 1994, 58).

The technological historians Derry and Williams (1960, 363) assert that "in the twentieth century the rapid development of the motor-car, and subsequently of the aeroplane industry opened immense new fields for the application of machine-tools. Although never a large industry in terms of the number of people employed, the machine-tool industry has long been of the most fundamental importance to technological progress of every kind".

A United Nations report on global machinery industries states that, historically, "the pace of development of machine tools governed the pace of industrial development" (UNIDO 1984, 57); the authors also claim that the entire industrial machinery sector plays this role (UN 1984, 3). Currently, "in terms of a country's development, machine tools play a crucial role" (UN 1984, 57).

According to a report commissioned by the National Academy of Engineering and the National Research Council, "The machine tool industry is of great strategic importance to the processes of economic growth and industrial development. Virtually every major manufactured product is produced on machine tools or on machines built by machine tools" (Machine Tool Panel, 1), and "Machine tools are crucial elements in heightening industrial productivity".

The following is a reproduction of a diagram found in their study. It shows the tripartite structure of production that starts with machine tools (reproduction of figure 2, page 6):

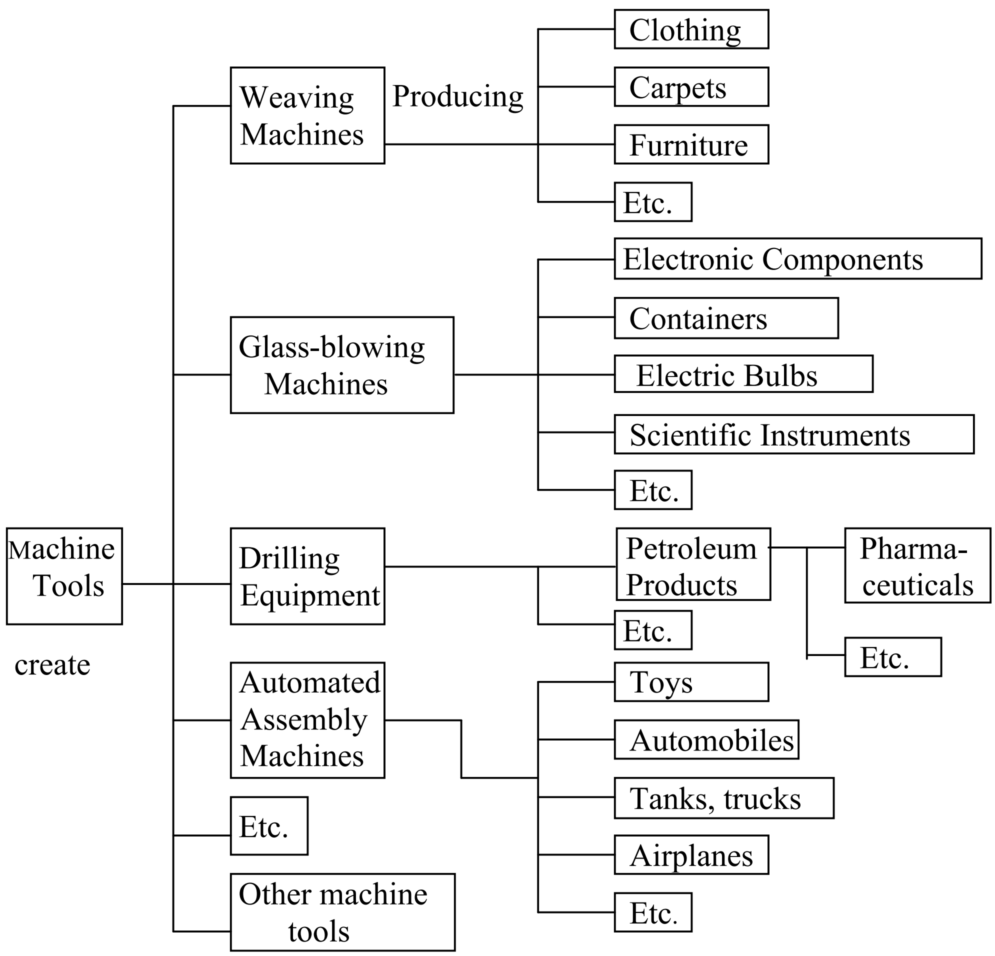

Fig. 26. Position of machine tools in production system.

Thus, machine tools create the production machinery that produces the goods people use. In a similar vein, the National Advisory Committee on Semiconductors (1990, 3) points out that the global semiconductor equipment and materials industry generates revenue of $19 billion, which is used in the global semiconductor industry, valued at $50 billion. Semiconductors, in turn, are used by the global electronics industry, which output $750 billion of goods in 1990.

Max Holland, summarizing his chronicle of the decline of the U.S. machine tool industry, states that "political primacy, economic wealth, and preeminence in machine tool production have always coincided because 'mother machines' are the heart of any industrial economy. The correspondence between the rise of the American tool industry, which began before the turn of the century and reached a peak in the early 1960s, and American politico-economic power was not mere happenstance. In like manner, the tool industry parallels the decline of the American economy since then" (Holland 1989, 264). This association of production competence and national power will be pursued in the chapters on systems of political economy (Chapters 9 and 10).

Any writer on the machine tool industry, as can be seen, makes statements along the lines of the technological historian Rolt:

> It is impossible to study the history of technology without becoming aware of the crucially important part played in that history by machine tools and their makers. It is scarcely an exaggeration to say that man's tools have governed the pace of industrial revolution. We should never have heard of James Watt, George Stephenson, Gottlieb Daimler, Rudolph Diesel or the Wright Brothers but for the tools which could alone give their ideas a practical shape…All down the ages the rate of man's material progress has been determined by his tools, because all tools represent extensions of the human hand, being designed to magnify its cunning or its power…The most versatile of all tools is the human hand, but it is feeble and fallible. The aim of all tool-makers from first to last has been to overcome these defects by enhancing the power of the hand and reducing its fallibility…the tool-makers attacked human fallibility by 'building the skill into the tool'. (Rolt 1965, 11-13)

While the structural production machine that dominates the public imagination is the assembly line, as Womack, Jones and Roos point out in their book on the automobile industry, "the key to mass production wasn't – as many people then and now believe – the moving, or continuous assembly line. *Rather it was the complete and consistent interchangeability of parts and the simplicity of attaching them to each other*" (Womack, Jones and Roos 1990, 27, emphasis in original). This interchangeability, according to these authors, was made possible by machine tools, prehardened metals, and auxiliary technologies such as gauges (corresponding to structural, material, and informational production technologies, respectively).

Speaking of the nineteenth century, Rosenberg writes that

> the machine tool industry, then, played a unique role *both* in the initial solution of technical problems and in the rapid transmission and application of newly-learned techniques to other uses. In this sense the machine tool industry was a center for the acquisition and diffusion of the skills and techniques uniquely required in a machinofacture type of economy. Its role was a dual one: (1) new skills and techniques were developed here in response to the demands of specific customers, and (2) once acquired, the machine tool industry served as the main transmission center for the transfer of new skills and techniques to the entire machine-using sector of the economy" (Rosenberg 1972, 98).

Thus, machine tools add to the productive power of a nation because they increase the speed of diffusion of innovations throughout an economic system. Rosenberg stressed the role of machine tools in spreading innovation. Speaking of the metal-shaping activities in general, he wrote that "it is because these processes and problems became common to the production of a wide range of disparate commodities that industries which were apparently unrelated from the point of view of the nature and uses of the final product became very closely related (technologically convergent) on a technological basis – for example, firearms, sewing machines, and bicycles" (Rosenberg 1976, 16), as well as automobiles. The point in terms of this study is that one set of production technologies not only was critical to the production of several categories of final goods, but that the skills learned in the production machinery industries spread, in a give-and-take fashion, throughout large portions of the economic system: "We suggest that the machine tool industry may be regarded as a center for the acquisition and diffusion of new skills and techniques in a machinofacture type of economy. Its chief importance, therefore, lay in its strategic role in the learning process associated with industrialization" (Rosenberg 1976, 18).

As Strassmann commented on Rosenberg's article, "But interindustry economics anoints none as king, not even machine tools" (Strassmann 1963, 444). There are important technologies within all four of the categories of production, although machine tools are the least known of them.

Steel-producing equipment is made from steel; therefore, this type of equipment helps to make more of its type of machinery. Electricity is used, by machine tools, to make the high-precision parts of electricity-producing turbines; the turbines help to make more turbines. Finally, semiconductors are used to produce the parts that make up semiconductor-making equipment, and thus every advance in semiconductor-making technology is self-reinforcing.

These technologies not only are used to make more of themselves, but collectively they are employed to make more of one another. The steel is used to make machine tools, and the electricity powers the machine tools that produce more machine tools. One of the greatest benefits of semiconductors has been to automate machine tools; computerization has led to large-scale automation of steel production. New metal alloys are used to produce more reliable electricity-generating turbines and material for semiconductors.

The historian of technology Basalla points out that Samuel Butler, the author of the utopian novel Erewhon, wrote that "the propagation of mechanical life depends on a group of fertile contrivances, called machine tools, that are able to produce a wide variety of sterile machines" (Basalla 1988, 16). Butler was calling attention to the fact that some technologies, in this case machine tools, are "fertile", which means that they are reproductive.

These reproductive machines not only make more of themselves, they are used to produce the production machinery that produces the final, consumed output. For example, machine tools, steel from steel mills, electricity from electrical systems, and computers are used to produce the following: construction machinery that builds the physical structures in the economy; the textile machinery that is used to make clothes; the food machinery that is used to process much of the food we eat; and the planes and trains that we use to travel.

I will use the term “production machinery” for machinery that is used to produce final output. Thus, reproduction machinery and production machinery are separate categories. The general term “machinery” will be used to refer to both reproduction and production machinery. Machines bought by consumers will be referred to as “consumer machinery”, but for the purposes of this study, will not be included in the general term “machinery”. When a truck is used to transport parts between factories it is classified as production machinery; when the same kind of truck is bought by a factory worker for personal use, that truck is classified as consumer machinery. Each machine is classified according to its use as either reproduction machinery, production machinery, or consumer machinery.

Most of the machines that are classified as a type of reproduction machinery can also be used as production machinery. Thus, most of the electricity generated by turbines is not used to make more reproduction or production machinery but is used for production of final output or home use. Most steel is used for final production, particularly in construction. Many machine tools are used in the auto industry. Sometimes the same machine may be used for different stages of the production process. A production machine takes on a particular function depending on what it is being used for during a particular period of time.

While certain classes of machinery, such as machine tools, can be used as both reproduction machinery and production machinery, there are certain classes of production machinery that never participate in reproductive processes. As Strassmann pointed out in terms of the nineteenth century, “Textile machines benefit as much as machine tools and motors from advances in metallurgy and power engineering…The fact that they borrow innovations from other industries without selling commodities to these industries means that they cannot expand and innovate with the increased scale of operations of these industries per se. During the nineteenth century the demand for metals, power equipment, and engineering tools grew at a much faster rate than the demand for textiles because of the strategic importance of these industries in the Industrial Revolution. The complementarity of innovations here was, in fact, the essence of that revolution” (Strassmann 1959, 214). The reproduction machinery industries as well as the production machinery industries gain from innovation in reproduction machinery, but the reproduction machinery industries do not gain from innovations in purely production machinery industries.

Thus, particular industries such as machine tools, steel, and electricity may be considered wholly within the reproductive sectors when the focus of study is the technological capability of a production technology to cause change throughout the system of production. In terms of modeling the economy as a production system, it will be more useful to split these industries into two or three pieces in order to show exactly how each stage is constituted in terms of types of machinery.

Thus, production in the industrial age has the following structure:

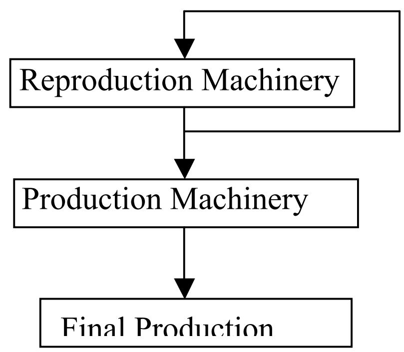

Fig. 27. The stages of the production system.

This is a sequence of stages of production. Reproduction machinery is used to produce more reproduction machinery and to produce production machinery. Production machinery is used to produce the goods and services that people use, including physical structures such as buildings and roads. This sequence of functions is ordered in time.

Because this sequence is similar to the tripartite generative sequence I proposed in the chapter on systems, I will refer to these stages as a tripartite sequence of production. There are similar tripartite sequences of production in the biological realm. For instance, the science writer Colin Tudge wrote of the co-discoverer of DNA, "Francis Crick has summarized molecular biology in what he calls the 'central dogma': 'DNA makes RNA makes protein'" (Tudge 2000, 72). In the discipline of economics, there have been two main efforts which are similar to my tripartite schema as presented here, one by a Marxist and another by a nonMarxist.

The Feld'man model is based on a model of Karl Marx. Marx developed a theory of economic production which included production machinery and production stages of production (the following is based on Domar 1957, 225). In Marx's Department (or Category) 1, the goods are made that are used to make the goods in Department (or Category) 2, which is the consumption sector. The Soviet economist Feld'man built on this basic idea to construct a model which Stalin later used as a basis for the Five Year plans. In the model, as Domar says, "in a growing economy some capital is used to make more capital" (235). As Domar shows in his article, investment in Category 1, that is, capital goods, can lead to exponential growth.

Feld'man stated that "the increase of the rate of growth of production depends on the increase of the capital of sector A as compared with the increase of the capital of sector B (consumers' goods sector). With expanding reproduction, sector A must supply sector B not only with producers' goods required to continue production at the current level of output, but also with additional fixed and circulating capital necessary for expansion of reproduction…This gives rise to the idea of dividing the capital of sector A into two sections, of which one (A_2) supplies sector B with the means of production required to sustain output at a given level, and the other (A_1) supplies all industries in both sectors with additional capital to enable reproduction to expand." (Feld'man 1964, 175-176). This is similar to my tripartite structure, where A_2 is similar to my production machinery sectors and A_1 is similar to the reproduction machinery sector. The difference is that A_1 also provides extra *production machinery* to the final production sectors, while in my conception of an economic system the reproduction sectors do not supply machinery to the final production sectors, but only to the production machinery sectors.

Using Feld'man's ideas, Stalin wrote that "a fast rate of development of industry in general, and of the production of the means of production in particular, is the underlying principle of and the key to the industrialization of the country, the underlying principle of and the key to the transformation of our entire national economy along the lines of socialist development…It involves the maximum capital investment in industry" (Stalin 1964, 266).

Stalin used this reasoning as part of a plan that resulted in rapid industrial growth as well as the starvation millions of peasants, among many other deprivations. However, he grasped the importance of the "production of the means of production". His use of the term "means of production" corresponds to my use of the term "production machinery", and the producers of the means of production therefore correspond to my use of the term "reproduction machinery".

As K.N. Raj notes, "The theoretical implication that it might be useful in certain contexts to break down the capital goods sector in the Marxian scheme of reproduction into two sub-branches, one devoted to the manufacture of capital goods for producing capital goods (which for convenience has been termed the 'machine-tool sector' by Dobb) and the other manufacturing capital goods directly for the consumer goods sector, has been reflected to some extent in subsequent planning literature" (Raj 1967, 217). Maurice Dobb (Dobb 1960), whom Raj referred to, used a tripartite disaggregation of the economy similar to the one used in this study, but he tried to make his model compatible with Marxist economic traditions.

The nonMarxist economist Adolph Lowe adopted a tripartite classification similar to my scheme, although he was more concerned with equilibrium than growth. After distinguishing between the consumer-goods and equipment industries, "among the equipment-goods industries I propose to distinguish between those that produce equipment to be applied in the production of consumer goods, and others that produce equipment for the equipment-goods industries themselves" (Lowe1987, 34); in other words, he distinguished between production machinery and reproduction machinery, respectively.

Lowe points out that in order to find a sector that makes itself, the problem of "infinite regress" must be solved (Lowe 1987, 36): that is, once having found the equipment which makes the equipment which makes goods, is not there also a sector that makes the equipment that makes the equipment that makes the equipment, and on and on? Solow (1962, 207) invokes this "infinite regress" to dismiss the possibility of identifying a separate equipment-making equipment sector.

Lowe solves this problem by considering reproduction in organisms, specifically wheat, and concludes that "the primary condition for the economic reproduction of wheat is its physical capacity for self-reproduction". He therefore finds that:

> "The lesson is obvious. Only if we succeed in discovering in the realm of fixed-capital goods certain instruments which share with wheat the capacity for physical self-reproduction can our problem be solved. In other words, we have to look for a type of equipment which is technically suited to produce other equipment as well as its own kind. What we find, as a matter of fact, is not one single instrument, but the comprehensive group of instruments which are classified as machine tools. They are for industrial production what seed wheat or the reproductive system in animals represents for agricultural production. They form an indispensable part of input whenever an equipment good, including machine tools themselves, is to be reproduced". (Lowe 1987, 37, see also Lowe 1965, 270)

I would only amend this statement to say that there is a class of machinery, including machine tools, which, as a set, reproduce themselves. In fact, Lowe uses machine tools, steel plant, blast furnaces, and extraction machinery as examples of his equipment-making equipment sector (Lowe, 1987, 38).

Many authors have commented on both the categories and stages of production, without putting them into a broader framework. This study is an attempt to provide the larger framework within which to understand the insights of these scholars and the long-term processes of the economy. Understanding production as a functionallydifferentiated system composed of a structure makes possible the construction of hypotheses which are theoretically-based and hold greater explanatory power for understanding the rise and decline of Great Powers than the various ad hoc statements exhibited in this and previous chapters.

Thus, there are two dimensions in the ordering of the elements of the system of production. Along one dimension, production technologies fit into categories of production. Along another dimension, technologies can be characterized according to their position in a sequence of stages of production. The next chapter (Chapter 7) will discuss the structure of the production system that results from the combination of these two orderings, and Chapter 8 will include a discussion of the other subsystems within the economic system, the capital subsystem and the distribution subsystem.