

# THEORIES OF THE INDUSTRIAL REVOLUTION: A FEEDBACK PERSPECTIVE

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## ABSTRACT

Historians have presented a variety of hypotheses to explain the spectacular socio-economic changes in late 18th and 19th century England known collectively as the Industrial Revolution. This paper seeks to clarify the feedback structures underlying these diverse theories and show how they may be viewed as separate pieces of one overall puzzle. Causal-loop diagrams are used to help explain the basic mechanisms necessary for rapid economic development and the roles of investment, agriculture, income demand, raw materials, and technological innovation in that process. It is suggested that feedback thinking can be a powerful tool for unifying the typically broad spectrum of ideas concerning a set of events as complex as the Industrial Revolution.

## INTRODUCTION AND PURPOSE

Economic historians and non-economic historians alike point to the British Industrial Revolution as one of the great discontinuities in human history. There is general agreement as to the nature of British society both preceding and following the tumultuous events of the late 18th and early 19th centuries. Documents of the transition process itself are certainly not lacking. The perplexing question, then, is not what happened (the pieces of the picture), but why it happened (how the pieces fit together). Theories of industrialization and modernisation should be more than descriptions of changes that occur in one or more sectors of an industrializing society; that is, they should attempt to get at the "deep structure" that underlies the observed behavior. By deep structure is meant that set of social and economic relationships that existed prior to, during, and after the Industrial Revolution. A typical piece of such structure is shown in Figure 1. This

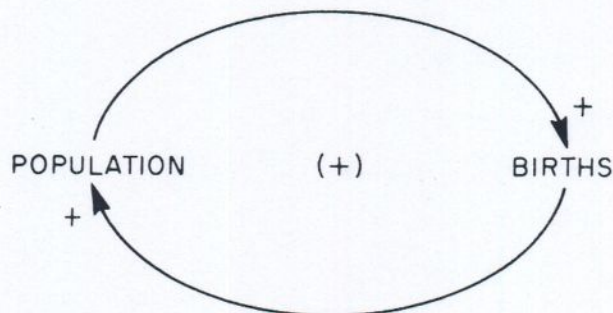


Figure 1: The Simple Population Growth Loop

figure introduces the causal-loop diagram format that will be used throughout this paper.<sup>1</sup> It says that, other impinging factors being equal, increases in population lead to further increases in population through the process of childbirth. The (+) sign in the middle of the feedback loop indicates that if other factors (such as death and infertility) did remain equal, population would increase explosively and without end. In real life, such positive feedback processes are eventually counteracted by negative feedback processes which constitute the natural constraints on runaway growth or decline.

The purpose of this paper is to examine various theories that deal with aspects of the Industrial Revolution, by clarifying their implicit feedback structures. This exercise is worthwhile for the following reasons:—

- (1) Feedback structures force one to adopt an "internal" view of the process in question. That is, one seeks to explain observed behavior in terms of the interactions of endogenous variables rather than the impact of some set of powerful exogenous influences (such as weather). Exogenous variables are viewed as important, however, in the sense that they form a kind of boundary within which the process is played out and may trigger (as opposed to force) characteristic system responses.
- (2) One can equally well represent and relate to one another psychological, sociological, economic, and other influences in feedback terms. As Musson has pointed out, such an interdisciplinary, qualitative approach is necessary for a complete understanding of the Industrial Revolution.<sup>2</sup> Important insights can be gained by simply making explicit tacitly agreed-upon, common-sense relationships for which no hard data may exist.
- (3) Radically different modes of behavior observed within a given time frame are explained in terms of shifting "loop dominance" within a constant structure, rather than as alterations in the system's structure itself. In other words, different aspects of a single social reality become apparent at different times in history.<sup>3</sup> This philosophy enables one to integrate seemingly opposed theories into a more complete view of the process in question. Using feedback structures can thus lead to a more balanced approach to theory-making. From this methodological viewpoint, the uniqueness of the Industrial Revolution lies not so much in either the supply-side or the demand-side of the British economy in the 18th century *per se*, but rather in the mutually reinforcing interaction of the two.



## INDUSTRIALIZATION, TECHNOLOGY, AND SOCIETY

Before discussing the factors which combined to produce an Industrial Revolution, the net "bottom-line" result of the process should be described. Hartwell defines the Industrial Revolution succinctly as "the sustained increase in the rate of growth of total and per capita output at a rate which was revolutionary compared with what went before."<sup>4</sup> This increase in output is mainly identified with the growth in an urban, industrial manufacturing sector that produces for both domestic and foreign markets. Much emphasis has been placed on the role of trade in the "Atlantic economy" of the 1700s as a spur to industrial growth. However, the discussion will be restricted to that set of processes generated entirely within Britain, under the assumption (shared by others) that the home market was the decisive one in determining growth.<sup>5</sup> The international economic and political conditions that existed should therefore be considered outside the boundary of the social system in question. The Industrial Revolution is thus defined as a self-generated boom in the output of manufacturers that radically changed British society.

All production requires inputs and a method for combining and transforming these inputs into a product. A generalized production function has inputs of raw materials, capital (buildings and equipment), labor, and technology. Technology is often seen as the key to production, in part because it determines the types and optimal (or desired) ratios of material, capital, and labor inputs. Technology is the critical variable in determining the efficiency or productivity of the transformation process, in terms of units of output relative to units of input. For this reason, the swift technical advances of the late 18th century — specifically, the introduction of Watt's steam engine and Cort's iron puddling and rolling process — are probably pointed to most often as the "root causes" of the Industrial Revolution. As Deane states, "The adoption of a metal-using technology employing decentralized sources of power, which the inventions permitted, lies at the heart of the first Industrial Revolution."<sup>6</sup> The new technologies removed the constraints on output imposed by the old technologies and changed the nature of the entire economy and its use of material resources, labor and capital.

While it is important for an understanding of the Industrial Revolution to trace out the effects of technology on production and, indirectly, on demand, it is equally important to examine these social and economic forces that provided the incentive to innovate in the first place. Technology and society are intertwined by feedback loops which can cause explosive growth of the economy. The social changes that accompanied the great increases in output and technology will be examined here, with special attention given to (1) the dramatic shift out of agriculture and into industry, (2) the connection between labor supply and consumption demand, (3) the importance of raw materials, and (4) the process of innovation in a scientific society. Values and institutions that developed largely prior to the 18th century (such as science, individualism, rationality, laissez-faire, and a tradition of and positive regard for commerce and enterprise), are outside the boundary of consideration here, because of the long intervals of time over which these developed. Such factors played important roles in the development of a favorable climate for industrial change and are taken to be "preconditions" of radical change, as Rostow puts it.<sup>7</sup>

## A THEORY OF UNFETTERED ECONOMIC GROWTH

Adam Smith's classic statement of the industrialization process (setting aside agricultural considerations for now) still forms the core of many modern theories; and rightly so, since it describes feedback processes that can lead to continuous (as opposed to transient) market growth, and in so doing, connects supply to demand.

On the supply side, business profits are invested in new, more efficient, and more specialized techniques of production. The resulting increase in productivity increases actual output for a given level of capacity utilization. On the demand side, expansion of capacity generally generates additional employment.<sup>8</sup> Assuming that wages are sticky downward, the increased employment will push up the average standard of living. Given access to goods, a higher standard of living leads to a greater demand for goods, and so more purchases. This growth of a middle-class labor force is the most important aspect of Smith's concept of "market expansion".

Prices and other indicators of relative market balance, such as delivery delays and quality of service, will not change much if supply and demand keep pace with one another. As long as demand stays high and operating costs (labor, capital, and materials costs) are low, profits will continue to be made and ploughed back into productive enterprises for further expansion. (It should be noted that competitive prices actually fell during much of the 18th century, but innovations occurred rapidly enough to keep profits rising).

There are several crucial assumptions implicit in this "profit-produces-growth-produces-profit" idealization of an industrial economy: (1) Materials, labor, and physical capital are all in sufficient supply to keep their use economic; (2) A rising average income is sufficient to boost demand for the various goods and services produced; (3) Efficient unification of supply and demand for both inputs and outputs has been achieved through relatively cheap and rapid communication and transportation; (4) The economy is well-integrated, so that linkage and diffusion effects produce general growth, rather than localized or contained growth; (5) Production technologies in use steadily improve so that costs steadily decline, keeping profits from being swallowed up by competition; (6) The process of technical advance, from invention to entrepreneurial application, improvement, and diffusion, takes place without serious hitches. This requires that profits be ploughed back into industry instead of used to buy country estates or other items of luxury.

Figure 2 illustrates the story told so far. Loop 1 says that profits lead to investment in new techniques which lead to lower costs which lead to more profits. Loop 2 says that investment leads to an expansion of the labor force, which increases demand, thus increasing profits. As a result of these two loops, production will tend to increase exponentially. Supply and demand will march more or less in lockstep, because of the balancing or equilibrating mechanisms of price and delivery delay. Loop 3 (a negative, controlling loop) states that when demand runs ahead of (or behind) supply, prices and delivery delays will rise (fall), which then pushes demand back down (up).

The process of rapid economic growth described above may



seem facile, because of the strong, even unlikely, assumptions that lie behind it. The point to be made here is that the Industrial Revolution occurred and was unique exactly because all of these necessary conditions were met by the Britain of the late 1700s. It is only in recent times that all of the prerequisites for explosive growth could come together for the period of time required to produce radical changes in society. The remainder of this paper will explore some of the feedback processes that embody possible bottlenecks, barriers, and limits to growth of an economy and how the British economy managed to break free of these constraints.

### THE ROLE OF AGRICULTURE

Agriculture is important for economic growth for a number of reasons. Enclosures and the resulting interest in applying profits toward agricultural investment sparked off a series of innovations in land drainage, land extension, field rotation,

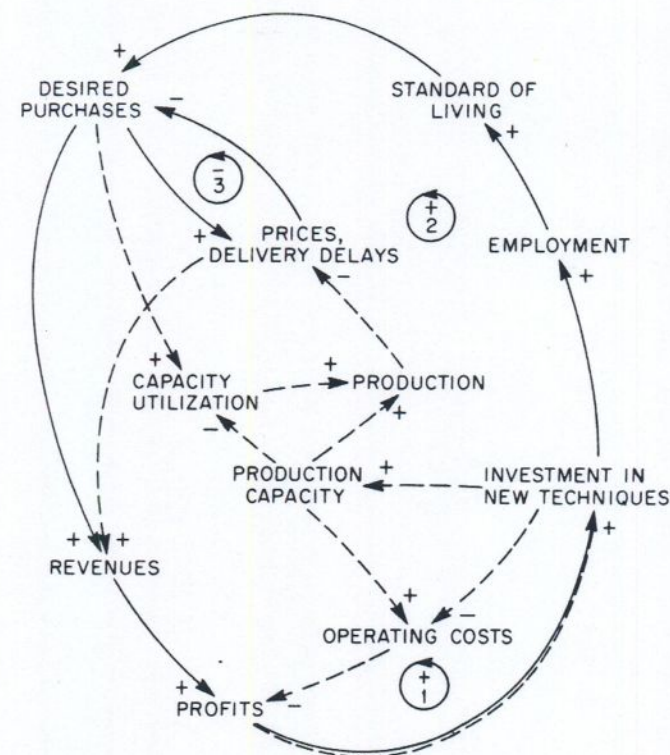


Figure 2: The Central Theory of Economic Growth

irrigation, animal husbandry, and other elements of farm productivity. Such innovations and the accompanying capital accumulation allowed food output to increase so that urban populations could continue to eat and so continue to grow. Since labor was increasingly demanded in the factories, food can be considered a potential constraint on industrial output.

Another way in which agriculture may be a constraint on manufacture is if the land requirements for agriculture compete with the land requirements for industrial raw materials, such as timber and wool. Adam Smith regarded this land competition as the single biggest stumbling block to industrialization, and he therefore advised developing

economies to focus their innovative energies on agriculture. The payoff for increased productivity per acre is theoretically a smaller agricultural land requirement, leaving more land for the development and extraction of industrial raw materials. This constraint was effectively removed by the replacement of timber by coal (a change Smith did not foresee), so the argument is of importance in understanding the barriers to growth that existed prior to the Industrial Revolution.

The effect of food prices on the demand for industrial goods is the third important factor in economic growth. When food prices decline, real wages rise, and more of one's income can be spent on non-food items. Many theorists identify the good harvests of 1715-1750 (resulting from unusually stable weather conditions) as the exogenous shock to the English economy that started the ball rolling, since demand for industrial goods responded quickly to the lower food prices.

Figure 3 summarizes the role of agriculture in economic growth discussed above. The idea of agriculture as a potential constraint on economic growth is reflected in the three negative feedback loops (1, 2, and 3). Loop 1 says that if food production cannot match one-for-one the growth in urban population, then there will be a natural limit to the urban population growth process, which in turn limits the labor supply. (This is a simple Malthusian food-production loop extended to show its possible implication for economic growth). Loop 2 says that increases in population lead, other

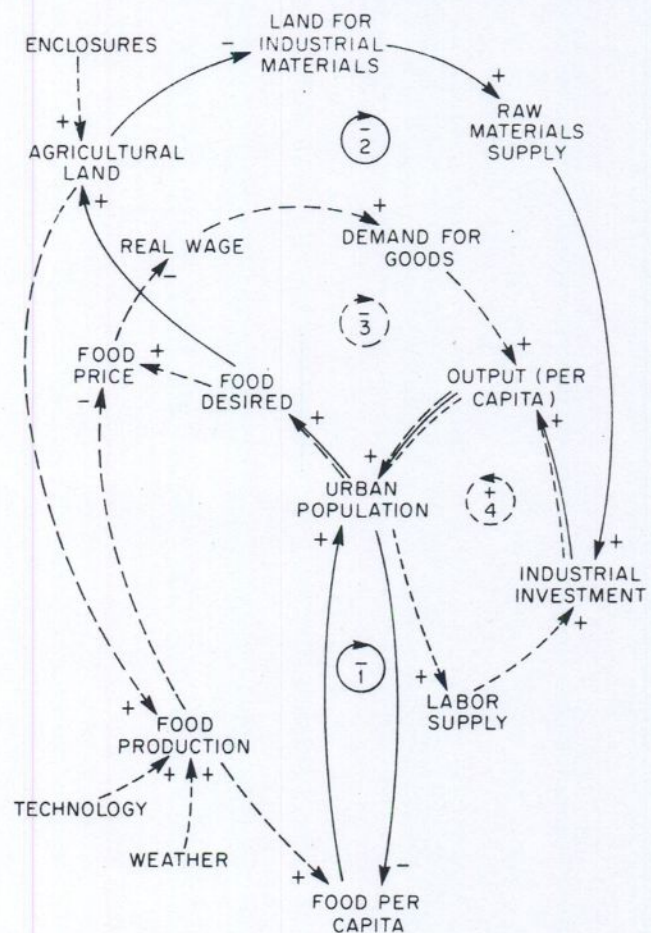
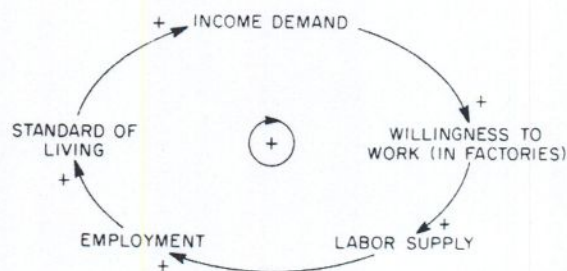


Figure 3: The Role of Agriculture in Industrialization



## THE ROLE OF LABOR SUPPLY AND THE STANDARD OF LIVING

Wage-consciousness is mainly a function of the standard of living. The standard of living is determined not only by the real wage, but also by an awareness of the variety of available products and a desire, born of social mobility, to “ape one’s betters”. Both product awareness and social mobility in 18th century England seem to have been legacies of previous eras (such as the commercial expansion of the 17th century), and are therefore outside the boundary of this study. They were probably necessary “preconditions” for the Industrial Revolution.<sup>9</sup> With this in mind, Figure 4 shows the simple positive feedback relationship between labor supply and the demand for goods. Assuming sticky wages and a concern with “apeing one’s betters”, this loop says that a rising standard of living causes people to work harder and more willingly and to push the standard of living up still further by the fruits of their labor.



## THE ROLE OF RAW MATERIALS

The use of minerals had numerous linkage effects with the rest of the British economy, the most important being the development of the steam engine and the canal and railway system. The steam engine was developed to pump water from mineral pits and later proved to be applicable throughout the industrial complex. The concentrated supplies and sheer weight of minerals made investment in the "social overhead" of transportation worthwhile, whereas the lightweight, widely dispersed nature of vegetable supplies (like wood and cotton) had never provided that incentive. Once the transportation system was built, however, everything could be shipped across it, including cotton, which formed a large portion of the nation's economy in the late 1700s. With the advent of efficient transportation, communication between regions was greatly improved and the market for industrial goods, both finished and unfinished, was expanded.

INDUSTRIAL INNOVATION AND INVESTMENT

PROFITS

RESOURCE USAGE: SHORT-TERM SUPPLY OF MINERALS

PRODUCTION

DEMAND

ACCESS TO GOODS

TRANSPORTATION (CANAL AND RR) SYSTEM

ACCESS TO MINERALS

MINERAL DEPOSITS

that any heavily used non-renewable resource faces. While the positive loops indicate increasing powers of production, they also indicate a growing dependence on the mineral resources, as more and more investment is devoted to a



mineral-based economy. Resource depletion eventually curtails growth of the transformed economy unless a new industrial revolution (with technologies based on different sources of power) is successfully staged. Resources play a crucial role in any culture and define its capabilities and its limits.

### THE ROLE OF TECHNOLOGICAL INNOVATION

The model of sustained growth used throughout this paper includes a positive link between profits and investments in new, more efficient technologies. But in addition to investment capital, innovation requires entrepreneurial attitudes, economic incentives to change technique, and previous inventions or knowledge which make possible the development of a new technology.

Entrepreneurial attitudes are often considered the most important element of economic growth, since the entrepreneur is the instigator of positive changes. The entrepreneur is willing to experiment with new technologies and introduce them well before the old technologies prove themselves insufficient to produce continued growth. The determinants of entrepreneurial ability are apparently related to child-rearing practices and thus lie in the philosophical, cultural, and religious roots of a people.<sup>11</sup> The English experience includes important religious and philosophical movements, such as Wesleyan Protestantism, laissez-faire, nonconformism, and the Enlightenment, but these are only clues to the great entrepreneurial blossoming of the 1700s. In any case, such entrepreneurial attitudes are generally accepted as a cornerstone of economic development, a "precondition", so to speak.

The economic incentives for innovation are rather well known. Innovations are often made in an attempt to overcome bottlenecks created by high factor prices.<sup>2</sup> When customer demand is high, producers are under pressure to increase capacity in the most economical way possible. In addition, patents and prizes for innovation offer tangible benefits for taking the risks involved in trying the new.

The success of the entrepreneur in the Industrial Revolution is often attributed to the advance of science. But Mathias has noted that the progress of scientific invention was not closely coupled to actual implementation: "Great areas of advance were relatively untouched by scientific knowledge, judging by result rather than by intention of endeavor, until the 19th century: agriculture, canals, machine-making, the mechanization of cloth making, ...., iron- and steel-making."<sup>12</sup> On the other hand, science helped change societal attitudes in the direction of experimentation, careful measurement, and standardization. In general, the procedures of science had more effect than actual scientific knowledge on the process of technical development and improvement. But scientific advances did sometimes pass into application, if only in bits and pieces. In addition, innovations were often studied by scientists who wished to discover the laws governing their operations. The results of such studies provided further knowledge upon which to base new technologies.

The successful diffusion of innovations and the instant fame of their creators caused the prestige of entrepreneurship to increase, thereby increasing the effort put into discovering new techniques to boost productivity. As entrepreneurs gained

experience with the new techniques, improvements came quickly. Even in steam power, the great gift of science, cumulative on-the-job improvement was quite significant.<sup>12</sup>

Figure 6 illustrates the process of innovation as it has been discussed above. Science, prestige, and experience provide increasing encouragement to an entrepreneur to plough back his profits into better machines and processes (and to borrow additional funds for the purpose, if need be). Rising input costs provide incentive to switch to a process that would reduce input requirements per unit of output (possibly involving a switchover to different types of input), thereby removing the bottleneck in production. Note that if the bottleneck is removed, the negative feedback relationship says that the incentive to innovate correspondingly decreases (other things being equal). Similarly, when capacity utilization is higher than is normal or desired, this indicates that demand is running ahead of the ability to produce, and investment in a more efficient technology might be necessary to eliminate the problem.

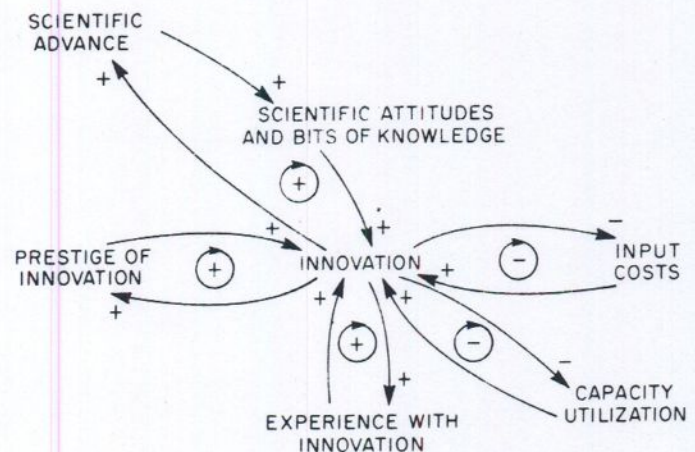


Figure 6: Innovation in the Industrial Revolution

### CONCLUSION

This paper has *not* presented a unified theory of the causes of the Industrial Revolution. Important elements, such as capital accumulation, finance, trade, governmental intervention and regulation, and specific "leading sectors", were discussed only briefly or not at all. Very little was mentioned of social value change, labor mobility, market extension, or linkages between specific sectors of the economy. What has been presented is rather an approach to the problem of understanding a historical event that seems to have a systematic or generic character about it.

Drawing causal-loop diagrams is only a first step in adequately modeling any complex process. However, such diagrams are quite useful for the purpose of thinking carefully about a dynamic process and explaining its essence to other people. The next step is to specify the system's stocks and flows of physical quantities (like machines or laborers) and information (like prices or experience) and their relationships. Theories of the Industrial Revolution have multiplied and fragmented to the point where a new attempt at unification, employing the central notion of feedback, might be very productive indeed.



## REFERENCES AND NOTES

1. In all diagrams, an arrow indicates that a change in one element causes a change in the other. If the arrow bears a + sign, the two elements change in the same direction; if a - sign, they change in opposite directions. The (+) or (-) sign in the middle of a closed loop indicates whether the entire loop is positive or negative. Generally speaking, positive loop elements tend to grow or decline exponentially, while negative loop elements tend to seek equilibrium. See: Goodman, M.R., 1974, *Study Notes in System Dynamics*, The MIT Press.
2. Musson, A.E., 1972, "Introduction" in *Science, Technology, and Economic Growth in the 18th Century* (A.E. Musson, editor), Methuen and Co., Ltd.
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6. Deane, P., 1965, *The First Industrial Revolution*, Cambridge University Press.
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