CHAPTER 3

The Economy as an Ecosystem

One day in the late 1970s, while I was a student at the University of California, Berkeley, I went to hear a talk from the great philosopher of science, Thomas Kuhn. While I was sitting outside the hall waiting for the lecture to begin, I looked up at one of the geekiest individuals I had ever seen, in a bowler hat and thick glasses, seemingly looking down at me. We looked at each other, both with a faint scent of disgust, I in my jeans, tee shirt, and long hair, he with short hair and a suit.

The next time I saw the individual, he was being introduced as Thomas Kuhn, and I was treated to a wonderful, personal lecture about how he had come to the field of the philosophy of science. Perhaps strangest of all, he described what he called an epiphany, or perhaps even a different state of consciousness. He related how he had been struggling with the thought of Aristotle, whom he had been studying in a course on the history of physics (he was at the time in the PhD program in physics). Nothing quite made sense, as he related, until finally in one magical instant he understood how Aristotle was thinking, in terms of a complete system, as a holism, or, as he was later to immortalize, as a paradigm. "My jaw dropped," I remember him saying, as I tried to imagine this so-very-gray-flannel person dropping his jaw, eyes wide open.

This insight drove him to drop his physics work and obtain a doctorate in philosophy instead. What he had experienced was a *paradigm shift*, moving from one worldview to another, in a flash of understanding. The important concept he discovered was that sometimes comprehension involves experiencing an entire set of ideas as one, interconnected web of ideas—not just as a series of analytical lessons.

Kuhn has been criticized for not giving one, concise definition of a paradigm,[1] but I always liked the way he explained it in that lecture. A *paradigm* is a linked set of ideas that serve to reinforce each other. Pull one idea out—perhaps it has been thoroughly discredited, an "anomaly" in Kuhn's wording—and the structure of the paradigm still holds up, because the other links in the web hold it together.

Pull enough links out, and the paradigm is in danger of collapse. The paradigm collapses only, as Kuhn explains, if there is a paradigm available that can better explain the paradigm's domain of reality. This is Kuhn's second great insight, after the idea of the paradigm itself: a theory, or paradigm, is not destroyed by criticism, although criticism lays the groundwork by weakening the old paradigm. A paradigm is *only* superseded by the introduction of a new, better paradigm. Thus is made a scientific revolution.[2]

The subject of Kuhn's thesis was the Copernican revolution, in which the process he describes is perhaps most clearly exposed. Copernicus advocated the idea that the Sun is at the center of the solar system, not the Earth, as was claimed by the then prevailing astronomical paradigm, the Ptolemaic system. To keep the Ptolemaic system at least somewhat synchronous with reality, Ptolemaic astronomers had invented many complex "circles within circles" in the heavens that sort of took care of various anomalies that had been discovered with the use of the telescope.

Negative observations did not overturn Ptolemaic astronomy; data plus a new theory did the trick (and quite a bit of literally putting one's body on the line). Similarly, conservatism, neoclassical economics, Reaganism, or any other economic, social, or political philosophy, will not be overthrown by pointing out the large and gaping holes in the theory, they will only be replaced if a better theory, or paradigm, is available.

WHAT IS A SYSTEM?

Is it possible to define a paradigm rigorously? A starting point comes from Kuhn: a paradigm is a set of interconnected ideas that reinforce each other, and that explain a particular domain of reality.

Another way of looking at a paradigm is to look at it as a system. But then, what is a system?

The simplest way to think about a system is as a set of elements and a structure that defines the way in which those elements relate to each other. The difficult part to master is the structure—that is what made Kuhn's jaw drop—the experience of taking what looked like a mush of disparate ideas from Aristotle and putting them together in a meaningful way.

The gestalt psychologists in the 1920s and 1930s advanced the understanding of the idea of a structure when they emphasized the totality (gestalt, approximately, in German) of a sensation. For instance, a face is not recognized by analyzing the nose, eyes, and mouth, although that is certainly part of the process, but by recognizing the position of the eyes, nose, mouth, and other features, together. A Rorschach test is useful because the human mind, constantly trying to perceive structure, displays some of its hidden tendencies in trying to make structure out of a splotch of ink when there really isn't any there.

Kenneth Waltz, the most important theoretician of international relations in the post-World War II period, based his theory of international relations[3] on a carefully constructed theory of systems. He drew on concepts from psychology, anthropology, biology, economics, political science, and his own synthesis of concepts—his own structure of the structure of systems. He emphasizes the structure of the international system, and thus his theory is called "structural realism," since it is also based on a view of international relations called realism, which emphasizes the allegedly "realistic" view that war is always a possibility in international affairs.

Waltz's theory about systems is actually designed as a general theory, although he only uses the theory for political science. Most systems have some kind of ordering—for instance, in music, there is an ordering in time, as when the notes are played, as well as an ordering of the musical scale, as well as an ordering based on which instruments play when (one could also include more subtle orderings like phrasing). In international politics, we have none of this, at least, not in Waltz's theory: since there is no overarching authority, international systems are anarchic, they have no ordering.

Actually, in older forms of international political theory, associated with a more geopolitical way of thinking, the actual geographic ordering of nations was deemed to be an important part of the international system. Of course, the United States worries more about what goes on in its own "backyard," as in Mexico or Cuba, then, say, in China's "backyard." Waltz is trying to model reality in the simplest possible way to be able to discern important processes that are obscured when more of reality is included in a theory.

In other words, a theory needs to *not* model some parts of reality to be useful. No theory reflects absolute truth, theories should be judged according to how useful they are in *explaining* a particular domain of reality. Simplification is essential; all theories leave something out, because if you don't leave something out, you wind up with an exhaustive description of reality, and you can't make out the patterns that are hopefully there and that allow you to make your way through the fog of complex systems.

Waltz assumes that the international system has no ordering, is anarchic, and that the relative position of various countries geographically doesn't make enough of a difference to be worth including in his theory. A similar simplification occurs in his second criterion for a system structure, the functional differentiation among the elements of a system. As he points out, in a domestic political system, we have an executive, legislative, and judicial branch, which fill those functions. In a human body, we have the various functions that the heart, stomach, and other organs and subsystems fulfill. But in an international system, because each nation has to basically fulfill all of its own functions and can't depend on its neighbor because the international system is anarchic, there is no functional differentiation among states.

Waltz's conception of an international system shares some similarities with the neoclassical economic paradigm. The market is conceived as basically anarchic, with no functional differentiation among its parts. By contrast, I will argue that the economy should be explicitly modeled as a system with functionally differentiated parts, which absolutely need outside, that is, governmental help to ensure that all the parts operate adequately in relation to the other parts. If the international system is a set of functionally similar entities set within an anarchic system, what patterns could we possibly see? Waltz adds a third criterion of a structure, the relative distribution of capabilities, which differentiates the various units, that is, the nations. According to Waltz, there is really a dividing line between "Great Powers," as they have often been called, and lesser or smaller nations that can't do much to influence international affairs.

TO FEEDBACK OR NOT TO FEEDBACK

Using Waltz's simplified model of the international system, we can see that there are a couple of main processes at work; there is a positive feedback loop, a process by which those who have power obtain more power; and there is a negative feedback loop, that is, those who have power are cut down to size, or prevented from getting more.[4] The first process, which is the accumulation of power, engenders the second, which Waltz (and many others) have called the balance of power. Without the balance of power to prevent the accumulation of power, there would be one globe-spanning empire; for instance, the United States and United Kingdom teamed up with the Union of Soviet Socialist Republics (USSR) to defeat Hitler, even though the United Kingdom and United States had previously been enemies of the USSR and would return to being enemies after beating Germany. They practiced a balance of power strategy to prevent Germany from attaining global supremacy.

Economic systems also exhibit a process of the accumulation of power. A once competitive market, as in cars, turns into an oligopoly, as in the case of the Big 3 automakers; at one point it looked like General Motors would become a monopoly and take over the entire industry.

Waltz stresses the negative feedback process in international relations, the balance of power, as a way to stabilize the system. In fact, he simplifies his discussion of a system so far that he winds up arguing that a bipolar system, that is, one with two Great Powers, is more stable than a system with more than two. People found it difficult to accept this hypothesis when the world became unipolar; he argued that he meant that a bipolar system is more peaceful, not longer lasting.

Most social sciences, and even sciences, tend to focus more on negative feedback processes than positive feedback ones; neoclassical economics steers clear of positive feedback as if it were toxic—which it is, for neoclassical economics. There has been some scientific work that focuses on the subject of positive feedback, and the cutting edge of mechanical physics has been led by the work of such thinkers as Ilya Prigogine,[5] who developed the field of nonlinear systems, or in more popular terminology, chaos theory.

Climate science has also had to use the idea of positive feedback, as in the concept of albedo, or the reflectivity of certain parts of the

Earth's surface. In particular, when the Arctic, or other areas covered by glaciers or ice, starts to melt, the melted areas become dark and soak up more heat, which causes even warmer conditions, which causes more melting, and more dark spots, and more warming, until the entire area has melted. This reveals another aspect of positive feedback loops—they always end up in some sort of "stable" state. The system appears to be "locked-in." For instance, if the Arctic melted, it would be extremely difficult to make it ice up again.

One field that has always been comfortable with positive feedback loops (at least relatively) is ecological and evolutionary biology. Clearly, biologists have to understand reproduction and the changes that take place as a result of the generation of "variation," Darwin's term for the raw material of evolution.

However, the kind of positive feedback loop that explains biological growth of populations is different from the positive feedback loop that leads to the accumulation of power. I will differentiate between two kinds of systems: those that generate, and those that control or distribute. Ecologists discuss ecosystems, which are mainly concerned with generation of new life, and which include processes of positive feedback that lead to growth. The dynamics that Waltz discusses vis-à-vis the international system, and the ones that economists discuss vis-à-vis a particular industry, are systems of control. Control can be accumulated, at the extreme by one unit in a system; within a country, this is called dictatorship. When control is dispersed equally, at the other extreme, we call this pure democracy.

The part of the economy that economists aren't very good at modeling, the production system, grows as a result of a similar positive feedback loop as occurs in ecosystems, that is, by generating output. An economy's growth is constrained by the need for all parts of the system to grow in some roughly equal relation to each other, and in particular, by the need to use ecosystems sustainably.

Thus there are four combinations of feedback processes and kinds of systems: a system of control has a positive feedback process that leads to the accumulation of power, and a negative feedback process that leads to a balance of power; a system of generation has a positive feedback process that leads to growth, and a negative feedback process that leads to the need for balanced growth and a constraint of limits.

A HIERARCHY OF HIERARCHIES

One other aspect of systems implied by Waltz is the possibility that the individual elements that make up systems are themselves systems. Waltz discusses the domestic political system, which is a nation, and makes up one unit of the larger international political system. However, one of his arguments is that by making the explanation of the system at the international level so spare, it is possible to ignore the inner workings of the domestic political system. In other words, a hierarchy of systems allows for much of the complexity of systems to be retained, while enabling a person to concentrate on one particular level at a time. If you want to explore other parts of the system, you either go down one level—for example, in biology, from the level of the body to the level of the organs—or up one level, back to the level of the individual. Thus a biology textbook will move from the cellular level, to the level of internal organs, to the level of the individual organism, to the ecosystem (which may also involve several levels).[6]

The definition of a system is itself a system of sorts, made up of various elements arranged in a specific way. A model of a system is composed of elements, which may themselves be systems, and of a structure. The structure is composed of an ordering, possibly a functional differentiation, a distribution of capabilities, and depending on these parts of the structure, particular negative and positive feedback processes. The system applies to a particular domain of reality, for example physics or economics.

The model of a system is itself not testable in a scientific or logical sense, but we can *use* the model of the system to generate *hypotheses*, and then we can test the hypotheses to determine if the model of the system is useful for explaining a particular domain of reality. The model of the system for a particular domain of reality, plus the hypotheses that the model generates, is what I will define as a paradigm.

THE NEOCLASSICAL PARADIGM

Neoclassical economics was built as a variation of the paradigm of statistical mechanics in physics, although the two are not exactly the same. Many of the early theorists were engineers or physicists; Leon

Walras, the founder of the theory of general equilibrium analysis, kept a copy of a statistical mechanical textbook by his bed, and was himself an engineer; Irving Fisher, one of the great economists of the pre-World War II period, was trained in physics and constructed a hydraulic model of the economy at Yale that still works. Many economists today have extensive training in physics, and use physics as a source of new ideas.[7]

Neoclassical economics started out as a paradigm by trying to explain the short-term behavior of a specific industry that is competitive (that is, no firm can set the price of its goods). Each firm is considered to be basically identical, as are the industries that the firms inhabit. As for how an industry relates to another industry, it is assumed that the entire economy is bound together as a set of points of investment opportunity, and that investment will flow where the return to investment is highest. This flow will reflect the best use of investment capital; in other words, returns on investments will reflect their true value to the economy. Other than this mechanism, there is no concept that there might be a functional differentiation or relationship among the various parts of the economy.

Thus the neoclassical system is composed of identical elements—firms—that are not themselves a system. There are theories of the firm, but since the firm is basically an organized dictatorship in most manifestations, the theory of the firm has not engendered too much attention.

There is very little structure in the neoclassical model, because there is no ordering among the firms (the industry is anarchic) and no functional differentiation; ideally, the relative distribution of capabilities, or power, among the firms is fairly equal, although oligopoly and monopoly can form where the distribution becomes uneven. The subfield of industrial structure acknowledges the idea of "increasing returns," that is, that as a firm becomes bigger, it may become more profitable, mainly for technological reasons; however, this phenomenon also does not play a central role in the neoclassical paradigm.

Negative feedback loops predominate in the neoclassical model, bringing the system back into stability, and positive feedback loops do not exist, with the partial exception of oligopoly. The neoclassical system really covers the domain of economic distribution, not production. Environmentalists sometimes accuse economists of being focused on production, but actually, production is not very interesting in the neoclassical view and is not well studied.

If the economy self-stabilizes, partly because capital and income flows to its optimal destination, then a hypothesis generated by the neoclassical paradigm is that the government has very little, if any, role, in overseeing the level of investment in any particular industry. I will argue that on the contrary, the government must shape the general structure of the economy, because the market can't do it. Neoclassical economics is really an economics of a very narrow domain of reality—the short-term behavior of a competitive industry, not the long-term processes of a production system.

What we desperately need now is a national and global coordination of plans to overcome the massive economic and ecological crises that humanity faces together. Such an effort would be aided by the existence of an economic paradigm that tries to explain long-term processes of production.

THE ECOSYSTEM PARADIGM

Instead of using statistical mechanics as a foundation for an economic paradigm, we should use ecological studies for our reference point (including evolutionary biology). The main unit of analysis in ecology is the niche, which means the part of an ecosystem that a particular organism, or set of organisms, lives in; that is, the niche specifies the resources and organisms that various organisms use and create. Each ecosystem might have a different set of niches; even if two ecosystems have similar niches, the niches will often be occupied by different organisms because evolution is unpredictable and yields different species, even in similar circumstances. For instance, in a forest, each plant has a different niche depending on how tall it is, and how much sunlight it can capture; different organisms might have different niches depending on what kinds of leaves they can eat, or whether they can occupy certain parts of trees to capture insects and other plant eaters; there may be some large, ground-based plant eaters, and then some large, ground-based carnivores that eat the ground-based plant eaters. There will also be whole sets of fungi, microbes, and small animals that decompose dead plants and animals. Each ecosystem might have a completely different set of species occupying each of these niches.

All of these niches can also be categorized as being part of a larger, or trophic, level; that is, most ecosystems have plants that are the main producers (production trophic level), herbivores that eat the producers (primary consumers trophic level), and carnivores that eat the herbivores that eat the plants (secondary consumers trophic level). Another way to think of an ecosystem is as a food web, made of several food chains, which traces who eats whom and who gets their nourishment from which niche.

Each of these elements, niches, is made up of a population of an organism or organisms, which grow or decline according to particular positive and negative feedback loops, depending on their environments; that is, they reproduce to grow the population, and may decline because of lack of resources or destruction, as in being eaten. Ecologists have used various dimensions to order these niches, and using trophic levels is one way of doing so.

Most importantly for our purposes, each niche in an ecosystem serves a function; the trees produce leaves, the caterpillars eat the leaves, the birds eat the caterpillars thus preserving the leaves, the fungi eat the dead organisms, thereby creating soil, which the plants mine for nutrition. Although some niches wax and wane, each one is important to the functioning of the ecosystem as a whole. Without a niche, or a specific species that fills a niche or part of a niche, the ecosystem will be much more vulnerable to disruption, at best, and, at worst might be destroyed. For instance, a keystone species[8] is one whose removal will mean that the entire ecosystem may be transformed; if all the trees in a rain forest are cut down, the whole ecosystem collapses and turns into something else entirely.

In just the same way, an economy is made up of a set of functional niches, and the disappearance of a niche—or the equivalent of an entire trophic level—is disastrous. In particular, the manufacturing and machinery sectors are like the plants in an ecosystem—everything else depends on them. An economy that loses, or never builds, its manufacturing sector, is like an ecosystem with no plants—a desert.

STAGES OF PRODUCTION

The definition of an ecosystem includes nonliving physical aspects, not just the organisms. The climate, rivers, mountains, oceans—all are part of the ecosystem. So the biotic community of organisms, as a system, interacts with the physical environment as a system to create a

higher level, the ecosystem. We now know that the biological part of this larger system actually changed the physical part, as when microorganisms created the oxygen that we breathe today, which in turn has a profound effect on geological processes.

In much the same way, the economic system is part of a larger system, a political-economic system, and that larger social system is part of the larger ecosystem that encompasses it. By building up a hierarchy of systems, we can describe and understand a very complex system (Earth).

I've argued that neoclassical economics doesn't actually explain the functioning of the economy as a whole; it concentrates on the short-term behavior of a competitive industry and then generalizes to the whole economy. It's sort of a "what's good for one industry is good for the economy" kind of view, or alternatively, "if you've seen one industry, you've seen them all."

Many economic textbooks define the economy in a useful way—the "production and distribution of goods and services." Let's bisect the "economic system" into a "distribution system" (of goods and services) and "production system" (of goods and services). Each in turn is composed of subsystems. On the distribution side, as detailed in Chapter 2 on myths of manufacturing, we have retailing and wholesaling, including the transportation services associated with them. The other major part of the distribution system is the financial system—recycling investment capital, either into retail and wholesale, or into production—or not so productively, back into the financial system itself.

On the production side, things are more complex. Think of the production system as three concentric circles, that is, one circle in the middle, surrounded by another circle, and those circles surrounded by a bigger one. On the outside circle, called the *final consumption system*, all the goods and services that are used by people, including buildings and infrastructure, are produced. Most of the production of goods takes place in factories, using machinery that I'll call "production machinery." Much construction is done using construction machinery, another kind of production machinery, outside of factories. Production that takes place outside of the factory includes agriculture, which uses agricultural machinery; mining, which uses mining equipment; and utilities, which use electrical, natural gas, and water-management equipment.

Most of what we do involves the use of machinery of one sort or the other (I'll use the word "machine" interchangeably with the word "equipment"). Even service industry offices are filled with office equipment such as computers, copying machines, and telephones, not to mention all the cars, trucks, elevators, and lights. Restaurants use many kinds of machinery, such as cooking equipment, and they use food that has gone through food processing machinery and been transported by trucks, gathered by agricultural machinery, and fumigated by pesticides made with chemical processing equipment. Even in the home, all of the remote devices, TVs, and kitchen equipment are forms of machinery. The machinery that makes the final consumer goods and services are themselves all made with a whole different set of machinery-making machinery.

The machinery that makes machinery I will refer to as *reproduction machinery*. Reproduction machinery not only makes all of the production machinery, but makes all of the reproduction machinery. This is a vast oversimplification—you could conceivably keep going back further and further to determine which machinery made the previous set of machinery, and so on. But as I stated earlier, it is a characteristic of theory that reality is simplified, so that we can discern important patterns of reality. Dividing production into three levels seems like a good way to explain the process of modern production, while hiding much of the detail.

So we have an ordering of the elements of the production system, in a series of three stages—stages of production. At the first level, reproduction machinery makes more reproduction machinery. The reproduction machinery that is not being used to make more reproduction machinery is then used as the means of production in the next level, the production machinery stage. Here, the construction, agricultural, mining, textile, telecommunications, computer data servers, and other equipment is made that will be used in the third stage, the final production stage, where all the final goods and services and infrastructure are made. This output of this final stage constitutes the wealth of a society, and the production machinery creates that wealth. Reproduction machinery, the source of economic growth, is not itself wealth, because people cannot use it in their daily lives, but it creates the means of producing wealth.

CATEGORIES OF PRODUCTION

These levels represent different functions within the economy—producing machinery, producing nonmachinery goods—but we can

also identify other kinds of functional subsystems, or niches, in this economic ecosystem that I am describing. Again, the problem is to reduce a complex system, the economy, into enough categories to describe the systems, but not too many to overload understanding. Since we have the concept of hierarchy available to us, we can put some categories within others; we can create a taxonomy.

We have stages of production, from reproduction machinery to production machinery to final production; we can also devise a set of *categories* of production, and divide each of the stages by those categories, to form a matrix of niches, all of which are necessary for a production system to function properly. How do we choose a few categories out of the massive complexity of a modern economy?

Depending on the epoch, different kinds of technologies are declared by various thinkers to be the penultimate, revolutionary, more-important-than-anything-ever-was-or-could-possibly-be technology. Currently, because of problems with oil prices and the emissions of carbon dioxide from fossil fuels, energy is often proclaimed to be the basis for all of human society. Just 10 years ago, we were being informed that information was the key to all—the Internet was changing everything because information was everything. And indeed, information has also always been important, which is why writing was such an important discovery, for instance.

About a century ago, history as a process of ever-better materials was all the rage, as was a fascination with all things mass production. We had gone through a Stone Age, Bronze Age, Iron Age, and now we were witnessing the power of the Steel Age (Superman was the Man of Steel, and Stalin means steel). Mass production was possible because of improvements in machine tools, which allowed for parts to be made of such exacting similarity, that an uneducated assembly line worker could pick up a part and repetitively insert it into a predetermined place, monotonously, for thousands of hours per year. We are in the Age of the Automobile, or Plane, just as 100 years ago we were in the Age of the Railroad.

Looking over these proclamations of the-one-most-important technology, it appears that it is possible to put together a "metaphysics" of production, to try to account for four or five categories of production that have, at one time or another, been claimed to have precedence in technological change, but in reality have all been important all of the time.

First, within production we need the ability to make a particular material; steel has been the premier material for the last century or so, but wood has always been and is now very important, as are certain minerals (think of glass and cement), and other metals, and chemicals. The key to these materials and their use is not the materials themselves, but the capacity to make or transform them; for instance, the history of steel is the history of steel-making machinery, which is at the core of our ability to make materials. There are other important processes such as turning bauxite into aluminum or sand into pure silicon—all part of the category of *material-making* production. Food can be considered part of the material-making category of a production system.

Second, possessing an unshaped blob of material, one can then fashion a shape or an entire piece of material that can be used with a machine or to make a machine. Machine tools and other structure-forming equipment are used to fashion parts out of materials. The cutting tools that were human beings' earliest inventions were used to fashion other implements, including other tools, as well as to kill animals for food. We also use other kinds of machinery, such as plastic-molding machinery to make plastic parts, or sewing machines to put clothes together, or construction machinery to put buildings and infrastructure together. These all fall into the category of *structure-forming* production.

Aristotle asked what is the cause of the existence of a statue; a statue has two things, form and substance.[9] The substance is the marble of the statue, which had to be created in some way, and the sculptor creates the form with a chisel. In the same way, any material object has to be produced with structure-forming machinery (or tools), and has to be made from a substance, generally created with material-making equipment.

Third, we need some form of energy conversion to have the energy needed for production. During Aristotle's day, much of the industrial energy conversion came from people, that is, from slaves. Horses were also used, and a bit of wind and water. With the advent of steam engines humans captured a dependable source of machine-generated energy. Then came internal combustion engines, then the electricity-generating turbines, usually using a form of fossil fuel. Now we need to shift to fuel-less forms of energy, mostly electricity generation, for most of our *energy-converting* production.

Fourth, we need some way to transport materials from one part of the production system to another. The assembly line is an example of an important innovation in *goods-transporting* production, and there are other kinds of "materials handling" equipment that are used in factories. Trucks carrying goods between factories are another example. Of course, in the final goods and services stage of production, cars are the dominant transportation machinery right now.

Fifth, goods and services are created using some form of *information processing* production, even if it is as basic as one engineer explaining to another engineer how a piece of machinery works, face-to-face-to-machine. Writing and then printing were revolutionary innovations in information processing, while obviously computers of various forms fill that role now.

In other words, to make something we need to have a material, we need to shape the material, we need an energy source to make the object and perhaps to allow the object to use energy after it has been produced, we need to transport pieces around the production area or region, and we need information-processing equipment (or processes) to make the object and perhaps to enable the object to process information itself.

These categories of production—form-making, material-making, energy conversion, goods moving and information processing—are filled in the reproduction machinery stage by the most important technologies of their age. Currently, the machine tool fills that role for form-making, steel-making machinery for material-making, electricity-generating turbines for energy conversion, materials handling equipment for goods moving, and semiconductor-making equipment for information processing. These technologies, collectively, reproduce themselves.

THE PRODUCTION SYSTEM

When we transpose these five categories of production on top of the three stages of production, we have 15 production niches, in the same way that an ecosystem has a multiplicity of niches of production. So each stage of production has five categories of production. Conceptually, stages of production are more important than categories of production, because each stage of production uses all five categories of production, while a category of production needs more than just the other stages of production in its category. We can also model another stage of production for physical infrastructure, each infrastructure niche corresponding to a category of production. Ever since the early 1800s water infrastructure has probably been the most important system, because it enables large cities to function by bringing fresh water in and taking waste water out. Water is a kind of material, and so occupies part of the material infrastructure niche. Garbage landfills form part of this niche; hopefully, an omnipresent recycling system will eventually exist as well.

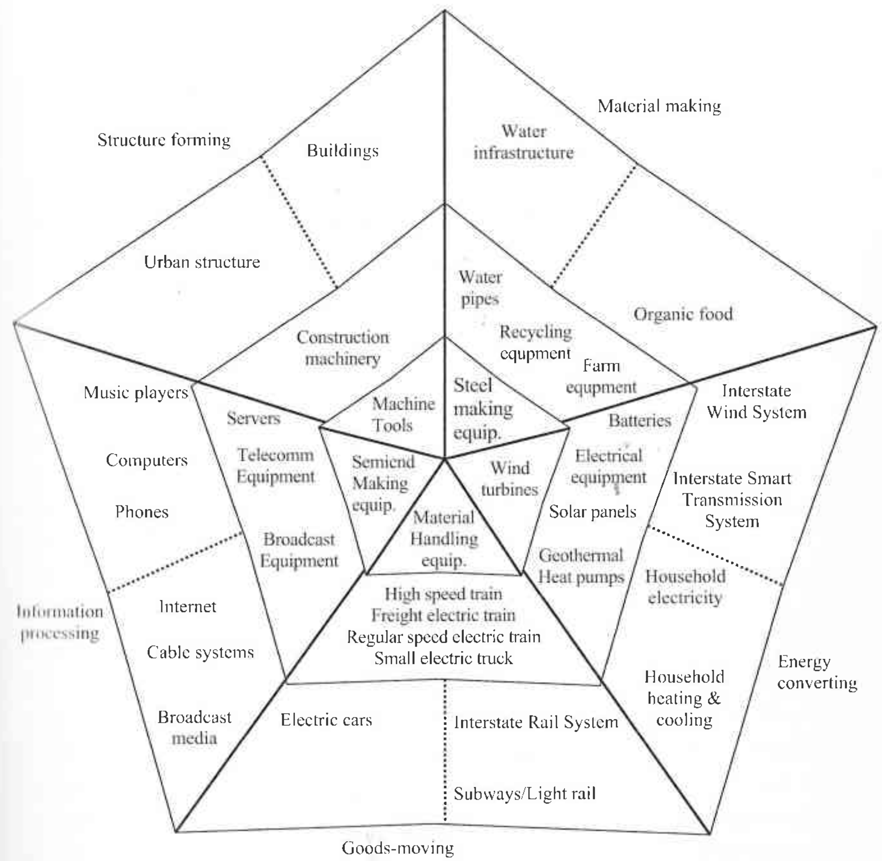
Buildings are themselves structures, and are created by structure-forming equipment, construction machinery. The way buildings are situated in relation to one another is also a kind of structure; the structure-forming part of the infrastructure can be called the urban structure. Currently, the United States is mostly composed of sprawl urban structure, although there are islands of walkable environments like Manhattan.

The energy infrastructure is a critical part of all energy niches. We need a robust transmission system and electrical grid to carry electricity from where it is created, mostly with electricity-generated turbines, but more and more with wind turbines.

The information processing part of the infrastructure is in the best shape of any other, having been overinvested in during the dot com boom, providing cable, phone, and data at rates which enable the Internet to be the force that it is. If we add these infrastructure niches to the previous 15 niches, the production system is composed of a total of 20 niches, which we can see in Figure 3.1.

I've now specified an ecosystem for the economy. This system is composed of units that each serves a specific function, each one being necessary for the efficient operation of the system as a whole. The economic ecosystem is greater than the sum of its parts. It has a structure emanating from two kinds of orderings of niches. First, there are stages of production, moving from the reproduction machinery stage, which makes and uses reproduction machinery to make reproduction machinery for the second stage, the production machinery stage. At the production machinery stage, reproduction machinery makes production machinery for the third stage. This stage uses production machinery to make the wealth of the society: consumer final goods and services, and the physical infrastructure:, that is, the urban, resources, energy, transportation, and information

Figure 3.1 The structure of a sustainable production system



infrastructure systems that envelope and enable the activity of the society. The second ordering of niches divides each stage into material-making, structure-forming, energy-converting, goods-transporting, and information-processing categories of production. Figure 3.1 shows many of the various technologies and infrastructure systems that might exist in a sustainable production system.

Now we need to understand how this system grows—and decays—both from its own internal processes and also when it damages the natural ecosystems that surround and nourish it.