Unholy Trinity: Labor, Capital, and Land in the New Economy

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Contents

Chapter 1

Complexity, Self-organization, and Political Economy

1.1 Introduction

My theme in these lectures is the capacity of the methods of the Classical political economists, Adam Smith, Thomas Malthus, David Ricardo, and their critic, Karl Marx, to reveal the self-organizing character of the capitalist economy regarded as a complex, adaptive, non-equilibrium system.

From one point of view this is an exercise in anachronism, since the language of complex systems theory and its application to economic problems is only about forty years old, and it is implausible to claim that Smith or Ricardo or Marx thought about the problems of the economy using the conceptual tools of complexity science. On the other hand, I will argue that the language and vision of the Classical political economists incorporates many insights of contemporary complex systems theory. There are also indirect but important intellectual pathways that connect the Classical political economists of the eighteenth and nineteenth centuries to the twentieth century emergence of complexity science. I also will argue that complexity theory sheds some light on the extraordinary effectiveness of the Classical political economists' methods and the depth of their analytical results. I believe that contemporary economists still have much to learn from these methods and results about the capitalist economy and its evolution.

1.2 What is a complex system?

Complexity theory represents an ambitious effort to analyze the functioning highly organized but decentralized systems composed of very large numbers of individual components. The basic processes of life, involving the chemical interaction of thousands of proteins, the living cell, which localizes and organizes these processes, the human brain in which thousands of cells interact to maintain consciousness, ecological systems arising from the interaction of thousands of species, the process of biological evolution from which new species emerges, and the capitalist economy, which arises from the interaction of millions of human individuals, each of them already a complex entity, are leading examples.

Complexity science starts from the bold and controversial conjecture that these diverse systems have important features in common that transcend their apparent differences in scale, material components, and organizing laws of motion. What these systems share are a potential to configure their component parts in an astronomically large number of ways (they are *complex*), constant change in response to environmental stimulus and their own development (they are *adaptive*), a strong tendency to achieve recognizable, stable patterns in their configuration (they are *self-organizing*), and an avoidance of stable, self-reproducing states (they are *non-equilibrium systems*). The task complexity science sets itself is the exploration of the general properties of complex, adaptive, self-organizing, non-equilibrium systems.

The methods of complex systems theory are highly empirical and inductive. The complex systems scientist tends to study the properties of particular simplified and abstract models of complex systems. These models often involve the study of the interaction of large numbers of highly stylized and simplified components in computer simulations, with the aim of identifying generalizable properties of adaptability and self-organization common to a wide range of complex systems. A characteristic of these stylized complex systems is that their components and rules of interaction, though they are often very much simpler than real neurons or proteins or capitalist firms, are *non-linear*, that is, that they exhibit qualitative differences in their behavior in response to stimulus of different intensities and scales. The computer plays a critical role in this research, because it becomes impossible to say much directly about the dynamics of non-linear systems with a large number of degrees of freedom using classical mathematical analytical methods.

Their are many potential pitfalls in this research project. Most of these arise from the difficulty of verifying the general character of the specific phenomena observed in particular models. A pattern of self-organization, for example, may turn out to reflect a particular symmetry of interaction implicit in the model system, and thus not to appear in similar systems that lack this symmetry. Skeptics question the premise that complex systems share any general determinable properties. The record of complexity research has not put these doubts to rest. Its triumphs remain largely in the realm of brilliant insights connected to particular models, and a unified synthesis remains an elusive goal. Nonetheless, the methods of complex systems science have had a growing impact on research in a wide range of fields, not least in economics. The vision of explaining complex and adaptive order as emerging from the interaction of large numbers of relatively simple components according to relatively simple laws presents a compelling challenge to many researchers.

1.3 The Classical political economic vision

The great theme of the Classical political economists was that individual economic actions have unintended social consequences. Economic life in the large is thus organized and coherent in a way that no single economic actor envisions or controls.

1.3.1 Smith

The most powerful example of this effect is the Classical conception of competition, enunciated, if not originated, in Adam Smith's *Wealth of Nations*. Smith observes that each owner of "stock" (capital) will seek to maximize its potential rate of growth, that is, its profit rate, by investing in the line of production he judges to be most promising. Capital, according to Smith's vision, will be disinvested from lines of production with relatively low profit rates, and moved to lines of production with relatively high profit rates. The intention of wealth-owners in reallocating capital in this way is to maximize their own rate of profit, but the effect of their actions is to *equalize* profit rates tendentially between different lines of production. This equalization of profit rates, which is of no particular interest to individual capitalists, is also the condition for maximizing the profit rate of the aggregate national capital, that is, the wealth of the nation.

Smith and the Classical political economists who followed him did not believe that this competitive process would lead to an actual equalization of realized or prospective profit rates at any moment in time. The movement of capital from line of production to another would upset the conditions of other lines of production, which, together with disturbances from outside the national economy, would always prevent the realization of a state of equalization of profit rates. They expected to see a ceaseless fluctuation of prices and profit rates as the outcome of the competitive process, rather than the achievement of a state of "equilibrium" in which prices settled down to levels ("natural prices") at which profit rates would be equalized. Nonetheless, the *concept* of this equilibrium state (often referred to as a "long-period" equilibrium) plays a natural and important part in the analysis of the real economy. The competitive dynamic, even if it is not stable in the mathematical sense of pushing the system to an equilibrium of equal profit rates, will prevent prices and profit rates from wandering indefinitely far from their equilibrium values. This idea is expressed by arguing that observed market prices tend to *gravitate* around the natural prices at which profit rates would be equalized. The *abstract* concept of long-period equilibrium natural prices plays a crucial analytical role in understanding the *concrete* fluctuations of observable market prices.

This sophisticated method of reasoning contrasts sharply, and, in my opinion, favorably, with the tendency of neoclassical economists to identify observed values of prices with their equilibrium levels in abstract models. The neoclassical vision requires an implausible degree of foresight and coordination of individual plans in its assertion of the attainment of equilibrium as a picture of the operation of the real economy. Furthermore, stable equilibrium systems cannot exhibit complex dynamic behavior, so the neoclassical vision remains blind to the evolutionary, path-dependent, and adaptive character of economic institutions. The Classical vision, on the other hand, is completely consistent with the complex systems view of the world. It does not insist that each and every component of the economy achieve its own equilibrium as part of a larger master equilibrium of the system as a whole. In fact, it is precisely from the *disequilibrium* behavior of individual households and firms that the Classical vision of competition sees the orderliness of gravitation of market prices around natural prices as arising. In the language of complex systems theory, Classical gravitation is a self-organized outcome of the competitive economic system. From the Classical point of view, competition need not be "perfect" in order to bring about the tendency to self-organization. The self-organization of complex systems is *robust* in the sense that it does not depend on any particular detail of the evolution of the system, and will reassert itself even when some of the mechanisms supporting it are frustrated.

Smith characterizes the capitalist restlessly seeking the highest profit rate on his capital as a "public benefactor", and the coordinated (or, more precisely, self-organized) outcome for the economy as the result of the operation of an "Invisible Hand". But the force of Smith's argument here has often been misunderstood. There is no reason in general why one individual in capitalist society benefits from another individual's increase in wealth. The benefits from individual accumulation lie in the growth of the *national* wealth, which Smith saw as the foundation of its military and diplomatic power. Presumably this effect arises in part because the wealth of individual capitalists is the foundation of the state's taxing power.

But Smith has another, more important, reason for regarding the accumulating capitalist as a public benefactor. Smith argued that the driving force of economic development was the *division of labor* that arises as a result of the widening *extent of the market*. It is precisely the accumulation of capital, in Smith's view, that drives the extent of the market, both by increasing the wealth and income of the population, and increasing population itself. The individual accumulating capitalist enriches himself, which is his intention, but in increasing the market for other capitalists' product, he also indirectly and unintentionally fosters an increase in the division of labor. The ensuing increase in the productivity of labor does benefit the other capitalists and, potentially, workers. The accumulation of capital is thus part of a "virtuous cycle" in Smith's vision. Accumulation increases population, wealth, and income, thus increasing the size of the market, which in its turn fosters a wider and deeper division of labor, increasing labor productivity, profit rates, and accumulation. This self-reinforcing cycle is the basic metabolism of capitalist economic development, responsible both for its creative triumphs and its destructive paroxysms. Smith's endorsement of laissez-faire policies is at its root an affirmation that this process will in the end be good for humanity.

But again we see that the Classical vision is far from the neoclassical version of Classical language. Neoclassical analysis identifies the Invisible Hand with the tendency for competition to achieve an equilibrium with an efficient use of existing resources, and laissez-faire policies with the end of efficiency, not of encouraging capital accumulation to take advantage of a widening division of labor. In fact, Smith's vision of the widening division of labor translates into neoclassical language as *increasing returns to the scale of production.* Neoclassical competitive equilibrium is incompatible with pervasive increasing returns except under special analytical assumptions. Thus the feature of economic life that Smith's puts in the center of the Classical vision is precisely the feature that is incompatible with the neoclassical vision of the efficienct allocation of resources through the achievement of a competitive equilibrium.

But Smith's vision of the widening and self-reinforcing division of labor is completely consistent with the systems theory conception of a complex, self-organizing, non-equilibrium process. Growth and development as irreversible processes are characteristic of complex systems. While particular self-organizing aspects of complex systems may have strong homeostatic properties that lead them to seek recognizable organized states (like the individual cell in an animal, for example), the systems themselves are open, adaptable, and indeterminate (like the life history of an animal), and not typically subject to simple equilibrium analysis. We know that the wolf, for example, must maintain nutritional balance with her environment to live, but this observation does not allow us to predict her life cycle, where she will migrate, mate, or, eventually, die. Smith's vision of capitalist economic development is analogous: he can explain the metabolic processes, accumulation and competition, that support the evolution of the capitalist economy, but not its history, the specific development of its technology, or its sociology.

1.3.2 Malthus and Ricardo

Smith's great immediate successors were Thomas Malthus and David Ricardo. Their characteristic discoveries were in fact in opposition to Smith's open-ended optimism about the prospects for capitalist economic development, but their methods grow out of Smith's arguments, and reflect the same preoccupation with unintended consequences of human actions.

Malthus argued that human societies always reach a *demographic equilibrium* in which high mortality from disease and malnutrition, especially infant mortality, balanced high fertility. His analysis of this problem centers on a stable feedback mechanism, in the language of modern systems theory. If mortality were to fall below the equilibrium level, the high rate of fertility would increase population. Malthus believed that an increasing population would encounter diminishing returns in the face of limited land and other natural resources, so that the standard of living would fall, increasing the incidence of mortality through malnutrition and disease. Malthus' theory turned out to be spectacularly inappropriate to understanding the actual process of capitalist development over the next three hundred years. But it is interesting to note that his method of reasoning depends on the same notions of unintended consequences and self-organization as Smith's. Malthus' procreators have no way of knowing that the indirect consequence of their fertility decisions will be a demographic equilibrium. They themselves are not in any kind of "equilibrium" according to Malthus' argument. The limitations of land and natural resources impose themselves as a pervasive system-wide phenomenon which shapes the uncoordinated decisions of individuals into the demographic equilibrium.

Ricardo extended and elaborated Malthus' notion of demographic equilibrium to a picture of a *stationary state* in which the pressure of capital and labor resources on limited land would force the return to capital, the profit rate, close to zero, and choke off the process of Smithian accumulation. Ricardo's vision rests, like Malthus' on the implicit assumption of diminishing returns to population and capital in the face of limited land resources. But his account of the equalization of profit rates, which underlies the mechanisms that enforce the stationary state, is the same gravitational mechanism we find in Smith. The individual capitalist does not see the rise in rents and in money wages that squeeze his profit rate as connected to his own accumulation. The process of accumulation does not necessarily follow any predetermined path toward the stationary state. Ricardo's arguments are powerful because he shows how *any* path of accumulation will run itself into the stationary state, given only the general phenemonen of diminishing returns associated with limited land resources. In the stationary state itself some capitalists may be making profits and accumulating, while others are making losses and decumulating. Ricardo's stationary state is not a reflection of a microeconomic equilibrium in which each agent finds itself, but a self-organizing state of a complex system that continues to adapt and change, even as it reproduces the stationary state as a macroeconomic average.

1.3.3 Marx

Karl Marx took the Classical political economy of Smith, Malthus, and Ricardo as the basis of his critical reconstruction of the theory of the capitalist economy. Marx instinctively and unquestioningly adopted the mode of argument of the political economists, which sought to discover aggregate regularities in the capitalist economy that did not depend on the detailed behavior of individuals. The power of his methods of analysis, which has been the frequent subject of admiring comment, rests on this foundation. Marx can reach powerful, general, analytical conclusions about the course and patterns of capitalist economic development without limiting himself to particular implausible and limited "models", and without claiming to predict the actual behavior of particular individuals.

Marx brought to political economy the language of "dialectics" that pervaded Continental philosophical thought, particularly through the writing of Hegel, in his youth. In my view, dialectics is best understood as an attempt to find a precise language to discuss the phenomena of system complexity and self-organization.

From one point of view, complex systems are "determined" by the propensities and tendencies of their constituent parts (the chemical properties of proteins in the cell, or the behavioral tendencies of households and firms in a capitalist economy, for example). But the aggregate behavior of complex systems is far from a simple reflection of these tendencies at the aggregate level. In fact, complex systems paradoxically tend to exhibit features that are in many respects the opposite of the tendencies of their components. The resolute pursuit of profit by individual capitalists, for example, may lead to a falling average rate of profit in the system as a whole. Dialectical language promotes this observation to the (contested) status of a "law".

Despite its features of self-organization, a complex, adaptive system is in a constant process of development and change. Self-organizing aspects of the system emerge because they are independent to a very considerable degree from the detailed function of any particular part of the system. Complex systems tend to be able to continue to function recognizably even when some of their constituent subsystems are disrupted. Randomly wired computers, for example, organize themselves in ways that cannot be destroyed by cutting a few links, while we know that even the smallest failure of a single component completely disables conventional computing machines. Thus the self-organization of a complex system appears to be "over-determined" in dialectical language, in that the destruction of one or even several pathways through which the feature reproduces itself may not succeed in altering the self-organization of the system as a whole.

While complex, adaptive systems are "determinate" in the sense that it is in principle possible to trace the interactions among their myrian components that are responsible for their aggregate behavior, they are not "predetermined" in the sense that we can hope to figure out the exact path of their future evolution. Complex systems share this lack of predeterminacy and predictability with chaotic systems, since it arises from the extremely large number of degrees of freedom that characterize both systems. Chaotic systems, however, are so unstable that they break down self-organizing structures very rapidly, while complex systems can sustain self-organizaing structures over long periods. Curiously, the disorder of chaotic systems makes them statistically predictable, while complex systems create irregular statistical patterns that are impossible to extrapolate. Dialectics acknowledges this lack of predeterminacy in complex systems by insisting that the future is genuinely open, though constantly being shaped by the actions of constituent particles in the present. This is a key point of difference between the conceptual worlds of equilibrium and self-organizing complex systems. Equilibrium systems tend to return to predetermined states, while complex systems undergo open-ended evolution.

Marx frequently refers to Ricardo, and uses Ricardo's arguments as the basis of his own reformulations of the discoveries of Classical political economy. In part this is due to Marx's appreciation (shared by many other readers) of the analytical power and sharpness of Ricardo's mind. But in substance Marx is a Smithian much more than a Ricardian. The crucial point here is the role of diminishing returns to capital accumulation. Marx shared Smith's view that the essence of capitalism as a social form of organization is its ability to overcome diminishing returns through the widening social division of labor and the technical advances the division of labor makes possible. Marx, in fact, elaborated a powerful systematic account (based on Ricardo's remarkable chapter on Machinery) of the way in which capitalism institutionalizes technical change through the struggles of particular firms to gain cost advantages from new technology. But, again, notice that this theory of Marx's is not a set of hypotheses about the specific course of technical change, nor about particular technologies. It is better seen as an account of a tendency of capitalist systems to organize themselves as engines of technical change, whatever the particular technical challenges they face might happen to be historically. Marx, like Smith, sees the essential character of capital accumulation as an ongoing, open-ended, evolutionary process.

Marx also believed that the capitalist system rested on a contradictory and morally unsustainable system of exploitation of labor. Smith is enough of a realist to acknowledge the class basis of capitalist society, but also enthusiastic enough about capitalist process to gloss over the problem of class divisions in the belief that workers will substantively share in the gains of productivity over time. On this point Smith, at least in the context of highly developed capitalist economies, has proved to be right so far. Smith foresees no particular fate for capitalism, unlike Ricardo and Malthus, who forecast the stationary state as a kind of "heat-death" for capital accumulation. For Marx, on the other hand, capitalism as a system would eventually have to evolve to resolve its class contradictions. Complex systems theory suggests that it is very difficult to resolve these speculative historical questions, since there is no way to compress the analysis of a complex system into a model that is any less complex than the system itself.

1.3.4 Classical method

Complex systems pose major challenges to our "common-sense" notions about determinacy, predictability, and stability. It might seem at first that complex systems are inherently invulnerable to systematic analysis. In some respects this is true. We cannot hope to model the future path of a complex system in detail, because of the intractable multiplicity of its degrees of freedom. The phenomenon of self-organization, however, opens up a sphere of possible analysis. It is possible to understand the forces that make for the self-organization of a complex system in some dimensions, and to model these limited aspects of the system. Classical political economists' theories of competition, demographic equilibrium, and technical change are good examples of this method. Understanding the self-organizing aspects of complex systems is immensely valuable knowledge, but inevitably frustratingly incomplete. For example, we might be very confident in predicting that insofar as the economy continued to function on the basis of commodity exchange, it will organize itself into markets with prices, and that competitive forces will create weaker or stronger mechanisms of induced technical change. This is a vitally important thing to know about the capitalist economy. On the other hand, it tells us nothing about the details of what products will become leading commodities, where the specific centers and bottlenecks of technical change will emerge, or even how markets will be organized or over what spatial or temporal regions. These are the things we would like to know to make good decisions about education, speculative investments, and public policy.

The self-organization of complex systems thus presents the apparent paradox of promising analytical knowledge about open-ended, evolutionary processes which are inherently unpredictable. The triumph of Classical political economy, in my view, was its uncanny power to discover this type of result. It thus points the way to a solution of a difficult philosophical dilemma. Those who remain committed to the idea of an analytically based social science without adopting the complex systems vision are forced to deny the open-ended, indeterminate character of human social life. These thinkers will force the complexity of social life into simpler forms for the sake of making them amenable to analysis. Those who remain committed to the vision of an open-ended, evolutionary account of human social life without recognizing the phenomenon of self-organization seem condemned to a kind of epistemological nihilism. For them the social world is complex and determinate, but it will be impossible to say anything systematic about it. The recognition of self-organization as a pervasive tendency of complex, adaptive offers the possibility of discovering and analyzing substantive regularities of complex systems like the economy without hypostatizing them as realized equilibrium states.

1.4 Self-organization and equilibrium

In some cases it is possible to study the self-organizing tendency of the economy in terms of homeostatic feedback mechanisms that can be represented by differential equations. For example, it is not hard to represent Malthus' theory of demographic equilibrium in a two-dimensional system of equations involving population and the standard of living, linked by a fertility-mortality relationship on the one hand and a population-productivity relationship on the other. (I will develop this system in detail later in these Lectures.) Mathematicians call the rest point of a set of differential equations an "equilibrium", but I am insisting on a sharp distinction between the concepts of self-organization and equilibrium. This suggests that the term "equilibrium" has different meanings in different contexts, as indeed it does. Mathematicians, physicists, and economists use the term "equilibrium" in significantly different ways.

A very fruitful notion in science is the concept of a *dynamical system*. The relevant aspects of a dynamical system at any moment in time constitute its *state*. The collection of all possible states the system might be in constitute the *state space*. For example, we might represent Malthus' system by defining the state of the economy at any moment as its population, productivity, fertility, and mortality. The notion of a dynamical system is that the motion of the system through time is determined by its current state.

Mathematicians call the rest points of a dynamical system (states at which there is no tendency for the system to move) *equilibria*. States that are close to an equilibrium constitute its *neighborhood*. An equilibrium is *locally stable* if the system remains in the neighborhood of the equilibrium whenever it starts in the neighborhood of an equilibrium. An equilibrium is *globally stable* if the system tends to move to a neighborhood of the equilibrium and stay there whatever state it starts from. A chaotic system is locally unstable but globally stable. The laws of motion of the system prevent it from converging to a particular equilibrium state, but also prevent it from moving very far from its globally stable equilibrium. Such a system restlessly explores all the states in the neighborhood of the globally stable equilibrium. In this case it is possible to describe the motion of the system statistically, that is, to predict accurately what proportion of time it will spend in any subset of the neighborhood of the globally stable equilibrium it occupies. Malthus' demographic equilibrium is globally stable on his assumptions that fertility increases and mortality decreases with productivity, and that productivity declines with population, but very likely would be locally unstable, with ceaseless small fluctuations in fertility, mortality, population, and productivity.

Physicists use the term "thermodynamic equilibrium" to denote a macroscopic state of a system that tends to reproduce itself, even if at a microscopic scale the system is moving around in the state space. For example, physicists regard the molecules of air in a bicycle tire under pressure as being in an equilibrium state, despite the fact that the individual molecules are constantly moving around and colliding with each other and the walls of the tire. If we open the valve of the tire, however, we create a thermodynamic disequilibrium between the air in the tire under pressure and the atmosphere. Thermodynamic or statistical equilibrium represents the tendency for macroscopic variables, such as temperature and pressure, to return to stable states, even though the underlying microscopic state of the system, representing the positions and momenta of individual molecules, is constantly changing. This thermodynamic notion of equilibrium is conceptually very close to the idea of self-organization of a complex system. The orderliness of a thermodynamic system at the aggregate level reflects, however, its complete lack of order at the micro-level. In fact, a basic method for computing the thermodynamic equilibrium of a system is to find the macro-state which is compatible with the greatest degree of disorder at the micro-level, as measured by the *entropy* of the system. In many cases the micro-level disorder is the result of the unstable chaotic motion of the corresponding mathematical dynamical system.

Curiously, economists have begun to adopt the thermodynamic notion of equilibrium as a conceptual tool only recently (see, for example, Foley, 1994). The traditional economic notion of equilibrium requires each household and firm in the economy to be in equilibrium at a microscopic level in order for the economy itself to be in equilibrium. The orderliness of an economic equilibrium system at the macro-economic level is a reflection of its complete orderliness at the microeconomic level. The traditional Walrasian conception of economic equilibrium has zero entropy: it is completely orderly at the micro-level.

Self-organized, complex, adaptive systems, on the other hand, cannot typically be regarded as being in equilibrium either in the physical or traditional economic senses. Self-organization cannot occur in a stable dynamical system, which tends to collapse all structures into the stable equilibrium state. Self-organization is also unsustainable in a completely locally unstable and therefore chaotic dynamical system. Any embryonic structure in such a system is quickly dissipated. Self-organizing structures are characteristic of systems that are mathematically neither locally stable nor locally unstable, which can sustain and reproduce recognizable structures over long periods of time. Like thermodynamic equilibrium systems, complex, self-organizing systems stably reproduce patterns in some aggregates, even though the underlying state-space dynamics are locally unstable. In contrast to thermodynamic equilibrium systems, however, complex, self-organized systems remain far from their maximum-entropy equilibrium states. Their self-organization is a sign of this thermodynamic equilibrium: the reproduction of their self-organized structures is incompatible with the complete disorderliness maximum entropy demands.

Complex, self-organized systems are, well . . . , complex. Some subsystems of a complex, self-organized system can be in thermodynamic equilibrium, even though the system as a whole is organized far from equilibrium. Our blood, for example, reaches thermodynamic equilibrium at a measurable temperature, even though it circulates as part of a self-organized non-equilibrium system, our bodies, that maintains itself out at a different temperature from its environment. Thus we can see several different types of order in complex, self-organized systems. Some parts may be in economic or thermodynamic equilibrium, which will reveal itself in an examination of their microscopic behavior. Self-organizing structures reflected in some aggregates reproduce themselves in an orderly fashion. But the system as a whole is in a constant process of development.

An example of Brian Arthur's (1991) may help to fix the phenomenon of self-organization in our understanding. Arthur considers a local bar (or pub) ("El Farol", in his original telling) which is the kind of place that is fun to visit when it has no more than 60 people in it. When the crowd gets much bigger than 60, it is noisy and boring. The bar has several hundred "regular" customers who like to go there. On any given night each regular has to decide whether or not to go. Arthur supposes that each regular has a whole group of models that are intended to predict how many people will be in the bar on any given night. These models use data on the actual attendance at the bar over the past as an input. Different regulars may have different models, or in some cases the models may overlap. At each moment in time each regular customer adopts the model in his or her group of models that has best fit the data over the past. If that model predicts attendance less than 60, the customer goes to the bar that night. In simulations the attendance at the bar hovers around 60 customers each night, which reflects a strong self-organizing tendency of this system. But there is no equilibrium in the micro-state which describes the model and behavior of each particular customer. The customers ceaselessly change the models they use, and their individual pattern of attendance does not follow a maximum-entropy statistical law. The system as a whole is far from equilibrium, despite the fact that attendance is extremely regular. One can imagine that similar forces might be at work behind many social phenomena, such as the distribution of taxis in large cities, the size and growth rates of urban centers, the outbreak of wars, and the like. It is possible to see why Arthur's system self-organizes in this dimension. If the number of customers attending rises for several nights much above 60, for example, those who attend must have received wrong predictions from their models, and will tend to shift to different models, typically, but not necessarily, to models that tend to predict a higher attendance at the bar and hence to discourage their users from going. A symmetric dynamic will follow a series of nights when the attendance is well below 60, due to the disappointment of those who stayed home when they would rather have gone out. This very general feedback mechanism stabilizes the number of customers attending, even without any tendency for the models or the behavior of individual customers to stabilize (or to converge to some "correct", or "perfect foresight" model). The analogy with the Classical theory of competition is also clear. The individual profit-seeking capitalists of the Classical story do not settle on one equilibrium plan or strategy. Like the customers in Arthur's bar model, they very well may be ceaselessly seeking new ways to look at the economy and to discover profit opportunities or recognize markets in decline. But despite their failure to reach any equilibrium in their own behavior, they tend to equalize profit rates.

From the point of view of political economy the phenomenon of self-organization opens up important methodological perspectives. The difficulty with the equilibrium point of view, whether thermodynamic or economic, is that it is forced to associate strong micro-level structure, in the case of economic equilibrium, or the maximization of micro-level disorder, in the case of thermodynamic equilibrium, with observed aggregate regularities. The equilibrium point of view is, in this sense, too strong methodologically. It can explain aggregate regularity only by positing a corresponding micro-level equilibrium or chaos. These micro-level predictions are often incorrect, leaving the equilibrium theorist either with the need to scrap the theory altogether, or to insist against the evidence on micro-level equilibrium that is simply not present in reality. The recognition of the phenomenon of self-organization can avoid these pitfalls, allowing the political economist to investigate the dynamics of self-reproducing structures in economic life without projecting them inappropriately onto the complex and evolving micro-level behavior of households and firms.

But the self-organizing point of view raises its own methodological problems. The success of the method depends on the power of the tendencies towards self-organization to operate over a very wide range of micro-level situations. Conventional economic modeling tends, on the contrary, to demonstrate the tendency of a *specific* micro-level equilibrium to give rise to an aggregate regularity. Any particular model of this kind inevitably raises the question of how general the demonstrated result is. When we demonstrate equalization of the profit rate in a specific model (assuming, for example, a given set of commodities and given technology), how do we argue for the generalizability of the result to a wide, ill-determined set of possible environments (such as changing commodity space or technologies)? Certainly demonstrating the result in particular models is necessary first step, but the longer-run goal is to get insights into the behavior of a large class of systems, of which the model represents only a part.

This methodological problem creates a gap between those who, in the name of scientific skepticism and conservatism, accept results only in the domain in which they have been demonstrated, and those who, in the search for insight and understanding, want to project or generalize results demonstrated in a narrow domain to a wider domain on the basis of intuition or instinct. This division, which characterizes the dialectic of scientific knowledge, becomes particularly acute in the study of complex, self-organizing systems. Self-organization may be meaningful only in complex, nonequilibrium systems that are difficult or impossible to represent in general, closed, tractable, mathematical models. It may be possible to demonstrate the self-organization only by simulating highly simplified and abstract models of the system in question on a computer. In this case all we have, in the skeptic's eyes, is a collection of specific examples, similar to anecdotes. The self-organization demonstrated may be due either to the general structure of the system (if we can even agree on what that is), or to specific, possibly obscure, peculiarities of the cases simulated.

The Classical political economists and Marx worked in an intellectual milieu that was much more sympathetic to speculation and extrapolation from example than many scientists are today. Still, even the strict constructionists of the present economic mandarinate accept at some level or other the general validity of the Classical theory of competition, even if only as a heuristic to guide the formulation of specific, narrow models. There is some hope that the Classical modes of argument and results can bolster the investigation of the economy as a complex, self-organizing system far from equilibrium.

1.5 From Malthus to Darwin to Kauffman

How anachronistic is it to suggest that the Classical political economists conceived of the capitalist economy as what we would now call a complex, adaptive, self-organizing system? On the one hand, the mathematical language of complex systems theory is the product of the last twenty or thirty years (though some mathematicians were thinking about this type of system before). On the other, there is a clearly traceable intellectual path from the Classical political economists to contemporary complex systems theory. Curiously enough, this path does not run directly through economic analysis, but through biology.

The development of mathematics in the seventeenth and eighteenth centuries was closely connected with the development of astronomy and physics. This era of physics aimed at deriving closed form expressions for the behavior of relatively simple systems, like the planetary system, from a small number of fundamental laws, like the law of gravity. The need for such closed-form solutions (actually approximations) arose from the primitive level of computational methods available, basically paper and pencil in the hands of a human being. (Newton, Gauss and other great mathematical minds of this period spent what in retrospect appears to be an astonishing amount of time and energy carrying out elaborate computations of planetary orbits by hand, an activity that strangely enough seems to have been the foundation of their scientific prestige.) The paradigmatic system in this era was the clock, a mechanical device maintained in regular stable motion by simple feedback mechanisms.

It is striking how little of this vision of a clockwork universe finds expression in the writing of the Classical political economists. As we have seen, Smith's vision of the capitalist economy, while it included the notion that the economy was in some dimensions self-regulating (if not self-organizing), was far from mechanical, and has closer affinities to living, developing and growing biological systems. Malthus advertises the "mathematical" character of his argument, but his mathematics turns out not to be a formal equilibrium system akin to the derivations of planetary orbits by celestial mechanics, but the demonstration of the asymptotic incompatibility of an arithmetically growing series to represent food production and a geometrically growing series to represent population. The explanation may very well be that the Classical political economists did not know enough of the advanced mathematics of their time to be influenced by it. But the Classical political economists, who were widely read and exhibited curiosity about everything under the sun, don't seem to have been very interested in the mathematics available to them. An exception is Marx, who thought rather hard about the philosophical basis of the differential calculus. The Classical political economists do not seem to have been attracted by the idea of representing the economy as a clockwork system governed by a simple principle of maximization or minimization like the principle of least action that unifies classical mechanics.

Statistical equilibrium concepts in physics emerged in the 1850s, after the work of all the Classical political economists except Marx (if one counts him as a Classical political economist). Statistical ideas originated in the empirical investigation of social phenomena in the first half of the nineteenth century, and are one important path by which the concepts of social science influenced the development of formal systems theory and the "harder" sciences. The mathematical roots of complex system theory lie in the rigorous investigation of the foundations of statistical mechanics, and the consequent discovery that systems with many degrees of freedom, even when they are governed by simple laws at the microscopic level, are capable of a bewilderingly rich range of aggregate behavior.

But there is another, more direct, and better known path connecting Classical political economy with modern complex systems theory, which runs through biology rather than physics. Charles Darwin's speculations on natural selection began from Malthus' image of the struggle for survival implicit in the relentless pressure of human population on food resources. Darwin formulated the evolution of species as the outcome of this struggle for survival in the presence of random mutations. The evolutionary process is a paradigm of a complex system. The principles that ultimately govern it at the microscopic level, mutation and fitness, are simple to state and understand, but their consequences on the macroscopic level are varied, path-dependent, and open-ended. Evolution is one of the central strands of modern complex systems thinking.

Economists, in the meantime, developed a curious schizophrenia in their thinking about the economy. With the invention of marginalism in the 1880s, the mechanical mathematics of least action, already on the wane in the physical sciences, arrived in economic thinking with a vengeance. Marginalist economists came increasingly to formulate models of the economy so as to be amenable to closed-form analytical solution in imitation of the physics of the eighteenth century. But at the same period the biological metaphor of evolution also appealed to many economists as the natural conceptual foundation for economics. The Institutionalist movement in economics, following Thorstein Veblen, attempted to found a scholarly discipline on the evolutionary metaphor. Alfred Marshall's attempted synthesis of Classical political economy, marginalism, and institutionalism unfortunately degenerated into a complacent neoclassical orthodoxy whose intellectual heritage still weighs heavily on economics. But Marshall was strongly drawn to the evolutionary model and to the idea that biology, not physics, was the appropriate model for economics. (For some reason the notion that economics might be better regarded as the conceptual model for physics or biology has not had much of a hearing.) Allyn Young, a highly respected American economist who had a foot in both the neoclassical and institutionalist camps, puts forward similar ideas. The sociology of American economics in the first half of the twentieth century is the story of an academic duel to the death between the neoclassical and institutionalist schools, a duel in which the neoclassical school won a Pyrrhic victory through wielding the weapon of mathematical sophistication.

Marshall and Young exemplify another connection between complex systems theory and economics. The marginalist resurrection of eighteenth century celestial mechanics as a mathematical model of the economy is incapable of dealing with the phenomenon of increasing returns to scale, a technical theme of great importance to Marshall and Young. At one level this difficulty appears in the theory of competition: with increasing returns to scale one firm tends to dominate each industry, thus frustrating the achievement of the static equilibrium of marginal cost and benefit that is the centerpiece of the neoclassical story. But when we look at increasing returns from a dynamic point of view, we see that it leads directly to the main themes of complexity theory. Increasing returns to scale destroys the local stability of the neoclassical equilibrium, but it is evident that firms cannot grow indefinitely large, and that countervailing nonlinear forces must come into play to regulate the evolution of the system even if competition cannot enforce the neoclassical marginal equalities. An increasing returns to scale economy (as Brian Arthur and others have emphasized) is inherently open-ended and path-dependent, like the evolution of species (where a fitness advantage operates analogously to competitive advantage with economic increasing returns). This line of thought leads forward through the ideas of Herbert Simon to the economic version of complex systems theory, which sees the economy as a complex, adaptive system governed by increasing returns. It is not hard to see that it also leads back to the Classical political economic theory of competition, which posits the self-regulatory character of an economy without insisting on achieved marginalist equilibrium.

Complex systems theory proper emerged in the 1960s and 1970s in the convergence of these intellectual developments in physics, biology, mathematics, computer science, and economics. Physicists and mathematicians such as Erwin Schrodinger, Alan Turing, and John von Neumann turned their attention to various aspects of the problem of understanding the reproduction and structure of living organisms. The development of population genetics revealed its close relations to dynamical systems theory and began to force theoretical biologists to consider the abstract nature of evolution as a system. These intellectual efforts produced an explosion of particular models of complex, self-organizing systems, such as von Neumann's cellular automaton, which made the distinctive properties of these non-equilibrium but organized systems vivid and inescapable. Biologists like Stuart Kauffman discovered deep structural similarities between self-organization in complex systems as diverse as the living cell, the ecology of species, and the capitalist economy.

Perhaps I speak from a biased point of view, but it seems to me that the master principle at work in these developments has been the power of the economic metaphor in the "hard" sciences, not the influence of physical or biological metaphors in economics. As human beings we have a direct existential experience of the operation of the capitalist economy as a complex, adaptive system, which informs our imagination in dealing with other complex systems in physics and biology. In this sense I would argue for the direct relevance of Classical political economy to the emergence of the contemporary complex systems vision, and claim a significant, perhaps even dominant, intellectual ancestry for the Classical political economists.

1.6 Classical themes

In succeeding lectures I will discuss some contemporary research that addresses key themes of the Classical political economists: population, distribution and productivity, and the impact of limited natural resources on capitalist economic development. Here I want to summarize the issues and major findings of this research.

1.6.1 Population

One of the most striking differences between the Classical political economy tradition and neoclassical and marginalist economics is the treatment of human population. The Classical political economists universally presumed that the size and growth of the population were a reflection of economic development and performance, that is, "endogenous" in the jargon of economic model-building. People are a by-product of economic activity in this way of looking at things. Marginalist economics, on the other hand, has a strong tendency to view the population as "exogenous", with economic development shaping itself to the limits set by population.

One might suppose that this shift in point of view was a response to new empirical data that called the Classical notions into question, but, as far as I can tell, this is not the case. Neoclassical demographic economics continues to pursue the question of economic determinants of fertility and mortality, and finds strong confirmation of the fundamental Classical insights in modern patterns of population growth and movement. Demography, however, has been marginalized and demoted to a respected but minor place in the neoclassical pantheon, along with locational economics, economic history, and the history of economics. I would suggest that what motivates this changed attitude toward population on the part of neoclassical orthodoxy is its attachment to a particular philosophical view of welfare economics based on its subjective and individual theory of value. Neoclassical economics sees economic value as expressing the ability of commodities to satisfy individual, subjective desires. Neoclassical welfare economics justifies the operation of the market as optimizing the satisfaction of individual, subjective desires, and evaluates public policies by analyzing their impact on individual subjective well-being. This philosophical approach to welfare economics and policy evaluation, enshrined in the discourse of consumers' surplus and Pareto-efficiency, only makes sense if the population of subjective individuals who are the focus of the analysis is given independently of the economic activity and policies being considered. If economic policy has the effect of increasing or diminishing the population itself, the analysis faces the insoluble problem of evaluating the welfare of non-existent individual consumers, either those who exist only as a consequence of the policy measure, or those who will not exist because of the policy measure. Serious attempts to resolve these questions have only revealed their fundamental intractability. Taking the population as exogenous to economic policy and development is a way of avoiding these awkward questions.

In the second lecture in this series I return to the Classical political economists' view that population, in this case world population, is governed by laws that arise in the economic sphere itself. Malthus and Ricardo argued that in the long run human populations would reach a *demographic equilibrium* through rising mortality induced by hunger and disease as a result of diminishing returns to labor in the face of limited land and natural resources. This analysis has proved to be spectacularly wrong as far as the actual history of world population in the last two centuries goes, but is still an immensely popular vehicle for contemporary anxieties about overpopulation and resource limits to growth.

I argue that Malthus proposed a viable method of equilibrium analysis, but reached flawed conclusions because of his uncritical acceptance of key assumptions about the response of fertility and mortality to rising income, and the relation between population and productivity. Malthus assumes that the difference between fertility and mortality rises with income (largely as a result of higher standards of living reducing infant mortality), but we now know that sustained increases in income lower fertility even faster than mortality. Thus there are two demographic equilibria: a low income, Malthusian, equilibrium at which high fertility is balanced by high mortality; and a high income, Smithian, equilibrium at which low mortality is balanced by low fertility induced by a high standard of living.

Malthus probably would have rejected the Smithian equilibrium, if he had considered it seriously, on the grounds that in the presence of diminishing returns, that is, falling productivity with increasing population, the Smithian equilibrium is unstable. For example, if the population were at the Smithian equilibrium level, an accidental increase in the population would lower productivity and income, which would raise fertility, and reinforce the increase in population, pushing the system away from, not back toward, the Smithian equilibrium.

But if the relation between population and productivity is positive, rather than negative, that is, if an increase in population *raises* productivity, the Smithian equilibrium is stable. In this case an accidental increase in the population will raise standards of living, and drive fertility below mortality, leading to a decrease in population back toward the equilibrium level. Smith argued that there is positive association between population and productivity because of the effect of the increasing division of labor with increasing population. If this Smithian effect outweighs the diminishing returns to limited land and natural resources, which seems to be the case at present for the world economy, the Smithian demographic equilibrium at a relatively high income and low mortality is stable. If the historical association between world population and world output reflects the structural effects of the division of labor, and current national relations of fertility to income continue to hold, this Smithian equilibrium will occur at a population about 25% higher than the current world population, and a world average income also about 25% higher than current world income.

In fact, it would be very difficult for world population to reach the Malthusian equilibrium (which is also stable), unless diminishing returns (say, in the form of environmental degradation) accelerated so rapidly as to overwhelm the effects of technical progress based in the widening division of labor.

The prospect of a world Smithian demographic equilibrium has comforting aspects on average, in that it offers the hope of managing environmental and resource problems in a context of stable population, and of productivity levels high enough to provide a secure and moderately comfortable standard of life. But all the signs are that the distribution of income and fertility at the Smithian equilibrium will be highly unequal. If so, we face a future polarized between advanced capitalist countries with high incomes, but aging and shrinking populations due to low fertility, and poorer, low productivity countries with young and growing populations due to high fertility. These sharp divisions will motivate trade in people, through the conventional paths of migration and the newer paths of adoption, surrogate parenting, and technological management of fertility.

1.6.2 Distribution and productivity

Malthus and Ricardo foresaw a future for capitalist economic development very different in terms of the distribution of income between classes and productivity of inputs to production from what has actually happened. They believed that the real wage of workers would not change very much in the course of capitalist economic development. Though they correctly foresaw that output would grow substantially through capital accumulation, they emphasized a pattern of overall decline in labor productivity, the ratio of output to labor input, due to diminishing returns with limited land and natural resources. They thought that the same diminishing returns would lead to a limited rise in land productivity, the ratio of output to land input. With a decline in labor productivity and a more or less constant wage, the share of wages in output would grow, squeezing profits and the profit share in output to zero. In Ricardo's stationary state, the whole surplus product of the economy above the subsistence wage level takes the form of rent.

In fact, the broad patterns of capitalist development have been dramatically different. The single most persistent and important feature of capitalist development has been the tendency for labor productivity to rise continuously and rapidly. If this increase in labor productivity had been accompanied by a stagnant level of the real wage, the wage share would have fallen dramatically, but in fact the real wage has tended, roughly speaking, to grow in proportion to labor productivity over the long run, so that the wage share in output has remained roughly constant. It is difficult to overstate the historical importance of these two factors in shaping the social and political development of capitalist society. While diminishing returns to land and natural resources have created occasional bottlenecks for capital accumulation, on the whole the productivity of land and natural resources has also grown very rapidly, in sharp contrast to Ricardo's and Malthus' vision of diminishing returns. In fact there seems to be little evidence of an increase in rent as a share of output.

Smith, in contrast, argues for a sustained increase in labor productivity through the widening of the division of labor. In place of Ricardo and Malthus' principle of diminishing returns, Smith puts a "virtuous cycle" in which capital accumulation increases the scale of production, which makes a wider division of labor possible through technical change, which in turn further encourages capital accumulation. Smith is characteristically vague about the tendency of wages, though he is clear that rapid capital accumulation tends to pull wages above the costs of reproducing labor at a subsistence level. He is perhaps inconsistent in his treatment of land, natural resources, and rent, since alongside his vision of the positive feedback of capital accumulation to the division of labor he pictures a stationary state (for example, in his comments on China) in terms similar to Ricardo's.

Marx follows Smith rather than Malthus and Ricardo in his analysis of labor and land productivity. Marx emphasizes the historically unprecedented technological progressiveness of the capitalist mode of production. The organization of the exploitation of labor through competing capitalist firms creates both the incentive and the ability for capitalists to discover and implement new technologies in an effort to reduce costs. This turns capitalist production into an engine of technical change. Marx argues that Malthus and Ricardo, in emphasizing diminishing returns to fixed land and natural resources, lost sight of the historical genius of capitalism, which is to overcome technical barriers to production. But Marx could not see any systematic reason for the wage to rise along with labor productivity in the course of capital accumulation. In the earlier phase of his study of economics he adopted a version of Malthus' and Ricardo's theory of the subsistence wage. In conjunction with rapidly rising labor productivity, a stagnating or slowly growing real wage leads to a fall in the wage share in output. This picture was politically congenial to Marx. If capitalism were to follow a path of rising labor productivity and a stagnating real wage, it would rapidly face a revolutionary situation, in which workers, conscious of their ability to produce a high standard of living, and systematically frustrated in their efforts to participate in the fruits of high productivity, would insist on taking control of the productive system.

Around 1860, as Marx was working on preparing *Capital* for publication, a tendency for real wages to rise in Britain, which he regarded as the bellwether of the capitalist nations, became apparent. I think this caused Marx considerable dismay, and perhaps a loss of confidence in his revolutionary project. He began to introduce a more nuanced and complex theory of wages and workers' standard of living into his economic analysis, emphasizing the constancy or fall in the value of labor-power (which correlates with the wage share in output) rather than a constancy in real wages in the course of capital accumulation, and to refer to the "relative" immiserization of workers, rather than their absolute impoverishment by capital accumulation.

But from the Classical political economy point of view the rise in wages poses an intriguing puzzle. Why should workers, relatively disorganized, easily divided, and constantly threatened by an influx of competition from various reserves of labor, be able to secure a rise in real wages in bargaining with a prosperous, politically unified capitalist class, even in a context of rising labor productivity? We are still far from understanding the complexities of the capitalist labor market, though some features of it have become clearer over the years. The labor market is highly segmented, so that the competitive pressure of reserves exerts itself only fitfully and gradually on specific wage bargains. The acquisition of skills, licensing and unions, the costs and risks of migration, linguistic and cultural differences, all present barriers to competition in the labor market. The rise in average wages that has taken place over the course of capitalist economic development has been extremely uneven. Both on the national and world scale disparities in workers' income are just as notable as the increase in the average level of the wage.

Recent work by Gérard Duménil and Dominique Lévy, revisiting from the perspective of Marx's theory of induced technical change the study of technical progress undertaken by earlier writers (Drandakis and Phelps, Kaldor and Mirrlees, van den Ploeg) suggests some new approaches to the problem of distribution and growth. From a Classical/Marxist point of view accumulation in capitalist economies fundamentally arises from profits, so that the rate of growth of capital, the most important determinant of the demand for labor-power, is closely and positively correlated with the profit rate. The profit rate in turn can be viewed as the product of the "productivity of capital", the ratio of the value of output to the value of capital, and the profit share in output (transformed versions of Marx's "organic composition of capital" and "rate of surplus value"). The profit rate in rapidly developing capitalist economies tends to be high enough to absorb local reserves of labor and create upward pressure on the wage and the wage share. One version of this type of account (the "profit squeeze" theories) sees the rise in the wage share, which corresponds to a fall in the profit share, as equilibrating the system by lowering the rate of accumulation to equal the rate of growth of the supply of labor-power. Robert Solow's influential model of growth reflects these ideas, which have the implication that the rate of growth of the capitalist economy is ultimately limited by the rate of growth of labor-supply.

Duménil and Lévy remind us that the rate of growth of the productivity of capital is also influenced by distribution. This point can be made in a number of modeling contexts, but at its root depends on the simple observation that the contribution of any input-saving innovation to raising the profit rate is proportional to the share of the input in cost. When the wage share is high, capitalists have a strong incentive to find labor-saving technical changes, and will be glad to implement them even if they cost something in terms of increased capital inputs. When the wage share is low, on the other hand, the incentives to technical change shift relatively toward capital-saving innovations.

This observation suggests, first of all, that the remarkable record of capitalism in fostering rising labor productivity is closely connected to a *high* share of wages in output. Attempts to bolster the profit rate by lowering the wage share through government policy, for example, have the side effect of lowering the rate of growth of labor productivity.

The implications of recognizing the dependence of the bias of technical change between labor- and capital-saving innovations on the share of wages and profit in output go significantly further. The profit rate can stabilize only when the rate of change of capital productivity is zero, no matter what the rate of growth of change of labor productivity may be. The mechanism of induced technical change tends to keep the wage share at the level at which the rate of change of capital productivity is zero. The *level* of capital productivity then must adjust to make the profit rate and rate of accumulation adapt to the availability of labor-power.

Thus this general approach offers a powerful explanation of the characteristic (but unexpected) pattern of capitalist economic development. The wage share in advanced capitalist countries has to be high enough to induce relatively low rate of change in capital productivity on average, and variations in the input-saving bias of technical change tend to stabilize the wage share at this level. The tendency for wages and labor productivity to rise steadily and roughly in proportion are a reflection of what Marx called the "revolutionary" character of capitalist production. This works because capitalism, in contrast to other modes of production, simultaneously gives capitalists control over technology, the means, through profits, of implementing new technologies, and a fierce competitive motive to cut costs of production.

To the degree that capitalist economies self-organize toward a state of zero rate of change of capital productivity through a high and stable wage share, the wage share itself becomes insulated in the long run from factors influencing both the supply and demand for labor-power, such as the rate of growth of the potential labor force, or the proportion of profits capitalists accumulate. These forces of supply and demand in the labor market regulate the level of capital productivity to keep accumulation in equilibrium with the potential supply of labor. Attempts through government policy to raise the wage share, for example, will tend to be frustrated by a process in which the adoption of labor-saving technical changes is accelerated, the productivity of capital falls, and the rate of accumulation stagnates.

This approach to the theory of capital also has implications for some of the most vexed and puzzling problems in economic theory. Neoclassical and marginalist economists want to see the *value* of capital as a measure of its real productivity in use-value terms. This makes no sense from a Classical/Marxian point of view, which sees the only "use-value" of capital as its potential to save wage costs by substituting for labor. Following Piero Sraffa's brilliant critical investigations, Classical economists showed that the neoclassical interpretation of the value of capital as representing some real productive factor is untenable, and that there is no reason to think that in general firms react to a lower profit rate by adopting more "capital-intensive" techniques of production. The induced technical change theory, however, explains regular tendencies in the ratio of the value of output to the value of capital not as the reflection of an underlying "production function" linking capital intensity to labor productivity, but as the outcome of a dynamic feedback process motivated by and responsive to the ratio of the value of output to the value of capital. From this point of view the real force regulating the capital-intensity of capitalist production is the profit rate and its tendency to stabilize, not an underlying "real productivity" of capital.

1.6.3 Land, the environment, and production

We now recognize that the emission of carbon dioxide and other "greenhouse" gases into the atmosphere as a byproduct of economic production will lead to pervasive and, in many ways, harmful changes in the earth's climate through "global warming". The design, evaluation, and implementation of public policy to mitigate global warming pose important questions for economic analysis. Because global warming unfolds on such a long time-scale, from two hundred to four hundred years, corresponding to the half-life of carbon dioxide in the atmosphere, the long-period analytical methods of Classical political economy promise to be particularly relevant in this area.

In principle the world can control the emission of greenhouse gases either directly by legally enforced mandates on emissions, or indirectly through the establishment of financial incentives for emissions reduction. The design, implementation, and enforcement of mandated emission controls are probably beyond our capability given the global extent and complexity of the problem. The Kyoto protocols agreed to in 1995 envision a system of tradeable emissions permits. While the details of the initial distribution and exact scope of the permit system are still unresolved, the scheme would require existing and new emissions sources to be licensed by acquiring these permits. Since the permits will be scarce, they will generate royalties (so many dollars per ton of carbon dioxide or its equivalent emitted per year). From the point of view of emitters, the permits will put a price on greenhouse gas emissions as an input to production on the same footing with capital, labor, and other priced natural resources like oil.

If indeed the uncontrolled emission of greenhouse gases will impose a net cost on economic production (through the balance of increased storm damage, flooding of valuable land, increased agricultural productivity in high latitudes, and the host of other impacts of world climate change) then it should be possible to design a mitigation scheme which improves the economic welfare of both current and future generations. The mitigation of global warming, from an economic point of view, poses the problem is distributing a net benefit to different countries and generations, not the problem of allocating a net cost, as politicians and diplomats tend to see it. Without a clearer understanding of the exact economic consequences of mitigation schemes like the emissions permit system the world may very well miss its chance for their enormous potential benefits.

Raising the price of greenhouse gas emissions as an input to production may in the short run induce some modest substitution of other inputs for emissions. But the possibilities of substitution in the case of already-existing power plants and transportation networks is limited. It seems likely that over the many decades involved in the global warming scenario the most important impact of emissions charges will be their influence on patterns of technical change through research and development. The difficulty this poses for economic analysis is that we do not have a very good understanding of the economics of long-run technical change, nor very good data from which to extrapolate over such a long time scale.

The Classical/Marxian theory of induced technical change as an explanation of the evolution of labor and capital productivity and the wage share offers a promising analytical approach to these problems. By extending the analysis to three inputs to production, labor, capital, and land (representing the capacity of the environment to absorb the byproducts of production such as greenhouse gas emissions), we can study the paths the world economy will follow with and without the pricing of scarce environmental resources like the atmosphere. In addition to labor and capital productivity, we now take account of environmental productivity and its changes through time.

A system of environmental resource pricing creates the same feedback between the share of output cost represented by the environment and technical change that favors the environment as is already present between the wage share and labor productivity. This feedback induces on average over time a rate of increase in environmental productivity that equals the rate of increase in output, thus stabilizing (though not eliminating) the stress production puts on the environment.

Without a system of environmental resource pricing, on the other hand, the analysis suggests a path of development that has quite disastrous consequences not just for the environment, but for the basic mechanisms of capitalist distribution. In the absence of explicit environmental resource pricing, firms will appropriate some of the value of the scarce environment in the form of profit.

Since there is no change in the incentive to invest in environment-saving technical change, firms will instead shift their investment towards capital-saving technical change. Eventually, in these scenarios, the wage share falls so low that the historical tendency of capitalist production to raise labor productivity is reversed. The incentives of the system wind up raising the stress on the environment without limit, and shifting distribution sharply against wages and in favor of profits.

We cannot quantify the magnitude of these effects or the exact time scale on which they might unfold without a better understanding of the exact dynamics of induced technical change than we have at the present time. But this line of thinking emphasizes the fateful importance of the decisions the world faces in relation to systems of environmental control.

1.7 Humanity's struggle to control its fate

One way of looking at human history sees it as a continuing collective struggle of humankind to control its fate. The development of nuclear weapons in the past century and the emergence of global environmental threats from production, not to speak of the implications of genetic engineering and revolutions in information and communications technology, are the form this struggle takes for our time.

We face a basic difficulty in controlling our collective fate that humankind is an assembly of individuals whose actions interact in complex ways to form an aggregate outcome. Attempts to solve human problems directly, say, through the invention of new medical or agricultural technologies turn out to have very different consequences as they play out through these complex interactions from the intentions of their promoters. We are only beginning to appreciate the implications of the complexity of human society for these problems.

Theory suggests that it is impossible to control complex, adaptive, self-organizing systems by directing the behavior of the individual entities that comprise them. Traditional conceptions of social policy, on the other hand, depend precisely on an ability to link individual behavior and aggregate outcomes. The methods of Classical political economy offer some hope of surmounting this apparent dilemma. We may be able to design systems that influence the self-organization of society as a complex, adaptive system in particular dimensions, even though we must give up any hope of stabilizing the actual evolution of the system in the hope of attaining once and for all such goals as justice and equality.

I would argue, in fact, that there is much to be gained from this shift in understanding. We avoid the Scylla of utopian fantasies of an end to the dialectical historical development of human societies, which, in the complex systems view, will continue indefinitely. But we also elude the Charybdis of conservative complacency in the face of the very real moral and social problems capitalist society creates and reproduces. What we need is a better understanding of the processes of self-organization that are amenable to our influence.

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