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Complex Landscapes in Economic Geography

By PAUL KRUGMAN*

How complex is the economic landscape? This rather mysterious question does not, of course, refer to the mountain ranges and rivers over which commerce must travel. It refers, instead, to an abstract landscape, one that represents the dynamics of resource allocation across activities and locations. When I speak about the complexity of this landscape I am in effect talking about some issues that have long been familiar in international trade: the relative importance of increasing returns versus comparative advantage in causing specialization and trade, the prevalence of multiple equilibria, the extent of path-dependence. In this paper I will argue that the metaphor of complex landscapes should be added to economists' vocabulary, for two reasons. First, it is a suggestive image that may help focus economists' work. Second, the idea of dynamics over complex landscapes is central to the growing interdisciplinary literature on "complexity"; since economists are already doing this kind of analysis under other names, there is no reason why they should miss an opportunity to get their fair share of the rents.

I. The Complexity of Economic Landscapes

Most models in international trade can be thought of as determining the allocation of resources in each country among a number of activities—labor between wheat and wine, capital between X and Y. It does not much change the story if some resources are allowed to be internationally mobile, although one needs at least some immobile resources to make location matter. It is also common to imagine that static models are embedded in some Marshall-type dynamic system, in which resources move gradually toward activities that yield a higher return. Thus one may, for example, assume that capital is sector-specific in the short run but fungible in the long run, and be willing to discuss the stability of that adjustment process.[1]

It is therefore natural, in some contexts, to represent the international economy as a dynamic system in a space defined by the allocation of resources. For example, Peter Neary (1978) long ago addressed stability issues for a two-sector economy by assuming that capital and labor are temporarily sector-specific and constructing a phase diagram in which the shares of capital and labor allocated to one of the sectors are on the axes. Such a phase diagram in effect defines a landscape in which economically interesting equilibria are local low points, surrounded by basins of attraction.

But what does this landscape look like? In the traditional constant-returns, competitive model of international trade, there is typically a unique equilibrium (unless there are strong income effects or factor market distortions of the sort that concerned Neary [1978]). When Marshallian dynamics are added, they effectively define a rather simple landscape, one in which the whole space of possible resource allocations drains to a single point.

Suppose, on the other hand, that there are country-specific external economies in a number of sectors, and that they are sufficiently strong relative to the forces of diminishing returns to support a number of locally stable equilibria. Then the landscape is

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[1] An important complication is introduced when one allows agents to base resource reallocation or accumulation on expectations about future returns. I ignore this issue here.

in effect quite complex, with many basins of attraction; which equilibrium the economy ends up in depends on which basin of attraction it started in. The common "new trade theory" themes of the importance of increasing returns, multiple equilibria, and the role of history can therefore be restated as assertions that the appropriate landscape is in fact a complex one.

Why is this restatement worth making? Because the idea of dynamic systems with complex landscapes has become a unifying theme in a number of research fields over the last few years. Some of these applications are well established in the mainstream. For example, solid-state physicists have created a huge literature on the dynamics of "spin-glasses," theoretical magnetic materials in which the interdependence between the orientations of dipoles in a lattice creates a complex dynamic system. (The residential segregation model introduced in the remarkable, underappreciated book by Thomas Schelling [1978] bears a strong resemblance to simple spin-glass models.) Others are more controversial, like the claims of Stuart Kauffman (1993) that the self-organizing properties of complex dynamic systems play a crucial role in evolution. Still, the now widely accepted view of evolutionary theorists like Stephen Jay Gould (1989) that historical accidents have large, permanent effects is in effect an endorsement of the view that the relevant landscape is very complex.

One surprising parallel that I personally find very interesting is between international economics and cognitive science. The breakthrough in the popularity of neural network theory came when so-called linear associative models were replaced with models in which the output of a neuron responds more than proportionately to the input it receives over some range—in effect, when the theory shifted from constant to increasing returns. The crucial boost was given by John Hopfield (1982), who pointed out that this kind of nonlinear response creates a dynamic system with many basins of attraction (a complex landscape) and that such systems can in effect process information. The literature on neural networks is surprisingly accessible to economists, and its feel (including the willingness to assume for analytical simplicity things that are obviously not true) is oddly familiar to someone who was worked in modern trade theory.

There are, as already stated, two reasons to make explicit the parallels between the work that international economists have already been doing and the growing interdisciplinary work on complex systems: to learn from the work in other fields and, perhaps even more important, to help bridge the congenital communication gap between the social and physical sciences.

II. Complex Landscapes in Economic Geography

The theme of the complexity of an abstract economic landscape arises very naturally in "new economic geography" models of the type that have become increasingly popular over the past several years. Consider the structure that I have used in a number of recent papers (e.g., Krugman, 1991, 1993). In this structure one imagines that there are two factors of production: immobile agricultural workers and mobile manufacturing workers. Manufacturing is a monopolistically competitive sector characterized both by increasing returns at the level of the firm and by transport costs. The interaction among factor mobility, increasing returns, and transport costs generates forces for agglomeration: firms tend to concentrate production in locations with good access to markets, but access to markets is good precisely where other firms are concentrated. Working against these "centripetal" tendencies, however, is the "centrifugal" pull provided by the geographically dispersed agricultural sector.

If one adds some rudimentary laws of motion, say, the assumption that manufacturing workers tend to move to locations that offer relatively high real wages, one gets a dynamic story in a phase space defined by the allocation of manufacturing workers across locations. This dynamic landscape can easily be very complex.

An example is the three-region case. Suppose that there are three equidistant loca-

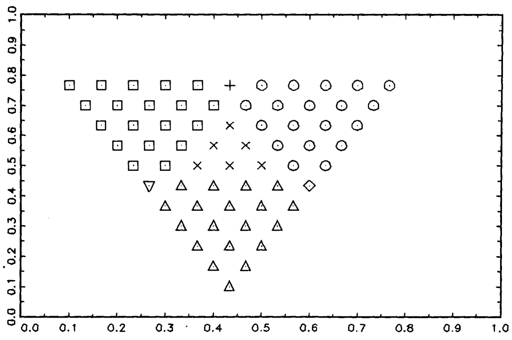

FIGURE 1. ALLOCATION OF MANUFACTURING WORKERS, THREE-REGION CASE

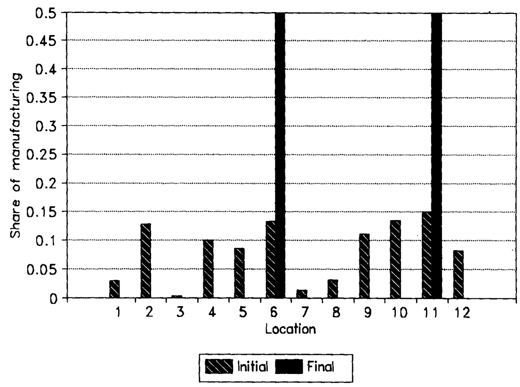

FIGURE 2. ALLOCATION OF MANUFACTURING WORKERS WITH 12 LOCATIONS

tions, with equal agricultural labor forces. The allocation of the manufacturing work force among the three locations can be represented as a point on the unit simplex in a space whose axes are the share of manufacturing in each location. Starting at any given point on that simplex, one can let the model evolve and see where it ends up. To draw the picture analytically is extremely difficult, but it is straightforward to compute numerical examples: for any given allocation of resources, one simply solves a small computed-general-equilibrium model, then uses the implied real wages to derive a new allocation of labor, and so on.

Figure 1 shows what is obtained for the most interesting range of parameters. (There are only three parameters in the model: the elasticity of substitution among products in the manufacturing sector, set for this example at 4; the share of manufactures in expenditure, set at 0.2; and the transport cost between any two locations, set at 0.4.) Each of a number of points on the simplex, representing an initial allocation of manufacturing workers, is assigned a different symbol depending on where it ends up. It turns out that there are four equilibria: three in which all manufacturing is concentrated in one location and one in which there is an equal distribution of manufacturing across the locations. There are correspondingly four basins of attraction: a central basin that leads to the equal-division outcome and three flanking basins that lead to concentration.

The landscape can become far more complex when there are more locations. In Krugman (1993) I introduced an example in which there are 12 locations, laid out in a circle like the numbers on a clock. (Twelve is a particularly convenient number because it is a fairly small number with a large number of divisors.) The dynamics once again take place on a unit simplex—but this time an 11-dimensional one. This is hard for most people to visualize. However, one can get a good idea of the properties of the model experimentally by starting with a number of random allocations of manufacturing across locations and seeing how they evolve.

Figure 2 illustrates a typical run. The initial random allocation of manufacturing eventually organizes itself into two manufacturing concentrations, at locations 6 and 11; that is, five part. This puts the two concentrations almost but not exactly opposite one another on the circle. (In this model, a successful location creates an "agglomeration shadow" that prevents the formation of another agglomeration too near by; thus the model tends to create a limited number of concentrations of manufacturing, roughly equally spaced.) In the course of a number of runs with these parameter values, two concentrations five apart occurred about 60 percent of the time, two concentrations six apart occurred on almost all other occasions. At rare intervals a run would lead to three equally spaced concentrations.

On a circle with 12 locations, there are 12 ways to replace two markers five apart, six ways to place them six apart, and four ways to place three equidistant markers. Therefore, it appears that with these parameters the model implies a landscape with 22 basins of attraction—complex terrain indeed. In such a world, the location of economic activity, and to some extent even the structure of the resulting economic geography, would depend crucially on initial conditions, which is to say on historical contingency.

What determines the complexity of the landscape? If the alternative locations are not symmetric, if some are inherently much better than others, there tend to be many fewer basins of attraction; the persistence of multiple equilibria in the presence of such asymmetries in the environment depends on sufficiently strong external economies arising from backward and forward linkages. This tug of war would be familiar to evolutionary theorists, who debate how much of the current form of species was determined by natural selection, how much by accidents of history.

The kind of complex landscape that can arise in models of economic geography can, of course, arise in many other economic contexts as well. Most notably, the choice among several technologies subject to network externalities will present a very similar picture, with the landscape complex if none of the technologies has too strong an inherent advantage and the externalities are sufficiently powerful.

III. The Emergence of Order

The most provocative claim of the prophets of complexity is that complex systems often exhibit spontaneous properties of self-organization, in at least two senses: starting from disordered initial conditions they tend to move to highly ordered behavior, and at least in a statistical sense this behavior exhibits surprisingly simple regularities (e.g., a power-law distribution relating the sizes and frequencies of earthquakes).

Some hints of these properties can be seen in the 12-region model of economic geography. Starting with a random allocation of manufacturing across space, the model organizes itself into a highly ordered structure in which manufacturing is concentrated in two or three equal-sized concentrations. Furthermore, while there are many such equilibrium structures, they share strong similarities: all involve roughly equidistant city locations, with a fairly narrow range of typical distances between cities. It seems reasonable to speculate that a more realistic model of the world economy would share similar features. That is, there would be many possible outcomes, depending on initial conditions; given a slightly different sequence of events, Silicon Valley might have been in Los Angeles, Massachusetts, or even Oxfordshire. But some broader features—say, that the pattern of trade would be approximately predicted by a gravity equation, or that city sizes would roughly obey a rank-size rule—would be more or less independent of historical contingency.

The hope of the apostles of "complexity" is that they will find broad generalizations that apply to all complex systems and thus create a kind of unified science of complexity that spans everything from fluid dynamics to sociology. This may prove no more than wishful thinking, but the pursuit of that dream has produced some powerful images and stimulating ideas. Economists should pay attention, because we have something to learn from these visionaries—and they have a fair amount to learn from us.

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