Emergence
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Abstract

With its philosophical pedigree and its recent use especially among life scientists as well as science writers over the last 15 years or so, the term emergence in economics is more evocative than precise, reflects influence from physics and biology, and has come to be associated with phenomena where economic structures evolve into qualitatively different forms. These exhibit properties that are emergent in the sense that they apply at an aggregate level but lack individual analogues and therefore are not describable at the individual level. This entry reviews selectively the recent usage of the term by emphasizing applications that possess firm economic foundations. These range from the evolution of patterns in international trade, to emergence of urban structure, to establishment of a common currency and others.

*Related entries:* economic complexity; multiplicity in macroeconomics; poverty traps; power laws; Schelling, Thomas C.; standards; statistical mechanics; social norms; spontaneous order; symmetry breaking; urban growth; urbanization.

*Keywords:* autarky, cellular automata, complexity, computation, division of labor, emergent properties, nonlinear dynamics, self-organization, social structure, specialization, stochastic stability, tipping point.

1 Introduction

Having acquired widespread use among life scientists and science writers over the last 15 years or so, the term emergence in economics is more evocative than precise, reflects...
influence from physics and biology, and has come to be associated with phenomena involving evolution of economic structures into qualitatively different forms. They exhibit properties that are *emergent* in the sense that they are novel and apply at an aggregate more “complex” level but lack individual analogues and therefore are not describable at, or reducible to, the individual level. A good case in point is the statement that consciousness is an emergent property of the brain. The notion of emergence originates in the philosophy of science, with John Stuart Mill being an important precursor. See Stanford Encyclopedia of Philosophy (2002).

This entry reviews albeit selectively the recent usage of the term by emphasizing applications with predominantly economic phenomena where emergence of macroscopic properties may be elucidated by means of economic arguments. These range from neighborhood tipping, evolution of patterns in international trade, to emergence of urban structure, to establishment of norms and institutions, and of a common currency and many others.

More generally, emergent properties or behaviors have been studied in a variety of circumstances in nature, such as emergence of differentiated behavior in colonies of animals, of herding behavior in organizations and markets, of specialization of individuals into occupations and of cities, regions and countries in specific products, of groups of biological cells in multicellular biological organisms and even of groups of processors in computer simulations involving cellular automata [see Holland (1998)]. The world wide web (WWW) is an example of a decentralized engineering system that is continuously being modified by human initiatives in the form of actions by individuals and firms. The web has not been deliberately designed and no central organization administers how different sites are linked to others. Some of the properties of the graph topology of the web may be termed as *emergent*, such as the number of links pointing to each page follows approximately a power law, with a few pages being pointed to by many others and most others are seldom linked to, and the fact that any pair of pages can be connected to each other through a relatively short chain of links in the average.

The presence of emergence within the vocabulary of economists does suggest some interplay with multidisciplinary research by scientists who have been associated with the Santa Fe Institute (http://www.santafe.edu). Quoting from Kauffman (1995), p.
an alternative definition of emergence is that “[t]he whole is greater than the sum of its parts.” And “life itself is an emergent phenomenon ... arising as the molecular diversity of a prebiotic chemical system increases beyond a threshold of complexity. If true, then life is not located in the property of any single molecule — in the details — but is a collective property of systems of interacting molecules.” The entirety of complex molecules together are able to reproduce and evolve, a “stunning property.”

Blume and Durlauf (2001) argue that emergence plays an important role even within the body of neoclassical economics proper. For example, the extent in which macroeconomics is a distinct discipline from microeconomics would be explained by emergent properties as alluded to by the statement “aggregation is not summation” [c.f. Kirman (1992)]. But even within microeconomics and general equilibrium theory, the metaphor of the invisible hand of the market (which goes back to Adam Smith), whereby individuals’ pursuit of their own selfish aims leads to social outcomes that obey important social properties. Under certain conditions, after markets have brought about an equilibrium, it is impossible to make anyone better off without making someone worse off. Thus, the first fundamental theorem of welfare economics is an emergent property of social outcomes. However, the more modern work on emergence in economics has emphasized emergence of patterns. Similarly, Hayek’s concept of spontaneous order may be considered an instance of emergence. [See entry on “Spontaneous Order,” The New Palgrave.]

There are numerous other contexts where emergence has been argued to occur. Next this entry explores a number of examples of emergence that are limited to social and economic settings. They underscore the scope of the concept of emergence in such settings. As discussed earlier, there are many other contexts in socioeconomic settings and beyond, ranging from computation to the life sciences.

2 Emergent Social Interconnections

Suppose that a society consists of \( I \) individuals, where \( I \) is large, where any two individuals may be linked in a way that allows for communication, social relations, or social interactions. Let \( p_k \) denote the probability that each individual is connected with
exactly $k$ other individuals. A literature going back to Erdős and Renyi (1960) and continuing up to this date to Newman et al. (2001), has studied the topological properties of the (random) graph formed by the agents as nodes and connections between agents as edges when each agent’s connections with other follows a given distribution $p_k$ and the number of agents is large. In the latest statement in ibid., depending upon whether the quantity $E[k^2] - 2E[k]$ is greater or equal to 0, or falls below 0, there emerges, as $I$ tends to infinity, a proportion of all individuals being interconnected, or alternatively, the economy consists of different groups of finite sizes. In other words, the social structure undergoes a phase transition when this quantity exceeds 0: emerges a giant interconnected component emerges. Intuitively, starting from a connected component of the graph consider adding a new edge that connects with a previously isolated node of degree $k$. Doing so will change the number of node on the boundary of the connected component by $-1 + (k - 1) = k - 2$. The likelihood that a node is on the boundary of the connected component is proportional to $k$. The expected change in the number of nodes on the boundary when an additional node is connected is given by $\sum_i k_i (k_i - 2)/\sum_i k_i$. If this quantity is negative, then the number of nodes on the boundary decreases and the therefore the size of the connected component will stop growing. If it is positive, on the other hand, then the number of boundary nodes will grow and the size of the connected component will grow without limit and be limited by the size of the network.

In the simple case of the Erdős and Renyi random graph, where the number of connections is proportional to the number of individuals, the phase transition occurs when the factor of proportionality is equal to $1/2$ and the corresponding average number of connections per person is equal to 1. Below this value, there are too few edges and the components of the random graph are small; above that value, a proportion of the entire graph belongs to a single, giant component. In this case, emergence of a qualitatively different social structure depends on the value of a single parameter [Kirman (1983), Ioannides (1990), Durlauf (1997)]. Individual behavior that leads to a law for the number of individuals’ connections does not necessarily imply the same macroscopic outcome in all circumstances. Similarly, social outcomes are not described by means of mere summation of individual actions; aggregation is not summation [Kirman (1992)].
Kauffman, ibid., 57, invokes this in the context of autocatalytic reactions and goes as far seeing this “as a toy version of phase transition that I believe led to the origin of life.”

3 Patterns of Residential Segregation

Next we turn to a description of neighborhood tipping, which is originally due to Thomas C. Schelling [Schelling (1978)] and has been adapted here from recent works. Suppose that individual $i$ is white and would live in a neighborhood provided that the percentage of whites among her neighbors, $\omega \in [0, 1]$, is at least $w_i$, $\omega \geq w_i$. She moves out, otherwise. Individuals differ in terms of preference characteristic $w_i$, which is assumed to be distributed in a typical neighborhood according to $F(w)$, when the analysis starts. For any neighborhood with a share of white residents equal to $\omega$, the percentage of white individuals who would find acceptable to live there are those with $w < \omega$. Their share is given by the value of the cumulative distribution function at $\omega$, $F = F(\omega)$.

In Figure 1, let the horizontal axis $e_1$ denote $\omega$ and $w_i$, the vertical axis $e_2$ the cumulative distribution $F$, and $(O, \bar{O})$ the 45-degree line. As long as $\omega > F(\omega)$, whites have an incentive to exit the neighborhood, causing a reduction of $\omega$, and this process continues until there are no whites left; $\omega = 0$. If, on the other hand, $\omega \leq F(\omega)$, additional whites have an incentive to enter, and this process continues until $\omega = 1$. Thus, the process has three equilibria, $(O, O^*, \bar{O})$, of which the two extreme ones, either only blacks or no blacks in the neighborhood, are stable and the mixed one, with $\omega^*$ whites in the neighborhood, where $\omega^* = F(\omega^*)$, unstable. The mixed equilibrium defines the tipping point. Individuals’ preferences differ widely, but only extreme outcomes emerge at the social equilibrium. Schelling (1978) underscores how outcomes that persist may not be what individuals had intended.

Could such a stark outcome be due to the fact that the respective populations of individuals are not being replenished? It turns out that if one goes deeper and allows for stochastic shocks, persistence of stable states may be rigorously characterized by means of the tools of stochastic stability theory [Blume and Durlauf (2003) and Young,...
Multiplicity of equilibria allows, of course, for accidents of history to become reinforced over time. Also, thinking about what happens to individuals who exit a particular neighborhood leads to issues of self-organization of communities, so that accommodation of all individuals may be sustained in an equilibrium fashion.

4 Emergence of Urbanization

The concentration of economic activity that we associate with emergence of cities punctuates the physical and economic landscape throughout the world. How did it emerge? While small-scale agriculture and home production could be reasonably accurately referred to as spatially uniform distribution of economic activity, world population is increasingly concentrated in cities. Also, urbanization has been closely associated with economic development.

Let us consider a simple setting where utility $U$ depends on individual productivity, itself an increasing function $f(n_\ell)$, of the total number of others in the same location, $n_\ell$, and on the share of a fixed resource, $R/n_\ell$. Even when utility is assumed to be increasing and concave in both arguments, as a function of $n_\ell$ it is initially increasing, may reach a peak for $n^*$, and then may start decreasing. In other words, a larger population initially means more innovation and mutually beneficial interaction until congestion offsets them. Consider then two alternative locations, $\ell = 1, 2$, that do not interact spatially and a total of $N$ individuals who wish locate so as to maximize utility. At a locational equilibrium, individuals must be indifferent as to where they locate. If $N < 2n^*$, the symmetric equilibrium, where $n_1 = n_2 = \frac{1}{2}N$, is unstable and agglomeration, that is either site occupied by the entire population, is stable. Therefore, the tradeoff between the value of agglomeration versus the cost of congestion moves the economy away from the symmetric outcome [Anas (1992)].

Let us consider next a setting where interactions do explicitly depend on distance to others, as with accessibility to others being valuable and congestion being disliked. If individuals are allowed to relocate, with probabilities that depend on expected utilities in each site relative to all other sites, then a dynamic model may be formulated that describes locational outcomes for an entire population. The economy may attain steady
states that are either uniform, populations are equal across all sites, or uneven, with some sites having large and others small populations. Such a stylized reduced-form model of spatial patterns of human settlements [c.f. Papageorgiou and Smith (1983)] yields spatially uniform outcomes that are either stable or unstable. Agglomeration is determined by the interplay between the value of agglomeration relative to cost of congestion. If the former dominates, spatially uniform steady states are unstable. Fujita, Krugman and Venables, Chapters 6 and 17, develop a model with ingredients from economic geography that incorporates trading costs and also allows for uniform distributions of economic activity to exhibit different stability properties. Again, conditions under which agglomerations prevail possess intuitive economic appeal.

5 Emergence of Poverty Traps

In a standard neoclassical growth model that extends over discrete time, with a demographic structure consisting of two overlapping-generations and individuals living for two periods, working only in the first and retiring in the second, individual savings would be proportional to the wage rate under Cobb-Douglas preferences. Let the aggregate production function expressing output $Y_t$ as a function of capital, labor and total factor productivity, $K_t, L_t, A_t$, respectively, be of the constant elasticity of substitution form,

$$Y_t = A \left( \delta K_t^{1-\frac{1}{\sigma}} + (1 - \delta)L_t^{1-\frac{1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}.$$

If the elasticity of substitution is sufficiently small — that is, complementarity between capital and labor is high — and total factor productivity sufficiently large, the time map of the economy, that is the amount of capital per person next period (axis $e_2$) as a function of the amount of capital per person in the present period (axis $e_1$) may be loosely graphed as in Figure 1. Therefore, depending upon the economy’s starting point, it may end up at a steady state either with high or with low capital per person at a steady state. The mid-range (“symmetric”) steady state is unstable. Therefore, conditions of productive complementarities, (even small) initial differences in capital per person, and possibly historical accidents as well across countries in terms of char-
acteristics and endowments when growth starts, mitigate in favor of an explanation for inequalities in incomes per person across different countries. The same mechanism worldwide produces sharply different outcomes. See Azariadis and Stachurski (2006) for an in-depth treatment, and entry on “Poverty Traps,” *The New Palgrave*.

Similar arguments may be developed in order to understand persistence in the inequality of the distribution of wealth within an economy. Matsuyama (2006) presents a model of emergent class structure, in which a society inhabited by inherently identical households may, depending upon parameter values, be endogenously split into the rich bourgeoisie and the poor proletariat. For some parameter values, the model has no steady state where all households remain equally wealthy. The model predicts emergent class structure or the rise of class societies. Even if every household starts with the same amount of wealth, the society will experience “symmetry-breaking” and will be polarized into two classes in steady state, where the rich maintain a high level of wealth partly due to the presence of the poor, who have no choice but to work for the rich at a wage rate strictly lower than the ”fair” value of labor.

It is worth noting that similar modeling tools may be used to express Adam Smith’s famous dictum that “the division of labor is limited by the extent of the market” and thus endogenize specialization [Weitzman (1994)]. The division of labor emerges as individuals in an economy acquire specialized roles.

6 Emergent Structures in International Economics: Autarky, Specialization, and International Currencies

Krugman (1995) and Matsuyama (1995) discuss how a world economy where all countries are initially identical and live in autarky (a “symmetric” outcome) leads to a world that is separated into rich and poor regions, once countries engage in international trade. International trade *causes* specialization and agglomeration of different economic activities in different regions of the world to emerge, with some countries being rich and others poor. In several similarly motivated papers [see, in particular,
Matsuyama (2004; 2006) Matsuyama shows the effects of financial market globalization on the cross-country pattern of development in the world economy. In the absence of the international financial market, the world economy converges to the symmetric steady state, and the cross-country difference disappears in the long run. Financial market globalization causes the instability of the symmetric steady state and generates stable asymmetric steady states, in which the world economy is polarized into the rich and the poor. The world output is smaller, the rich are richer and the poor are poorer in these asymmetric steady states than in the (unstable) symmetric steady state. The model thus demonstrates the possibility that financial market globalization may cause, or at least magnify, inequality among nations, and that the international financial market is a mechanism through which some countries become rich at the expense of others. Furthermore, the poor countries cannot jointly escape from the poverty trap by merely cutting their links to the rich. Nor would foreign aid from the rich to the poor eliminate inequality; as in a game of musical chairs, some countries must be excluded from being rich.

Especially at times of political and economic upheavals, many different national currencies may circulate simultaneously within and across countries. From a modeling viewpoint, such circumstances fit neatly multiplicity of equilibria. Emergence of a particular currency as an international currency, which in turn depends on the degree of economic and financial integration, may be more of a decentralized phenomenon than the emergence and establishment of a national currency [Matsuyama et al. (1993)]. To start with, a national currency is typically fiat money, whose use is decreed although not necessarily ensured. World monetary history suggests that a bewildering variety of commodities have served as medium of exchange, unit of account and store of value and may have coexisted at times of financial uncertainties. It has been known at least since Menger (1892) that fiat money comes to dominate other options, thus leading to establishment of monetary equilibria, because individuals accept fiat money in trade when it is convenient and they trust that others will do the same. Such an outcome may be fragile, when trust in the currency is weakened, especially in time of war and other upheavals. Howitt and Clower (2000) employ “rules” concerning transactor behavior (instead of relying on a priori principles of equilibrium and rationality) to show
computationally commodity “money” as a possible emergent property of interactions between gain-seeking transactors who are unaware of any system-wide consequences of their own actions. Similar is the emergence of standards in new industries described by many writers.

7 Concluding Remarks

The scientific literature, along with popular science literature, on emergence has sought to explain the emergence of persistent patterns as outcomes of dynamic interactions between individuals, groups of individuals and other entities. Such emergence is typically intrinsic to specific nonlinear dynamic processes and represents learning. Not all possible outcomes may be sustained at equilibrium, and economic and political structures emerge as a result of self-organization. Future research needs to go beyond evolutionary thinking and also deal with emergence in the context of purposeful action by forward-looking agents, as opposed to social outcomes of decentralized interactions of many agents.

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8 Bibliography


Figure 1: Neighborhood Tipping, Poverty Traps