Abstract: Symmetry-breaking creates asymmetric outcomes in the symmetric environment. It is the key concept for understanding self-organized pattern formations in natural sciences as well as in economics. We explain the logic of symmetry-breaking, some methodological issues, and discuss applications to urban and regional economics, international economics, growth and development, economic fluctuations, occupational choices, etc.

Symmetry-Breaking

Symmetry-breaking creates asymmetric outcomes in the symmetric environment. It is the key concept for understanding self-organized (a.k.a. endogenous) pattern formations. For example, cosmologists wonder why the matter in the universe is distributed in clusters, leaving much of the universe empty. Earth scientists study the formation of wave patterns, such as jet streams, ocean currents, and continental drifts. Material scientists study phase transitions, how molecules aligned themselves when they reach the critical temperature. Molecular biologists ask how life began in the primordial soup of amino acids, and developmental biologists attempt to explain how living organisms acquire forms through cell division and morphogenesis (Weyl 1969, Prigogine 1980). Similar questions of pattern formations also exist in economics. Why are there rich and poor countries? Why are industries clustered? Why are there booms and recessions? Why are some ethnic groups underrepresented in certain jobs or neighborhoods?

A simple model can illustrate the role of symmetry-breaking in self-organized pattern formations. Consider an economy with two inherently identical regions. Each region has an equal amount of an immobile factor, say land or labor. In addition, there is a single mobile factor, capital, whose allocation is measured along the horizontal axis in Figure 1. Two curves show how the rates of return to capital in the two regions changes with the allocation of capital. To the extent that capital has to compete for the use of the immobile factor, the rate of return to capital in one region declines as more capital is allocated to that region. Because the two regions are inherently identical, the two curves are symmetric around the midpoint. When capital is allocated evenly, the rates of return in the two regions are equalized, and hence this is an equilibrium allocation. Furthermore, this allocation is stable: if capital is allocated unevenly, the region with less capital offers a higher rate of return and hence attracts capital from the other region, and the resulting capital flow would restore the equilibrium allocation. Thus, the "centrifugal forces" of the resource constraint prevent one region from attracting more capital than the other.

Now let us add some agglomeration economies, so that the productivity of capital can be enhanced by concentration. If the "centripetal forces" of agglomeration economies dominate the "centrifugal forces" of the resource constraint, the rate of return in one region may increase as more capital is allocated to that region, at least over a certain range (Figure 2). The model now has two stable equilibria and both imply uneven spatial allocations of capital. The even allocation of capital is still an equilibrium but unstable. If slightly more than half of capital is allocated in one region, due to some small historical accidents, the rate of return becomes higher there and hence more capital flows from the other region. Once this process gets started, it would feed on itself, and the allocation of capital would be further away from the equal division. One region emerges as the developed core, and the other is left behind as the underdeveloped periphery. The model does not say which of the two asymmetric outcomes would emerge, but it does say that the observed outcome has to be asymmetric. Thus, the loss of stability of the symmetric outcome, "symmetry-breaking," generates the formation of the core-periphery patterns.

What separates the two situations depicted in Figures 1 and 2 is the relative magnitude of the centripetal to centrifugal forces, which may in turn be determined by a certain parameter of the model, say, λ. Figure 3 schematically traces out how stable outcomes might change as λ increases. For $\lambda < \lambda_c$, there is a unique stable outcome, which is symmetric; no spatial asymmetry appears. As it reaches to a critical value of the parameter, λ_c, the balance between the two forces are tipped, at which point, there will be an abrupt change. For $\lambda > \lambda_c$, there are two stable asymmetric outcomes (shown by the solid branches of the curve) and the symmetric outcome becomes unstable (as indicated by the dashed line). So, as λ exceeds its critical value, patterns are formed. Figure 3 shows that the rate at which a stable asymmetric outcome responds to a change in λ is arbitrarily large above the critical value. This is a fairly generic feature of models in which two competing forces are at work. At the onset of pattern formation, even a small change in the environment can be amplified to create a large effect.

Some physical analogies may be apt here. If you heat water at atmospheric pressure, nothing drastic happens until it reaches 100^{o}C, when it suddenly starts boiling. If you lower the temperature, it suddenly turns into ice at 0^{o}C. Such abrupt changes in the phase of matter are the results of a competition between the attractive intermolecular forces, which tend to order the system, and the individual kinetic energies of the molecules, which have the opposite effect. In a liquid phase, the random motion of water molecules is too violent for intermolecular interaction to hold them in place. Increasing the pressure, which favors the intermolecular forces, or reducing the temperature, which reduces the kinetic energies of the molecules, would eventually tip the balances between the two. Once the critical point is crossed, the attractive forces will be strong enough to keep molecules firmly in place and the crystal structure of ice will be developed. Many similar examples exist in nature. At room temperature, iron can be magnetized, but when it is heated above the Curie point, it loses its ferromagnetic property. Another example would be superconductivity, in which electronic resistance disappears discontinuously at the critical temperature.

Symmetry-breaking aims to explain the formation of the patterns, or the structure. In contrast, most economic analysis treats the structure of the economy as given, which can be a useful shortcut for many purposes. For example, if we are just interested in constructing a model consistent with the observed patterns, we could just assert that the regions are not similar and that some regions have more capital and produce more outputs, simply because they have better technologies. Although most economists might accept this as "an explanation," it merely raises another question in the mind of many. Why are some regions more productive than others? To this, one might say, because the market works more efficiently in some regions than in others, or because people in some regions are more diligent, or because people in other regions lack entrepreneurial spirits, etc, which would raise yet another question. As long as we try to explain spatial variations in one variable by introducing spatial variations in another variable, there may be no end in this process. The logic of symmetry-breaking does not require any exogenous source of variations, because of the circular causation. In the case of Figure 2, not only a better technology attracts more capital, but more capital leads to a better technology, due to agglomeration economies. Such a two-way causality can cause the instability of the symmetric outcome, which leads to the formation of the core-periphery patterns. In other words, symmetry-breaking explains such variations purely as an outcome of the internal mechanisms of the system, i.e., in a self-organized manner.

This is not to say that some exogenous sources of variations, such as the climate and geography, are unimportant factors in explaining the pattern formations. Rather, the central message of symmetry-breaking is that such exogenous variations do not have to be large; even small exogenous variations can be amplified to generate large variations. In short, a small cause can create a big effect. Once pointed out, this may seem obvious. Yet, some economists may look for a big change in the environment when trying to explain a big movement of a certain economic variable. But, the logic of symmetry-breaking suggests that their effort might very well turn out to be futile. Or when somebody proposes a hypothesis that the difference in X is due to the difference in Y, one often hear the criticism that the difference in Y is too small to have caused the difference in X. But the logic of symmetry-breaking suggests that such a criticism may be unwarranted.

The logic of symmetry-breaking has always been central in the urban and regional economics; see Fujita, Krugman and Venables (1999) for a recent treatment. Symmetry-breaking also gives us a fresh perspective on many familiar questions in other areas of economics. In international trade, the patterns of comparative advantage are linked to the cross-country difference in productivity, but the sources of the productivity difference are often left unexplained. If productivity improves through accumulation of the experience, there will be a two-way causality between trade and technology (Krugman 1987; Lucas 1988; Matsuyama 1992a; see Grossman and Helpman 1995 for a survey). In the presence of such a two-way causality, much of the observed patterns of trade can arise endogenously due to the cumulative effects of small historical accidents.

In the growth and development literature, the cross-country differences in per capita income are often attributed to the difference in Total Factor Productivity or the difference in the investment distortions, but these differences are often left unexplained. But, lower productivity or higher distortions may not only be a cause of the low income, but also the low income may be a cause for lower productivity or higher distortions. With such a two-way causality, the cross-border movement of goods, as in Krugman and Venables (1995) and Matsuyama (1996, 1999a), or capital, as in Boyd and Smith (1997) and Matsuyama (2004), amplify small inherent differences across the countries, which make the balanced development (the spatial symmetry) unstable, and the world economy may inevitably evolve into the system of the rich and the poor, where the countries are split into the developed core, characterized by high income, high TFP, low investment distortions, and the underdeveloped periphery, characterized by low income, low TFP, high investment distortions. If so, the problem of an underdeveloped country cannot be looked at in isolation; instead, it has to be examined as a part of the interrelated whole, because the rich may be rich in part due to the presence of the poor and the poor may be poor in part due to the presence of the rich.

Likewise, inequality within the society and the class structure might appear endogenously, even if people were identical in every conceivable dimension, which suggests the unattainability of a classless society; Freeman (1996), Matsuyama (2000, 2001). See also Francois (1998) and Burdett and Wright (1998), which suggests that the outcome, in which the two sexes are treated equally, may be unstable.

In macroeconomics, booms and recessions are often attributed to fluctuating TFP, and yet why TFP fluctuate are often left unexplained. Endogenizing TFP, either through innovation, as in Aghion and Howitt (1992) and Matsuyama (1999b), or through distorted allocation of the credit, as in Azariadis and Smith (1998) and Matsuyama (2004, 2005), could cause the instability of the stationary path (the temporal symmetry), which generates temporal patterns of booms and recessions, along which it appears that fluctuations are driven by the movements of TFP.

In residential choices, symmetry-breaking forces us to ask why an integrated or mixed neighborhood is difficult to sustain; see Schelling (1978), Miyao (1978), and Benabou (1993). And why are certain ethic groups overrepresented or underrepresented in certain jobs? The standard model of occupational choices in labor economics would suggest that there are large innate differences in skills across ethnic groups. The logic of symmetry-breaking suggests that, if the informational externalities in the process of skill acquisition or job search are greater within the same ethnic group, even small initial differences in skill distributions or some historical accidents may end up sorting different ethnic groups into different occupations. Or think of the problem of comparative economic systems. One might be tempted to attribute the differences in the labor market practices or the financial system across countries to the differences in the regulations or in the national cultures. However, symmetry-breaking suggests an alternative view. Due to some institutional complementarities across different practices and across different firms, either most firms in a country would adopt these practices, or else, very few firms would adopt them. Only some historical accidents happen to make them more prevalent in some countries than in others. Furthermore, the diversity of such national economic systems may be an inevitably feature of the integrated world (Aoki 2001). Finally, but not the least, spatial and temporal variations in social behavior, such as fashion cycles (Matsuyama 1992b), may also be better understood through the lens of symmetry-breaking.

For further discussions on the methodological issues on symmetry-breaking, circular causation, and multiple equilibria, see Matsuyama (1995a, 1995b, 1997, 2002).

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Figure 1

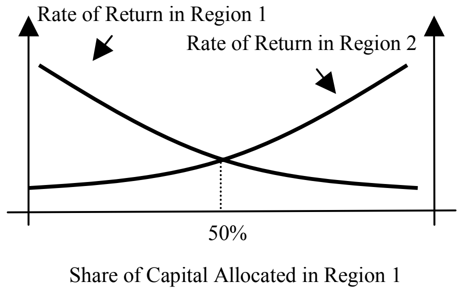

Figure 2

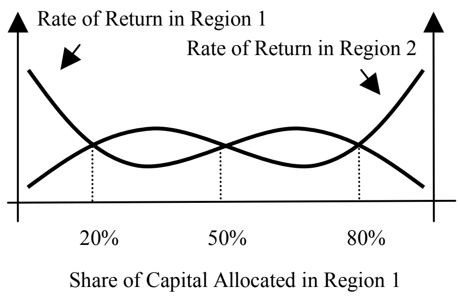

Figure 3