6 From a Natural Science Perspective

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Why are global issues difficult to contend with?

Vital economic growth is occurring in developing countries that have experienced the economic influence of globalization. On the other hand, a number of global issues have become evident, including the unremitting economic crisis, finite natural resources and energy and climate change. In these global issues, a variety of factors examined by both the social and natural sciences are intertwined in a complex manner. However, solutions to global problems elude us due to the lack of methodological frameworks that integrate the social and natural sciences. In this chapter, I discuss the current state of research on the integration of the social and natural sciences.

Link between natural and social sciences

The natural sciences have developed by dividing objects into relatively simple elements and analyzing these to understand the properties of the objects based on Descartes' theory of reductionism (Descartes 2008 [1637]). Science unveils interesting phenomena and the underlying mechanisms, and consequently our society and lives have undergone dramatic changes that would have been impossible to imagine 400 years ago. Below I attempt to reconstruct our universe using the various elements of knowledge clarified through the sciences.

Basically, as shown in Figure 6.1, our universe has a hierarchical structure. Science on a smaller scale has been conceptualized as providing the foundations of science on a larger scale. For instance, the physics of elementary particles and nuclei, specifically quantum mechanics and thermodynamics, provides the foundations of chemistry, where the properties of organic and inorganic molecules are studied microscopically. Subsequently, chemistry provides the

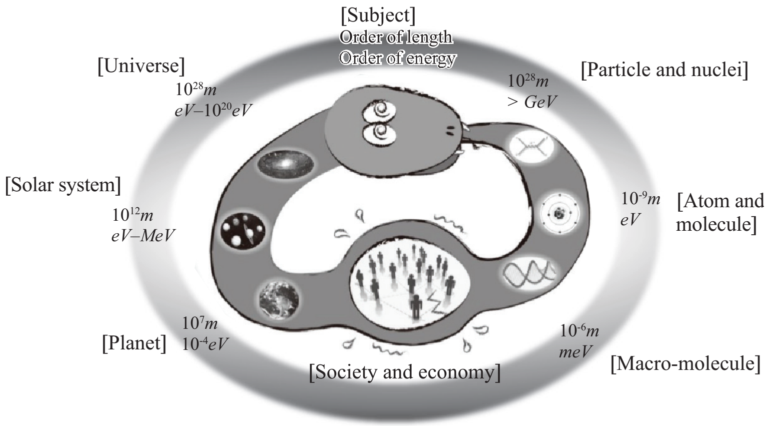

Figure 6.1: Hierarchical structure of the universe

foundations of biology and life science in terms of the study of macro-molecules such as DNA and protein, and their interactions. Next, biology explains aspects of the Earth's natural environment. The foundations of geoscience depend on knowledge of ecosystems and the structural properties of planets. Finally, geoscience explains the planets in solar systems. However, we have singularity here. Which science explains the properties of stars, e.g. the Sun, and of the aggregation of stars, i.e. galaxies? Particle and nuclear physics again plays the crucial role. Knowledge of the physics of elementary particles and nuclei is indispensable for understanding the evolution of the early universe and how stars are born and die. This situation is depicted as a snake eating its own tail, referred to as the Cosmic Uroboros.

Frankly speaking, the abdominal part of the snake that corresponds to society makes me uneasy. The snake has swallowed an egg protected by a hard shell, and is suffering serious digestive problems. I presume that some aspects of society could be the subjects of natural sciences, because society is an aggregation of living matter. However, the science that studies 'society' is entirely categorized under the social sciences today. Consequently, there is almost no research regarding the relationship between the natural and social sciences.

Now, turning to the social sciences, this domain developed very differently to the process undertaken by the natural sciences. It is often said that this difference is mainly due to the fact that precise experiments cannot be carried out using a social science approach. However, similar disciplines exist in the natural sciences, such as meteorology and astronomy, where, like many of the social sciences, only observation is possible. In particular, astronomers have sought to understand their observation of stars by conducting laboratory experiments, e.g. spectroscopy, on matters involving stars, and do not leave their observation results to speak for themselves (Hubble 1936). It is therefore hardly convincing to say that the social sciences are completely different from the natural sciences because of their difficulty in conducting precise experiments.

On the other hand, from the middle of the twentieth century a trend has emerged in academia that seeks to overcome barriers that divide specific academic fields in the process of expanding the scope of research of various sciences. The first signs of this trend were a theory for discussing the formation of living organisms using negative entropy, i.e. the emission of entropy outside a system (Schrödinger 2012 [1944]), game theory to explain the rational and deductive aspects of human decision-making (Neumann 2007 [1944]) and cybernetics to attempt to establish a general theory of control in nature, biological systems and society (Wiener 1965 [1948]). In the aftermath of these pioneering efforts, nonlinear phenomena called ‘chaos’ characterized by sensitive dependence on initial conditions, strange attractors and self-similarity were found in a variety of hierarchical layers of the universe. The existence of chaos is considered to be the strongest evidence of the breakdown of reductionism. At the same time, the mechanisms of pattern formation due to entropy decrease in a partial system in a state of non-equilibrium were clarified by studies of dissipative structure (Prigogine 1977) and self-organization and synergetics (Haken 1977). Subsequently, the study of non-linear and non-equilibrium systems evolved to complex systems and complex adaptive systems (Holland 1996; Gell-Mann 1995 [1994]), and game theory transitioned to bounded rationality and inductive reasoning (Simon 1996 [1969]; Arthur 1994). Today, a quiet revolution seeking to overcome academic barriers and cross the boundaries of specific fields is progressing through the development of a new strong perspective of complex networks (Watts 1998; Barabasi 2003). However, the current state of play cannot be deemed satisfactory. In the following sections, I explain the germination of Human Survivability Studies (HSS) in terms of the economy and energy.

Econophysics as a prototype of HSS

Establishing ways of overcoming the academic barriers between the natural and social sciences is an orthodox methodology in HSS. Here, we first consider a conventional methodology in the field of economics.

Economics is a social science that can describe economic equilibrium. Economics assumes that economic systems are at equilibrium as a final state after undergoing fluctuations, without knowing whether or not this is the actual case. We know that our economy is constantly fluctuating. Accordingly, it is possible that our economy is far from being in a state of equilibrium, even if it tends toward that state. In addition to this unrealistic assumption, economic theory is basically described by linear equations. However, in reality numerous factors are involved in the economy, and it is necessary to consider the multiplicative relations between these factors. Thus, a basic theory of economy is necessarily non-linear. From this simple consideration, we must note the possibility that the actual economy is non-linear and in a state of non-equilibrium, although economics is a non-linear theory for the state of equilibrium. For this difficulty in economics, we can examine the economy through a different lens. Econophysics is a field of non-linear physics that studies the collective motions inherent in various complex systems using statistical physics, complex networks and agent models. In econophysics, data analysis plays an important role, so it can be positioned as the beginning of data science or big data analysis. More specifically, econophysics is a prototype of HSS.

The economy grows via business cycles. For example, the growth rate of GDP or the index of production shows temporal change repeating positive and negative growth periods over a cycle of several years. This temporal change is a business cycle that occurs due to inventory adjustment. If we take an average of the growth rate of GDP or the index of production for a period involving more than a few cycles, we obtain a positive value. This is the rate of economic growth, and its typical value is a few % for developed countries and 5–10% for emerging countries. We will study business cycles in this section and economic growth in the next.

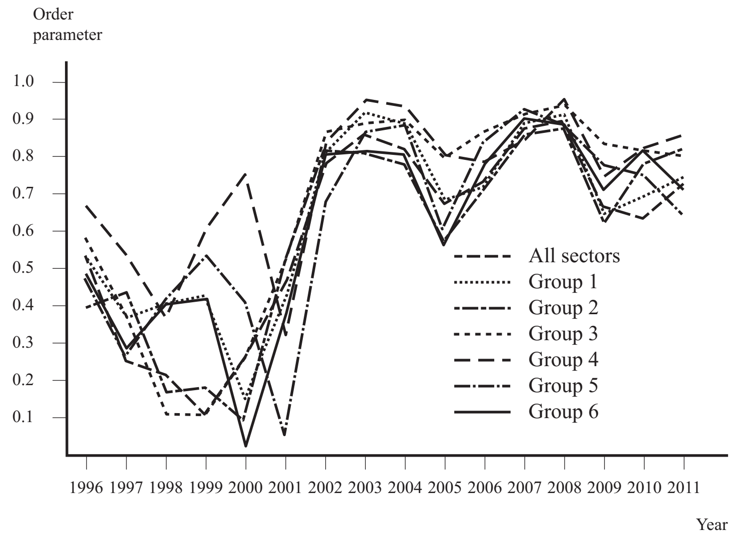

Figure 6.2: Synchronization of the international business cycle

There are various types of business cycles, but the clearest and shortest is that due to inventory adjustment. In the Japanese economy, there are a variety of industrial sectors: the mining, precision machinery, transportation equipment, chemical, electric machinery, construction, wholesale and retail industries. The cycle periods are almost the same, i.e. around four years, for each sector. The question is whether the phase of the business cycle of each industry is coherent or randomly distributed. If we turn our attention to the global economy, we notice that since the early twenty-first century, the industrial structure has changed from a domestically and vertically integrated form to a globally and horizontally distributed one. Consequently, international trade is vitalized toward the regional free-trade zone. How is the relationship between the various industries' business cycle phases affected by this change in circumstances?

Speaking of periodic movement, we recall an oscillator in the natural sciences. The curious collective motion in an oscillator system is known as Huygens' pendulum clock (Huygens 1986 [1673]). Here, two less accurate pendulum clocks hanging on two different columns will show a gradually increasing time difference, but hanging on the same joist, the two clocks will show the same time in perpetuity. This collective motion is due to the interaction through the joist, and is called synchronization. Synchronization is a collective motion where an oscillator system with interaction that is stronger than a certain threshold has a coherent phase, and it is mathematically modeled by the Kuramoto oscillator (Kuramoto 2003 [1984]). It is not easy to imagine the connection between pendulum clocks and business cycles. In fact, it might be confusing to learn that the common point is not an allegory but an essential mechanism of the temporal evolution of the system. How common is an economy in which well-educated people work using their intellects that can be compared to a mind-less pendulum clock? This is a question of degree.

I have studied the synchronization in the international business cycle using the value-added time series of 1,435 industries (thirty-five industries in forty-one countries) and trade dates between these for the last sixteen years. If we assume that the business cycle phase is incoherent, an economic shock will propagate rapidly through the industries. We know empirically that an economic shock that occurs in a certain country is immediately propagated to the rest of the world. For instance, the global economic crisis initiated by subprime mortgage defaults in 2007 and the subsequent bankruptcy of a major investment bank affected by the devaluation of mortgage-backed securities and collateralized debt obligations in 2008 is still fresh in our minds. Does this empirical fact suggest the synchronization of the international business cycle?

The industrial sectors of countries with a large volume of trade are identified through the complex network analysis of international trade. Three stable groups that experienced a high volume of trade between 1996 and 2011 are presented in Figure 6.2. I extracted a phase time series from the Hilbert transform of value-added time series of each industrial sector, and calculated the temporal change of the order parameter of the phase time series. The order parameter is an index that shows the degree of synchronization varying between zero and one, with a larger value indicating a higher degree of synchronization. Figure 6.2 shows that the degree of synchronization is considerably low. Until 1999, the order parameter for each group was about 0.3, which means sectors in each group were weakly synchronized, but there was almost no synchronization across the sectors. In the 2000s, the order parameters increased up to the range of 0.7 to 0.8 for each group in all industrial sectors, although the order parameters in 2005 and 2009 were relatively low. This is evidence of the synchronization of international trade. We know that the amount of international trade has increased monotonically since the 1990s. The volume of trade exceeded a certain threshold in the early 2000s, and consequently the synchronization of the international business cycle emerged as an example of a social law beyond the free will of economic agents. Thus, to a certain degree the business cycle behaves like a pendulum clock, and if an economic shock were to occur in a particular country, its instantaneous propagation might be unavoidable.

Energy, entropy and economy

Economic growth is strongly correlated to energy consumption. Recently, the large-scale integration of renewable energy has been in progress mainly in advanced countries as a last resort for achieving greenhouse gas reduction. In this section, we discuss the effect of the large-scale integration of renewable energy on economic growth.

Electricity is perishable and difficult to store for long periods of time, and therefore supply and demand need to be balanced at each moment. Basically, electricity demand is determined by the total amount of production in the economy. We therefore need facility investment planning and operation planning to satisfy electricity demand for the healthy growth of the economy. Once the supply/demand balance is lost, the frequency of AC power deviates from the standard value. This frequency deviation not only affects the operation of production facilities on the demand side, but can result in nationwide blackouts.

The outputs of renewable energy generation such as solar photovoltaic generation and wind power generation fluctuate depending on changes in the weather in addition to daily and seasonal changes. For this reason, utility companies are not capable of controlling output from their load-dispatching centers. Controlling the output of thermal power plants to absorb the output fluctuations of renewable energy in order to achieve a supply/demand balance is called 'grid integration'. Today, a variety of energy policies have been designed to increase the share of renewable energy integrated into the power grid. However, the increase will be a major factor in breaking the supply/demand balance and will decrease the share of thermal power plants, which play a key role in the supply/demand adjustment in today's power grid. The rise of renewable energy will

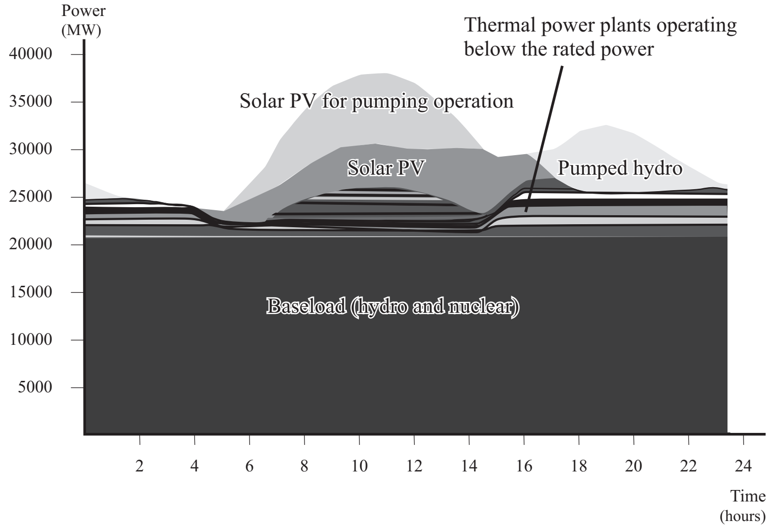

Figure 6.3: Supply/demand balance for the large-scale integration of renewable energy

consequently be a major factor in decreasing the balancing power of thermal power in terms of the supply/demand adjustment. In fact, a variety of issues have been raised in Europe regarding the integration of wind power generation on a scale of several MW.

Figure 6.3 shows the estimated daily supply/demand balance in the Kanto area (Tokyo and the six neighboring prefectures) in 2020 by considering the fluctuation of renewable energies. The portion of the stripe pattern above the baseload depicts the fact that many thermal power plants are operating far below their rated power in preparation for a rapid decrease in output from solar photovoltaic generation. When the share of solar photovoltaic generation increases to about 20%, wide-area operation occurs by enhancing transmission lines and curtailing the excess output from this source. Furthermore, if we want to integrate more than a 20% share of renewable energy, institutional design that maintains a sufficient level at the thermal power plant to balance the supply/demand adjustment will be required, in addition to demand response equipment and energy storage devices. However, it is concerning that the lack of capacity of the thermal power plants will gradually become evident, because no company invests in facilities that operate once a year, even as existing thermal plants grow older.

Let's consider the relationship between renewable energy such as solar and wind power in terms of entropy. Economic activity is undertaken by producing goods with the input of energy and resources (materials) and by trading goods that are transported to areas of consumption, and finally by emitting industrial waste, air pollution and greenhouse gas. During the transportation of goods, greenhouse gas is emitted. In this manner, the economy is an open system and is in a state of non-equilibrium as a result. The economic system will decrease the entropy within the system by placing materials with small entropy and energy into the system and materials with large entropy outside the system in the same way as living matter. Releasing materials with large entropy outside of the system corresponds to the destruction of the environment, and the accumulative decrease of entropy inside the system corresponds to wealth accumulation, i.e. economic growth.

In general, it is well known that the temporal development of a non-equilibrium system proceeds in order to maximize the entropy production rate, and this is called the principle of maximum entropy production (Sawada 1981). Here, let's assume that we can apply the principle to the economy and discuss economic growth. For the sake of simplicity, we restrict input energy to only two kinds: conventional fossil fuels such as coal, oil and natural gas, and renewable energy as described above.

Solar insolation as an example of renewable energy is widely distributed as an energy density of as low as 1 kW/m^2 on the surface of the ground. This means that the entropy of solar insolation is larger than that of fossil fuel. Accordingly, the usage of fossil fuel is selected based on the principle of maximum entropy production, and the emission of entropy due to economic activity to the outside of the system is maximized.

However, the emission of entropy outside the system results in a decrease in economic activity, introducing renewable energy by policy instead of fossil fuel. Consequently, economic growth slows down by necessity due to the decrease of the entropy reduction inside the system. For this reason, the upper limit of the share of renewable energy is limited by social laws beyond free will, if we set economic growth as a policy target. This is similar to the case of the synchronization of the business cycle. However, we must point out that the integration of renewable energy increases energy security. It is up to each country to choose economic growth or energy security.

Meta-analysis to urgently establish an orthodox method

It takes a long time to establish an orthodox method to overcome the academic barriers between the natural and social sciences. Many believe that global issues are pressing concerns, and that we do not have time to wait for the establishment of convention. Here, I propose an alternative method whereby global issues are tackled by focusing on best practices published in academic papers and reports from international organizations instead of clarifying the relationship between the natural and social sciences theoretically. I assume here that it is possible to extract a methodology (or point towards it at least) to integrate the natural and social sciences by conducting a meta-analysis using academic papers and reports from international organizations. The meta-analysis used in this chapter is a method of text mining to extract the relationships between keywords related to global issues and academic concepts using complex network analysis. I refer to the keywords as ‘nodes’ in accordance with the usage in network science.

In this section, I outline a case for analyzing research reports written about citizens’ understandings of and responses to climate change. This is a typical global issue in which the natural and social sciences are intertwined. A research report consists of a large number of sentences. I extract the nouns as the keywords in each sentence in the report and link them. The attributes of the keywords are provided by a dictionary prepared in advance. I then complete a network consisting of academic concepts as nodes by contracting the nodes without mentioning the attributes in the dictionary.

This academic concept network is a complex network for which the probability distribution of degree (the number of links from each node) is in accordance with the power-law distribution, located in the abdomen of the snake in Figure 6.1. The links from each node are not connected uniformly to the rest of the nodes, but to a specific group of nodes. As a result, the network forms several groups of nodes densely interlinked inside the group, which is called a ‘community’. The academic concept network is shown in Figure 6.4 by coloring the communities in green, red and blue in descending order of the number of nodes in each community. The

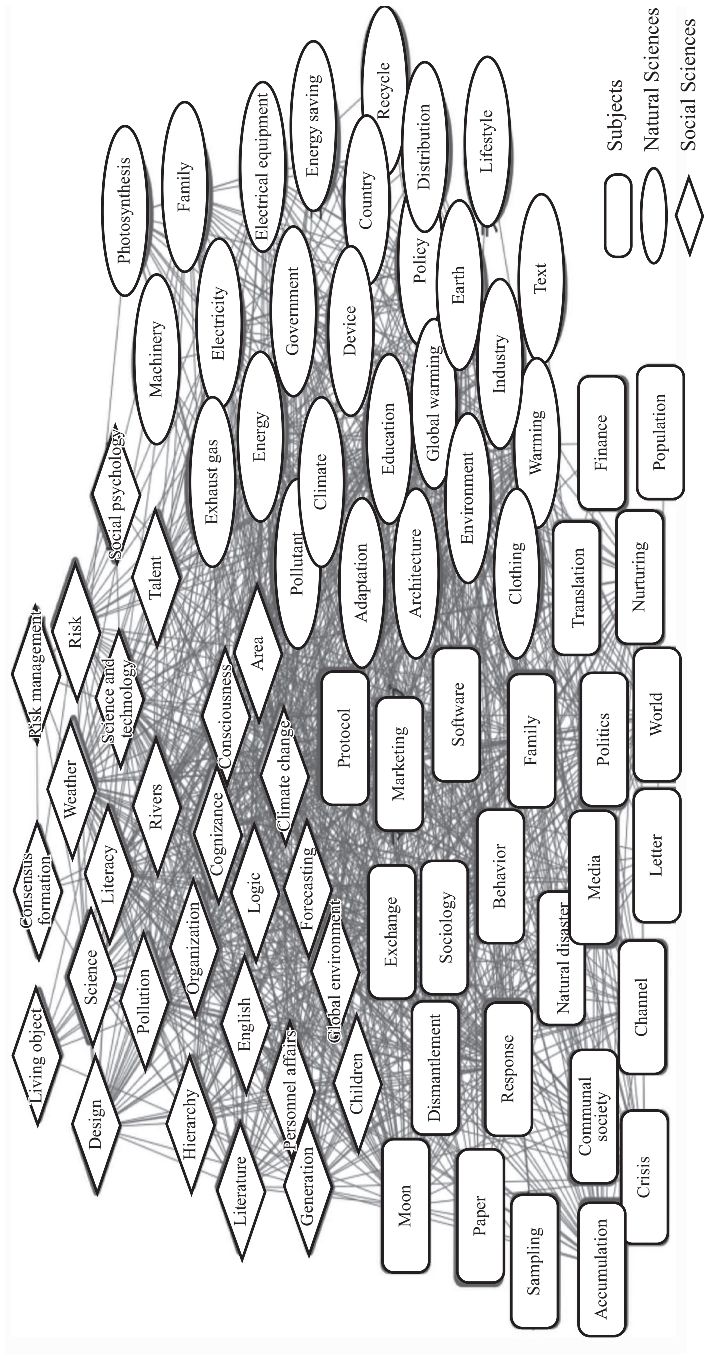

Figure 6.4: Identification of community structure to show the relationship between the social and natural sciences

blue community mainly includes the subjects of academic study. The red community primarily includes academic concepts within the natural sciences and engineering, such as aquatic science, earth and planetary science, environmental studies, resources system engineering and architecture. Finally, the green community includes academic concepts within the social sciences and health science, such as psychology, science education, educational engineering, human information science, nursing and social medicine.

In this manner, it was clarified that natural and social science concepts are used in the study of citizens' understandings of and responses to climate change. We therefore expect that we will obtain hints for the integration of the social and natural sciences through a detailed study of the relationships between the keywords of academic concepts and those of the subjects of academic study using a large amount of research publications.

Current perspective

A recent controversial book explained that the economic disparity between those with a large amount of capital and those without capital increases as the economy grows, because the growth rate of wages is almost on par with economic growth, and the return of capital is higher than that of economic growth (Piketty 2014). The most interesting aspect of the book was the proposal to progressively tax capital as a measure to reduce economic disparity. The rate of economic growth of advanced countries has already reached a low level, and the growth rate of emerging countries will decrease during their economic growth. If progressive taxation is introduced to target the reduction of economic disparity, competition between economic agents will be lost and economic growth will slow as a consequence.

On the other hand, I explained above that economic growth will decelerate through the introduction of renewable energy to replace fossil fuel due to the decrease in the emission of entropy outside the system. From a global perspective, the point of controversy is the extent to which measures for the reduction of greenhouse gases are introduced in advanced or emerging countries at which stage of economic growth. Emerging countries refuse to introduce measures for the reduction of greenhouse gases because it will slow their economies down. Conversely, emerging countries want to use the latest technology introduced as a result of investments or aid from advanced countries to achieve greater economic growth with relatively small levels of greenhouse gas emissions. It has been pointed out that their attitude is logically inconsistent.

Technological and social innovations may continue far into the future, but there are no more economic frontiers due to the development of a global economy. In the future, if the economic growth of all countries converges to a low level, consequently, after sufficient economic growth, the global economy may reach a state of equilibrium, i.e. the fate of economic growth. It is an act of extreme curiosity to ask whether or not we move toward the fate of economic growth and how to reach a state of equilibrium. This is somewhat analogous to the fate of the universe in cosmology. As explained above, our society cannot be determined entirely by our free will, and part of it is determined by social laws beyond our free will. Social sciences such as economics magnify the former aspect, and natural sciences such as econophysics highlight the latter. In the study of human survivability, we need to establish a methodology for integrating the social and natural sciences and conduct practical research aimed at finding solutions to global issues.