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Taking the pulse of urban economy: From the perspective of systems ecology

Xi Ji *
School of Economics, Peking University, Beijing 100871, PR China

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ABSTRACT

Pulsing paradigm is regarded general for all scales of ecosystem. The pulsing succession view insists that a resource-dependent system will approach its peak through intensive consumption of resources, then move towards recession and get ready for the next cycle. Urban economy, as an open and resource-dependent subsystem in the whole ecosystem may pulse, and its quantitative growth in physical scale will be limited by the finite ecosystem eventually. This raises one problem: what would be the future of urban economy when it gets to the physical climax under the ecological constraint? Modelling is a feasible approach to simulate and reveal the pulse of a large scale system whose wave length is too long for individuals to witness. In this study, systems ecology-modelling, as a combination of ecological modelling and theories of systems ecology, is applied to take the pulse of urban economy. Cosmic emergy is applied to synthesize the material, energy, information, currency and population flows and stocks, which greatly facilitates and simplifies the simulation. Taking Beijing city as a case, the systems ecology-modelling is carried out, and the pulses of Beijing's economy and its components are partly observed. Suggestions on urban management are proposed accordingly.

1. Introduction

The pulsing succession view insists that global economy, as a typical resource-dependent system, will reach its peak through intensive exploitation of natural resources accumulated in a long time, then move towards recession into a low consumption stage and getting ready for the next cycle (Odum, 1983a,b). This pulsing paradigm is depicted as Fig. 1, from which four main stages of the pulsing cycle can be recognized: (1) Sharp growth of the size of socioeconomic capital based on abundant available resources, with low-efficiency and high-competition; (2) Climax and transition, when the economy reaches the maximum size allowed by the available resources, the efficiency increases, collaborative competition pattern forms, and the information is stored for descent; (3) Descent, as a decrease in the quantitative size of socioeconomic capital but qualitative improvement with adaptations to less available resources; (4) Low resource restoration for a new cycle ahead, in this stage, socioeconomic capital reports no growth, and consumption of resources is smaller than its accumulation (Odum et al., 1995; Odum and Odum, 2001).

With the booming growth of urban economy, people are confronted with increasing ecological crises, such as the drastic decline of natural capital (natural resources inside cities) and the shrinkage of environmental capacities to carry waste emissions (Chen et al., 2006; Chen and Chen, 2006; Ji et al., 2014). As an open and resource-dependent subsystem in the whole ecosystem, the growth of urban economy as a quantitative increase in physical scale will be limited by the finite ecosystem over long periods of time (Daly, 1974, 1990, 1991, 1992). This raises the problems: would urban economy evolves with its pulse from a long time scale? what would be the future of urban economy when it gets to the physical climax under the ecological constraint? Therefore, taking the pulse of urban economy and adjusting its growth pace according to surrounding conditions are of great importance towards sustainable development. Urban economy is a large scale system, and modelling is hence necessary since it is almost impossible for individuals to witness the whole pulse cycle of the urban economy. Decision makers are supposed to alter the planning and management ideas in different pulsing stages and only by adjusting attitude and behaviour according to environmental pulse can we ensure the sustainable development of both the human economy and the environment. The modelling and simulation can safeguard decision makers a better understanding of the evolution mechanism of urban economy and the environment, as well as export a general idea of the current stage at which the urban economy works.

* Tel.: +86 10 62755283; fax: +86 10 62754237.
E-mail address: jixi@pku.edu.cn

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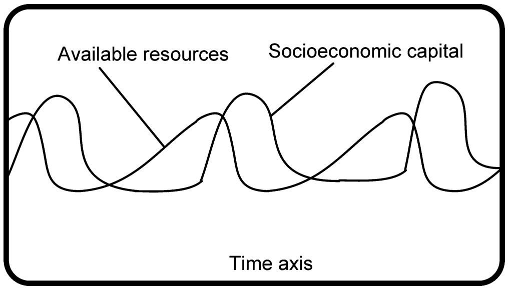

Fig. 1. The pulsing succession of global economy. (Referring to: Odum and Odum, 2001).

The method of ecological modelling is frequently used by planners and decision-makers for management and regulation. The idea of ecological modelling first came out in the 1920s when mathematical models such as Lotka and Volterra's competition and predation model (Lotka, 1922a,b; Volterra, 1926) and Verhust and Pearl's logistic growth model (Pearl and Reed, 1920; Sibly and Hone, 2002) were introduced into ecological fields. The 1970s witnessed the fast development of ecological modelling. The International Ecological Modelling Institute was founded and later became the academic frontier of its field, when ecological problems become unprecedentedly complicated, and the conflicts between human activities and the environment are more prominent (Ji and Chen, 2010). Thus, ecological models are more macroscopic in order to take human society into consideration (Ulgiati and Brown, 1998; Coulter, 2002; Jiang and Chen, 2011; Chen and Yang, 2013), and more and more decision makers are using ecological modelling to better their plans and lower the risks. Since the rapid urbanization challenges facing urban sustainable development all over the world, ecological modelling for urban strategic management has attracted keen interest from a lot of scholars and policy makers' interests (Yuan et al., 2008; Feng et al., 2013), and numerous studies have applied ecological modelling to reveal the metabolism of cities recently (Kennedy et al., 2007, 2011; Churkina, 2008; Chen and Chen, 2012, 2014; Chen et al., 2014).

However, with the development of ecological modelling, associated problems are raised, such as the subjectivity in parameter assessment and the lack of reliable models for either natural or socioeconomic system. Systems ecology brings novel ideas that are effective in building an ecological model. Ecological modelling founding on the theories of the perspective and the theories of systems ecology is entitled as systems ecology-modelling in this study, which is a dynamic integration of systems ecology and ecological modelling. Systems ecology as the application of system theory in ecology (Odum, 1971), mainly focuses on the inter-connection within an ecosystem and the performance of the entire system (Odum, 1971, 1983; Brown and Ulgiati, 2011). As one of the pioneers to study the operating mechanism of ecosystem with the aid of computers, Odum gradually set up a series of Macroscopic Mini-models in the basic framework of systems ecology, and these models are applied in several studies to realize a macroscopic forecasting (Huang, 1998; Huang and Chen, 2005; Jiang and Chen, 2011). This study would like to further strength the intrinsic laws of ecology and eco-thermodynamics embedded in these models, especially the maximum empower principle which is regarded widely existing in ecosystems (Odum, 1989; Odum and Odum, 1989; Kleidon, 2009a,b). Based on the maximum empower principle, the systems ecology-modelling is able to use the simplest method to highly integrate and generalize the dynamic mechanism of complex systems on a large scale. Such models aim at conceptualizing the development trend of a system rather than giving an accurate prediction (Odum, 1989), which is more feasible to get a general idea of the functional dynamic mechanism of a system. Compared with conventional ecological modelling, systems ecology-modelling follows the intrinsic designs and laws of ecosystem, and thus avoids complex explanation of mathematic methods, lowers the subjectivity and uncertainty rooted in the parameters assessment, and brings the model closer to reality (Kangas, 1995).

Urban economy emerges with complicated structure of diverse ecological stocks of natural resources, suburban agricultural capitals, urban centre capitals, population, as well as culture and information capitals, and various ecological flows of material, energy, currency, population, and information. The diversity of stocks and flows leaves the modelling of an urban economy great complexity and uncertainty. This study combines systems ecology-modelling and the theory of cosmic emergy to dissolve the complexity instigated by the diversity of ecological stocks and flows in urban economy. Cosmic emergy, as a combination of cosmic exergy and the existing solar emergy, is proposed by Chen (2005, 2006) to construct a biophysical evaluation paradigm from the perspective of systems ecology. Cosmic exergy is defined as the maximum work that the thermodynamic system of earth can perform when the thermodynamic equilibrium is achieved between solar radiation as a hot thermal reservoir and cosmic background as a cold thermal reservoir (Chen, 2005, 2006). Cosmic emergy as embodied cosmic exergy, refers to the cosmic exergy consumed directly or indirectly in making or sustaining a general product or service. The theory of cosmic emergy proves that cosmic exergy is the primary driving force of the earth system to revitalize the metrological system, feed the hydrological system, renovate the biosphere and make all other natural and anthropogenic phenomena possible (Chen, 2005, 2006).

As the real wealth of the ecosphere and the human society, cosmic exergy is proved scarce related to the scale of human activities (Ji, 2011). Being characterized universal, scarce and exclusive, cosmic exergy as the primary driving force of the biophysical world, is proved qualified as the fundamental metric of ecological stocks and flows, no matter those are natural and manmade. Therefore, the diverse ecological stocks and flows of material, energy, information, currency and population in urban economy are able to be integrated into cosmic emergy, which largely safeguards the briefness of the model and preserves the accurate information.

In the author's doctoral dissertation, cosmic emergy based ecological accounting and modelling are systematically discussed and applied in the evaluation of urban economy of Beijing (Ji, 2008), with the main results primarily reported in Chen et al. (2010). Based on the doctoral dissertation, the theory of cosmic exergy as the primary driving force of the biophysical world and as the fundamental metric of ecological value of both natural and man-made resources was discussed, and the method of cosmic emergy as an alternative to conventional monetary based accounting and evaluation of urban economy is illustrated in Ji (2011). To move a further step to those mentioned studies, this study brings more comprehensive views on the pulse paradigm, and aims at taking the pulse of urban economy by modelling. On the basis of the accounting results displayed in Ji (2011), the evolution trends of Beijing's economy and its component stocks of natural resources, agricultural capitals, urban capitals, population, as well as the culture and information capitals are simulated. Policy suggestions on the urban management of Beijing City are proposed accordingly.

The remainder of this paper will be structured as follows: part 2 illustrates the theoretical basis of the superiority of systems ecology-modelling which follows the intrinsic design and laws of ecosystem. Several systems ecology theories of autocatalysis feedback design, maximum power principle, pulsing paradigm and hierarchy are discussed and necessarily updated according to the theory of cosmic emergy. Then, part 3 takes Beijing City as a case to display how to get the pulse of an urban economy by systems

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