Learning Urban Resilience from a Social-Economic-Ecological System Perspective: a case study of Beijing from 1978-2015

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Abstract

After the People's Republic of China (PRC) established in 1949, central planners have made much efforts to greening the capital city, Beijing. However, with the increasing population and consumption in the city, the increasing environmental risks continually flow into the local social-economic-ecological system (SEES) through ecological intercorrelation from neighborhoods, so that the thresholds of risks challenge the urban resilience of Beijing and the surrounding area. Thereby, we analyze the 139 selected indicators to deeply understand the systematic risks across temporal scale during 1978-2015 in Beijing. Results show the development pathway of Beijing experienced three stages from "entrance", "soar" to "coursing". In the current new stage, the ecological impacts and resource use *per capita* are main constrains to future development in Beijing. This implies to a framework of urban growth for a demonstration pilot path of eco-urbanization in five aspects: 1) strategic clarification of the growth space; 2) design the urban growth path based on ecosystem planning with functional landscape architecture; 3) higher standards of industrial establishments with advanced environmental assessment and monitoring; 4) construction of environmental infrastructures with smart resource recycling; and 5) based on strict implementation of institutions and regulations to maximize the function of market allocation.

Key words: Beijing; Development; Eco-urbanization; Environmental indicator; Urban resilience

1 Introduction

In urban transformation, megacities are representatives that have social-ecological and social-technical networks nested into a social-economic system (Wilkinson, 2012; McGinnis & Ostrom, 2014). Urbanization in developed countries have already entered an advanced stage, but the natural environmental change still challenges urban resilience in social transformation. While, in populous developing countries such as China, Brazil, and India, the social production is structurally transforming to a higher productive level and aiming to lower the Greenhouse Gas (GHG) emission (Xie *et al*, 2014; Wang & Feng, 2015). Especially individuals and households' consumption behaviors become more influential to urban environment (Mi et al., 2017). This trend arouses the policy inclination of central planning to shrink the difference between rural and urban area and promoting the cohesion between economic development and environmental conservation. However, the key indicators of urban resilience are distinctive due to geographical diversity. As a complex system, an urban system in a transforming process encompasses both urban and peri-urban, or suburban area, and sprawling to rural area. Thereby, the definition of "urban" becomes the first line of the significance to discuss the urban resilience within administrative boundaries or environmental impact boundaries (Meerow, Newell & Stults, 2016). In this research, we discuss the urban resilience based on administrative boundaries. It allows the research intends to minimize negative spillover effects on neighborhoods across administrative boundaries and maximize positive spillover effects across chronological variation (Wang, Deng & Wong, 2016a; Wang et al., 2017c; 2017d). Then, we can identify the short boards of systematic risks for seeking efficient policies to improve the urban planning system.

Recent discussion of systematic analysis on an urban system in a sustainable manner starts from a global perspective to improve urban environment against from climate changes or saying climate variation. This has been stressed since the European Economic Community (EEC) announced the 6^{th} Environmental Action Programme (EAP) in 2001. Stakeholders have successively appealed advanced stricter legislations and regulations to large-scale landscape conservation planning for enhanced urban environmental quality in European Union (EU) countries during 2002-2012. The most ambitious strategy in EU spatial planning tried to model an advanced framework to support behavior-based individual choices for multi-targets of social, environmental, and economic development in a sustainable manner. Other strategic aspects in dealing with specific issues all towards urban environmental sustainability. Thereafter, the 7^{th} EAP has further addressed urban resilience response to climate challenges. Three main research objectives are natural capital, resource-use-efficiency, and environmental risks to human health. Besides these efficient implementations of regulations and investments, cities are in pressing needs to seek solutions for urban resilience based on regional characteristics.

Because geological features diversify large-scale spatial planning, ecological resilience is the baseline of urban resilience. Planners aim to build a healthier city. However, short term planning is not used to meet the demand of environmental capacity in long-term social-economic transformation. Bengtsson et al. (2003) proposed an approach of large-scale dynamic landscape planning based on the ideas of land use/cover changes for response to urban development to strengthen the resilience of regional environment reservation in a sustainable manner. They addressed ecological flows as key linkages to individual location choices in coordinated urban-rural development. Although climate change is arguable by varying in a long chronological climate history, urban resilience against natural hazards is necessary, particularly for those coastal regions and those regions influenced by oceanic climate. Brenkert & Malone (2005) proposed a conceptual framework to model regional sustainable resilience by using categorized indicator analysis approach. They compared the categorized sectors in sensitivity indicators with adaptation capacity indicators, and explored their gaps to conceptually define exposure, vulnerability, and resilience to climate changes. However, the long-term positive impacts of economic capacity were poorly positioned even if they stressed *per capita* GDP would be highly uncertain to alter the Greenhouse Gas (GHG) emission and other environmental indicators changes in the future.

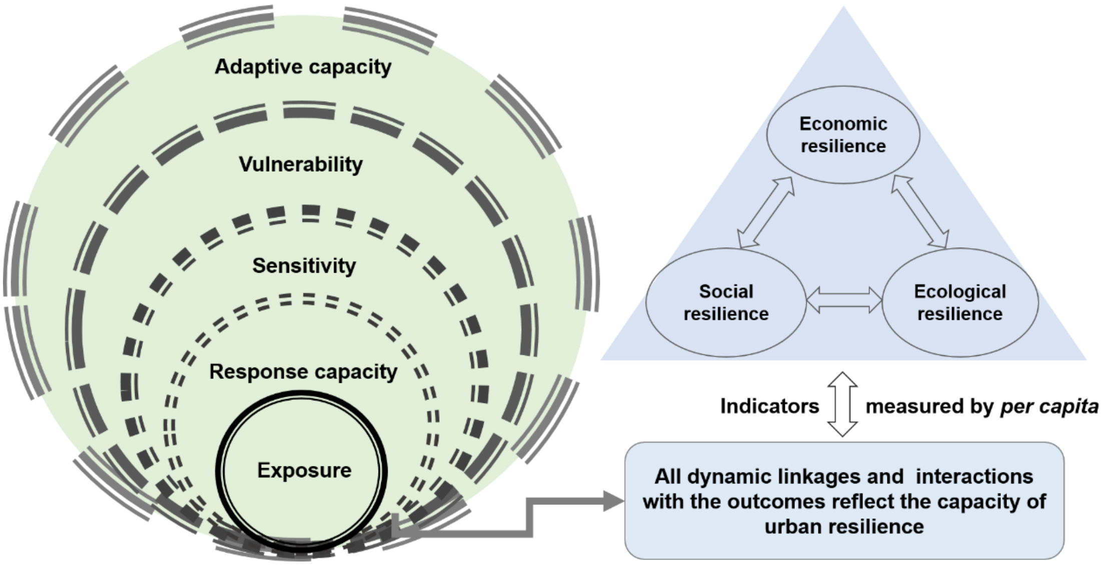

Figure 1. Conceptual interpretation of urban resilience

Economic growth is not always the main drive to negative environmental impacts on sustainable development. Instead, it is highly likely a positive driver even if environmental outcomes can be negative periodically or temporally. When personal income rises, higher advanced techniques can be applied to lower the economic losses of environmental degradation. In other words, relationships among resilience, adaptive capacity, and vulnerability are dynamically and relatively changing when economic capacity increases. By following Brenkert & Malone (2005), Gallopín (2006) further clarified the logic relationships among these concepts for performing the definition of resilience better. He proposed that the exposure should be sequentially included by the capacity of response, sensitivity, vulnerability, and adaptive capacity in an urban system. All dynamic linkages and interactions with the outcomes among these concepts reflect the capacity of resilience. It indicates that the higher resilience is the larger adaptive capacity beyond the vulnerability beyond the sensitivity beyond the response capacity and beyond the exposure in an urban system. Thus, we argue to measure the resilience of an urban system should find the lower boundary of variational space between two conceptual capacities that are closely related (Figure 1). In practical case, the minimum of that the variational space of capacities is regulated by urban planning legislations according to regional characteristics, so that can be defined as to meet the minimum *per capita* requirements of urban resilience.

Thereby, urban resilience can be understood in three aspects of ecological resilience, economic resilience, and social resilience. Some evidences have shown social stability and climate stability are concomitant in anthropological history and climate historical records; for instance, social chaos and peasant rebellions highly probably occurred during the changing period from warm to cold climate (Ge et al, 2010; Ge, Fang & Zheng, 2014). Especially for those ecological fragile regions, local cultures and community collective behaviors can significantly alter social transformation and having impacts on economic capacity (Deng, Wang & Zhao, 2016). Moreover, Bahadur & Tanner (2014) addressed that a lower level of civil conscientization is the main cause of urban poverty and crime, so that politics at the community level should pay more attention to those low education people because they highly likely induce social instability and weaken the urban resilience when some natural hazards and big events occur. Tompkins & Adger (2004) examined the coherence between social resilience and adaptive management for response to climate changes. They emphasized the function of social dimensions to analyze adaptive strategies. Newman & Dale (2005) responded to their works but emphasized more managerial adaptations of infrastructures to intensify regional adaptive capacity in strategic planning of urban resilience. Thereafter, contemporary planning studies adapt sociological research methods to develop smarter plans of urban governance for climate adaptation. To minimize the side-effects of an urban system by using the multi-dimensional analysis of indicators for seeking adjustment planning policies.

Integrated indicator analysis is the most used method for urban and regional planning (Wong, 2006). Because urban resilience tends to be a systematic approach to urban sustainability (Fiskel, 2006; Folke, 2006). Tanner et al. (2009) proposed a set of integrated indicators in five categories to qualitatively evaluate urban resilience including: decentralization and autonomy, transparency and accountability, responsiveness and flexibility, participation and inclusion, and experience and support. However, there are lack of a conceptual model in a clear hierarchical framework (Leichenko, 2011). The function of ecological infrastructure for ecological resilience had been significantly emphasized as the first line of urban resilience (Tzoulas et al., 2007; Leichenko, 2011; Cameron et al., 2012; Demuzere et al., 2014; Li et al., 2016). However, the capacity of regional economic development and the implementation of governance and institutions can dynamically and interactively influence the ecological resilience. Because social impacts play a more important role to alter economic behaviors and having impacts on local environmental changes. Tyler & Moench (2012) summarized four features of social resilience including to foster civil rights, robust decision making, transparent information, and strong knowledge spillover; to improve infrastructure system and ecosystem networks; to enhance community resilience; and to efficiently implement institutions. So that, recent integrated indicator analysis is prone to be more comprehensive. For instance, Broto & Bulkeley (2013) surveyed 100 cities and found urban infrastructure improvement is significantly enhancing urban resilience even though they originally intended to study energy flows. Thus, it is arguable what the first line of urban resilience in a region, and why some aspects can be cohering but some of others cannot, and how planners understand an urban system and seek a better solution to minimize the side-effects of interim policies.

Therefore, we collected 139 indicators to represent systematic urban resilience of Beijing. Beijing is a typical megacity. She is the capital city of the People's Republic of China (PRC), and the center city of Beijing-Tianjin-Hebei (BTH) region. The eco-urbanization of this region has been set up as the second of three largest strategic plans by the central government of PRC since 2015. On April 1st in 2017, the planning of a second largest new special zone in PRC was released to the public. This plan aims to alleviate the environmental pressures of Beijing and improving the urban-rural coordinative development of BTH. Unlike the previous plan to construct a sub-center at Tongzhou District in the east side of Beijing, this plan of "Xiongan new special zone" is more ambitious for a millennium development plan. At this point, deeply understanding the historical changes of social-economic-ecological system (SEES) in Beijing becomes more critical to contribute to the implication of Xiongan and other places in China.

We aim to draw lessons from history of the development pathway of Beijing to suggest a framework of urban growth for the implications to a demonstration pilot path of eco-urbanization. In the rest of this article, we will introduce the historical background information of the social-economic-ecological system of Beijing in section 2; then, the methodology with indicators statistic descriptions will be stated in section 3; sequentially, the components of analytic results will be provided in section 4. We will discuss the implications of the historical evidence of Beijing in section 5; and finally give the conclusion of chronological stages in the development pathway of Beijing with corresponding policy implications in five aspects to the demonstration pilot path of eco-urbanization in the last section 6.

2 Background information

Forest coverage rate as the main indictor of ecological resilience in Beijing was used to be nearly close to zero in the past millennium years. But it increased sharply after the establishment of the New China. Before the Yuan Dynasty (A.D.1271-1368), Beijing used to have a high forest coverage rate. Since the Yuan, Ming, and Qing Dynasties (A.D.1271-1921) set the capital city at Beijing area, local forest coverage rate had reduced to 1.3 *per cent* before A.D.1949 (Zhao, 2005). After PRC established, central government highly focused on capital city construction with 'brand effects' to show the urban green environment. There were 61.7 thousand hectare afforested during 1953-1957, 63 thousand hectare afforested during 1962-1965, and 96 thousand hectare afforested during 1966-1976. Until 1980s, the forest coverage rate in Beijing was about 16.6 *per cent*. Until 1995, this number reached to 36.36 *per cent*. In the 13th five-year plan during 2016-2020, Beijing municipal government targets 44 *per cent* of forest coverage rate which will increase to 45 *per cent* in the final promulgated 2016-2035 Beijing municipal government comprehensive plan on Sep 29th in 2017.

During 1949-2015, the growth of *per capita* ecological functional land was much lower than the growth of *per capita* built-up land in Beijing. Since 1949, population density had been fast increasing. After open policy and reformation implemented in 1978, urban population experienced an accelerating growth. Until 2005, urban population was doubled. During 2005-2015, the total resident population increased 41 *per cent*, and urban population reached 86.5 *per cent* of the total population until the end of 2015. After 2000s, except built-up area *per capita* successively increased, all other ecologically functional land[1] decreased in Beijing (Table 1). Until 1997, the urban built-up areas were five times more than in 1949, and *per capita* built-up area was 1.3 times of that in 1949 (Lu, Zhan & Ren, 2001). Although Beijing municipal government highly focused on green infrastructure construction and strategically mitigated the growth of the proportion of built-up area before the 2008 Olympic Games, the proportion of total built-up area still increased from 40.47 *per cent* to 41.03 *per cent* after the Olympics during 2008-2015, and the *per capita* green land declined from 48 to 39.84 square meter during 2007-2015. Therefore, do these *per capita* ecological land use changes decline the ecological resilience? is that the key issue for a better planning of Beijing?

Table 1. Land use changes in annual average (m^2) *per capita* of resident population in Beijing, 1988-2015.

Year[2]	dry/paddy	woodland	grassland	water/wetland	built-up	Unused
1988-1995	-160.21	57.85	-9.45	22.33	87.38	66.38
1995-2000	49.06	-45.36	1.39	-8.93	5.22	-67.53
2000-2005	-65.61	-2.18	0.18	-3.72	71.36	0.02
2005-2008	-11.75	-1.61	-0.81	-1.04	15.21	0.00
2008-2015	-11.74	-2.38	-4.84	-3.86	23.17	0.01

Note: reclassified remote-sensing land use data in 100*100m^2 published by Chinese Academy of Science (Liu, 1996; Liu et al., 2003); and the statistics of population published by PRC Beijing Bureau of Statistic which is adjusted by PRC National Bureau of Statistics 1978-2015.

The income inequality growth was determinate even though population rapidly grew with structural effects of ecological intercorrelation on the pattern of urban-rural landscape changes in Beijing during 1980s-2010s. After opening reformation policy implemented in 1978, Beijing had experienced an accelerating economic growth. Local GDP and *urban resident disposable income* in 2015 had increased near to 145 times of that in 1978[3] (Figure 2). However, urban-rural income inequality during 1978-2015 had been increasing as well. The annual average growth rate of *urban resident disposable income* in Beijing was 13.1-14.7%, which was higher than her neighborhoods Tianjin (11.78-13.12%) and Hebei (11.97-13.36%). While, the annual average growth rate of *rural resident pure income* in Beijing was 11.89-13.17%, which was lower than Tianjin (12.62-14.16%) and Hebei (12.04-13.56%). Wang et al.

[1] Ecological functional land is ecological infrastructure including cultivated land, woodland, grassland, water/wetland, and unused land (Li et al., 2016).
[2] The error rate of land use data in 1995 is technically little bit higher than the other years (Liu, 1996; Liu et al., 2003), but it is not enough to alter the analytic pattern of land use changes.
[3] The statistics of Beijing GDP, population, rural resident pure income, and urban resident disposable income are published by PRC Beijing Bureau of Statistics 1978-2015. The rural resident pure income was renamed to rural resident disposable income by NBS of PRC in 2015.

(2017c) founded that the *backward-wave effects* of Beijing growth had exceeded her *spillover effects* to neighborhoods. Therefore, do these expanding income inequalities decline the economic resilience? is that the key issue for a better planning of Beijing?

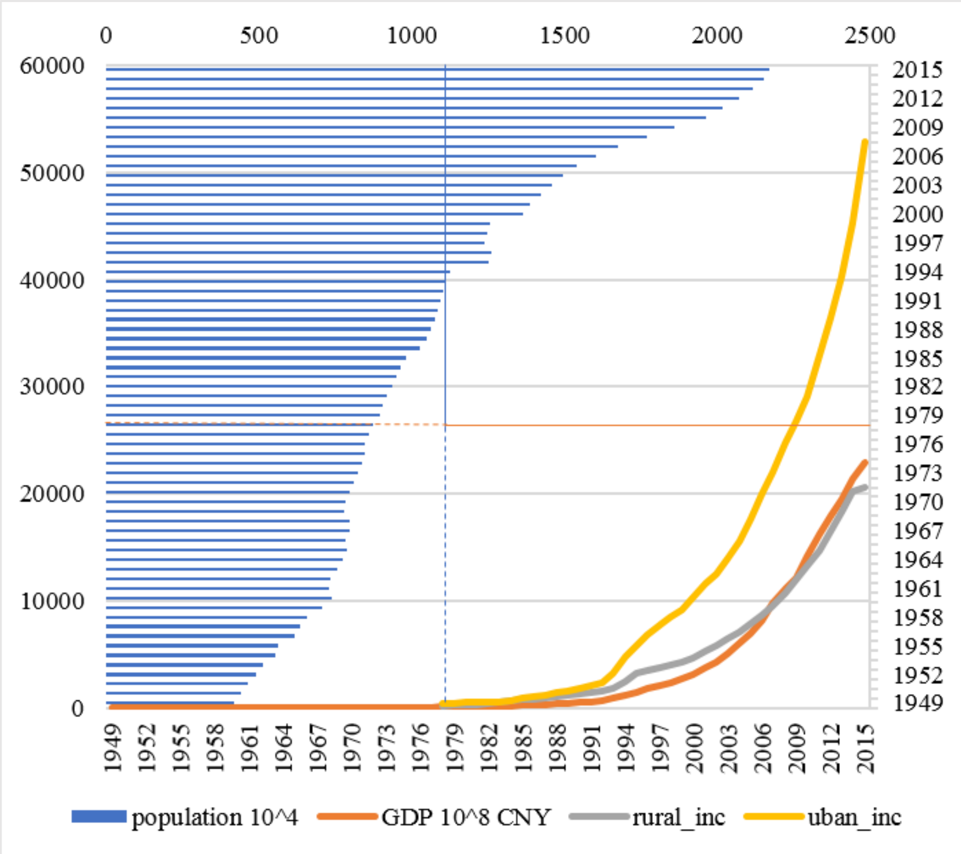

Figure 2. Resident population, nominal GDP, rural resident pure income, and urban resident disposable income in Beijing, 1949-2015.

With *per capita* infrastructures and other public services declined during 1978-2015, social resilience become more critical to urban resilience in Beijing. Until 2014, all 16 administrative districts consist of 141 streets have been urbanized. There are including about 1450 administrative resident committees, and 1700 administrative village committees, in total managing about over 2460 residential communities, and each community usually consists of less than ten housing property committees. Most of communities are located at the *urban core area* (Xicheng and Dongcheng Districts) and the *urban function extension area* (Haidian, Chaoyang, Fengtai, and Shijingshan Districts). While, the *urban development zone* in Beijing, including Tongzhou, Shunyi, Changping, Fangshan, and Daxing Districts, still lacks public services. Beijing *ecological conservation development area*, including Mengtougou, Huairou, Pinggu, Miyun, and Yanqing Districts, will consistently keep ecological functions in the 2016-2030 Beijing comprehensive planning. When population increased, do these *per capita* public service changes decline social resilience of functional zones? is that the key issue for a better planning of Beijing? How to make detailed planning schemes to enhance urban resilience and meeting an increasing demand of the quality of life at community level?

3 Methodology

We analyze 139 indicators of the social-economic-ecological system to comprehensively understand the performance of development pathway in Beijing during 1978-2015. Integrated indicator analysis provides some synthetical clues in our conceptual-structure of urban resilience (Figure 3). Unlike the life cycle assessment method usually confronts a very difficult data processing task (Hermann, Kroeze & Jawjit, 2007), the multi-dimensional analysis method provides the systematic scale-effects of normalized indicators by using the numerical scaling techniques. Thereby, the multi-criteria analysis of environmental performance is more comprehensive to evaluate these normalized multi-dimensional indicators. Li & Wang et al. (2005; 2011; 2016) suggested an extended conceptual framework of social-economic-natural complex ecosystem. They addressed human activities have significant impacts on environmental changes and climate responses. Niemeijer & de Groot (2008) also proposed a conceptual framework of social-economic-ecological indicators for urban sustainability. Tanguay et al. (2010) further proposed a concept to define urban sustainability which should be livable, viable and equitable. With reference to these proposals, we developed a conceptual framework based on Wang, Deng & Wong (2016a).

Some background information of our conceptual framework need to be stated firstly. Understanding urban environmental degradation starts from environmental indicator analysis. In 1970s, Los Angeles air pollution was distinct from other places in United States. Because the monthly environmental monitoring data reported the significance of volatility during 1950s-1970s. Some insightful scholars thus proposed time series analysis to identify relatively long-term changes in relationship between environmental quality and economic performance (Box & Tiao, 1975). Thereafter, relevant scholars have tried to use different environmental indicators to evaluate environmental quality and its driving forces. Shafik (1994) discussed the relationship between economic growth and environmental quality by using environmental indicators including safe water, urban sanitation, deforestation, fecal coliform in rivers, ambient suspended particulate matter (SPM), sulfur dioxide (SO_2), municipal waste *per capita*, and carbon emission *per capita*. He estimated their relationships with income rises, and found the relationships were quite different by different indicators to illustrate urbanization progress. Arnold & Gibbons (1996) addressed land use in urban planning as the first layer of impervious surface with threshold effects to avoid deeper environmental degradation. In this case, the design of land use has systematic functions to mitigate environmental impacts. Cole et al. (1997) did a paper which anchored a research direction that urban vehicle emission significantly contributes to a higher level of air pollution when *per capita* urban resident income progressed to a higher level because that induced driving cars more frequently. On the one hand, they provided evidence about different environmental indicators that have different relationship with economic growth; on the other hand, they proposed a debatable finding that vehicle emission is the main cause of urban environmental degradation occurred not only in LA of US, so that the hypothesis of the environmental Kuznets curve may be wrong because environmental impacts would continually increase when income rises. The latter has been not systematically proved even if a group of researchers have been conscientiously working on this point for many years. In fact, managerial studies have shown some evidence about social factors highly likely having critical impacts on systematic urban environmental degradation.

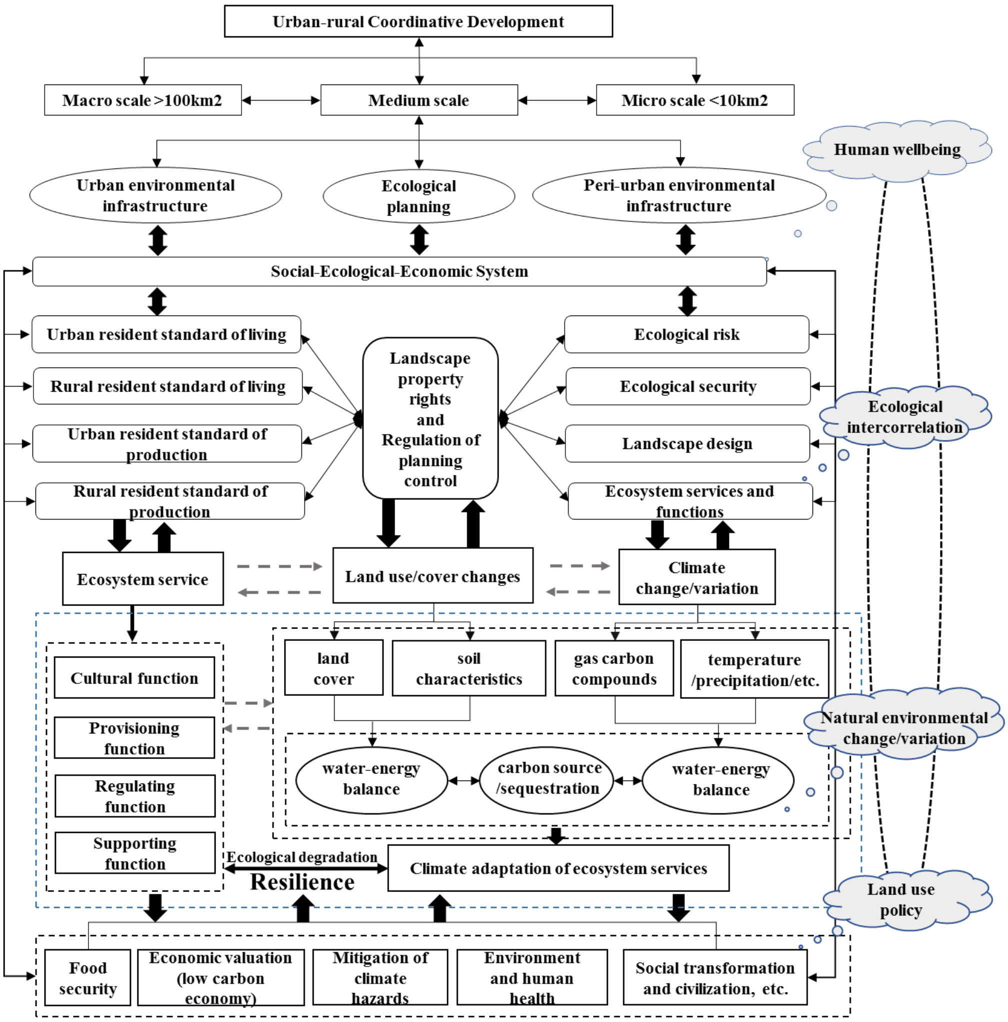

Figure 3. Conceptual framework of indicators in Beijing's social-economic-ecological system.

Systematic indicator analysis becomes the mainstream method around 1995 after US and EU(EEC) announced environmental governance policies in succession. Strategic planning of environmental management has been targeted for evaluating the sustainability of long term socioeconomic development. Sequentially, indicators for evaluating environmental performance were systematically designed. Jasch (2000) proposed to use input-output analysis to evaluate environmental performance through indicators in two aspects: one set of management performance indicators about policies implementation, audit conformity, financial performance, and community relation; and the other set of operational performance indicators about materials, energy, services supporting, physical facilities, product flows, public services, wastes, emissions, effluent to land and water, and some other pollution emissions. Walz (2000) used 140 indicators to examine the environmental performance in Germany. He stressed the conflicts and trade-offs among different requirements of the OECD's and domestic frameworks. Then, he proposed the life-cycle assessment to review the environmental performance *via* 140 indicators. Because German geographical conditions and domestic economic base are distinctive from other EU countries, he emphasized domestic characteristics to find adaptive solutions for response to the OECD proposed pressure-state-response approach.

Economic indicators are emphasized to the systematic indicator analysis approach. Spangenberg (2002) summarized interlinkages in '*Prism of Sustainability*' framework and pointing out the lack of economic indicators in this evaluation scheme. Because energy consumption, material resource utilization, and structural land use changes in social transformation are dynamically altered by regional economic growth. The threshold level of environmental space, or saying the environmental capability in a region, may become more uncertain to stay on the sustainable path if the one exists consistently. It means the unified minimum level of urban resilience may be highly inconsistent to all future cities. For instance, agriculture production is the first level of social production, so that it is usually called as the first industry to transfer raw natural resources to man-made capital. Local farmers take higher risk of natural hazards than urban residents (Van der Werf & Petit, 2002). When natural hazards occurred and induced agriproducts price rises, urban *consumer price index* is highly likely higher than rural. Thereby, urban resilience also need to consider those indirect impacts of agriculture productions *via* economic system which are so-called multiplier effects. However, multiplier effects are different from a region to another region. Moreover, social transformation due to urban-rural migration or income rises would be uncertainly influenced by synergistic or complementary changes in ecosystem or economic system. Thereby, Bringezu, Schütz & Moll (2003) explained the limitations of regional economic indicators to illustrate resource use efficiency because financial system can absorb risks of resource shortage in some countries. Such like international trade system may not better depict resource use efficiency because environmental impacts caused by physical flows are ambiguous.

Therefore, based on these features about integrated indicator analysis, we constructed a set of systematic indicators of social-economic-ecological system (SEES) to discuss social transformation in Beijing during 1978-2015, and employed the normalization method of Laspeyres index[4] to examine the changes from the standard of living in the base year of 1978. The necessity of normalization aims to numerically analyze the volatility from the average value of indicators. It implies to refine the key factors that have principle impacts on the distance between tested factors and the average scale of system development across temporal scales. Based on these chronological 'memory' records about dynamic changes of Beijing's SEES, we employ the *non-metric multidimensional scaling analysis* (NMDS) for sorting chronological changes in three stages, and by using Euclidean distance[5] estimation, the methods of the *principal coordinate analysis* (PCoA), the *correspondence*

[4] Such as the methods of standardization: Divisia index, Laspeyres index, Paasche index, Fisher ideal index (Price index) are used to evaluate economic performance across temporal scales.

[5] There are many mathematical methods to calculate the numerical distance, such like the absolute value distance, Euclidean distance, Minkowski distance, Chebyshev distance, etc., in which the Euclidean distance is most used.

analysis (CA), and the *principal component analysis* (PCA) can figure out key factors across temporal scales[6] (Wang et al., 2016b). The systematic decision-making method usually intends to reach the *multi-attribute utility* for a long-term development (Kiker et al., 2005), and serve to the *multiple objective decision-making* (Lai, Liu & Hwang, 1994), so that the *multi-attribute utility theory* (MAUT) with *the technique for order of preference by similarity to ideal solution* (TOPSIS) can provide policy options of environmental governance. Their basic ideas are to test the numerical distance between different normalized indicators in a conceptual framework. Based on their estimated Euclidean distance among indicators, a pooled analysis can provide the "short board" of a system even if it may not provide a convinced standard of a specific environmental indicator because each indicator may have specific criteria that quite differ from others. Such like Herva & Roca (2013) did a review work of *multiple-criteria decision analysis* (MCDA) to criticize that fuzzy analysis on a dataset of systematic indicators may underestimate the environmental risk. Thereby, we further clarified three sets of indicators to represent social, economic, and ecological performance respectively. This aims to evaluate systematic changes to serve multiple criteria decision-making across different temporal stages. This kind of systematic analysis will provide the threshold of a system in each category with a critical value of a normalized dataset of indicators (Table 2), so that the "short board" of threshold results are the estimated main factors of urban resilience in Beijing's social-economic-ecological system. Furthermore, historical records of Beijing municipal development can be the evidence to test the results of estimated factors corresponding to these systematic changes across temporal scales.

Table 2. Indicator descriptions of Beijing's social-economic-ecological system, 1978-2015.

Variables			Normalization		
Code	**Name**	**Unit**	**Mean**	**Std. Dev.**	**Data Source**
E01	built-up	%	1.01	0.06	Duan & Hu (2015)
E02	automobile production	10^4 cars	26.41	35.98	NBS[1]
E03	R&D investment	10^4 CNY	1.37	0.87	NBS
E04	forest investment	10^4 CNY	3.36	5.63	NBS
E05	investment on waste gas	10^4 CNY	2.12	1.96	BMBEP[2]
E06	delivery quantity	10^4 packages	660.58	1651.27	NBS
E07	employment	10^4 population	1.76	0.72	NBS
E08	economic scale impact	10^4 ton	1.13	0.27	Wang et al. (2016d)
E09	chemical fiber	10^4 ton	36.14	24.46	NBS
E10	cement	10^4 ton	3.32	1.76	NBS
E11	rolled steel	10^4 ton	4.13	2.41	NBS
E12	power generation	10^8 kilowatt hour	1.73	0.82	NBS
E13	hydropower generation	10^8 kilowatt hour	13.31	7.95	NBS
E14	capital asset	10^8 CNY	2.56	1.27	NBS
E15	road investment	10^8 CNY	45.84	73.57	BUDY[3]
E16	tourism	10^8 CNY	1.57	1.11	BMBS[4]
E17	total retail sales of consumer goods	10^8 CNY	53.13	69.01	NBS
E18	local budget income	10^8 CNY	21.93	32.52	NBS
E19	local taxation	10^8 CNY	42.08	67.57	NBS
E20	local finance urban maintenance and	10^8 CNY	3.11	3.90	NBS

[6] The employed packages of PCNM, Matrix, AEM, vegan, ade4, gclus, ape with the script code files of CA, evplot and cleanplot.pca were updated on April 21st of 2017 in software R(i386 3.2.3).

	construction tax				
E21	local deed tax	10^8 CNY	5.61	7.68	NBS
E22	local special financial revenue	10^8 CNY	3.39	5.40	NBS
E23	local state-company revenue	10^8 CNY	0.89	0.24	NBS
E24	local budget consumption	10^8 CNY	66.68	100.50	NBS
E25	local public service consumption	10^8 CNY	1.09	0.20	NBS
E26	local education consumption	10^8 CNY	1.25	0.57	NBS
E27	local social security consumption	10^8 CNY	1.26	0.64	NBS
E28	local urban-rural community consumption	10^8 CNY	1.31	0.83	NBS
E29	local A&F water consumption	10^8 CNY	1.28	0.71	NBS
E30	GDP	10^8 CNY	48.25	62.48	NBS
E31	first industry GDP	10^8 CNY	1.53	0.63	NBS
E32	second industry GDP	10^8 CNY	3.43	3.26	NBS
E33	third industry GDP	10^8 CNY	9.60	12.73	NBS
E34	construction GDP	10^8 CNY	3.37	3.31	NBS
E35	retail and wholesale GDP	10^8 CNY	5.37	6.29	NBS
E36	transportation and telecommunication GDP	10^8 CNY	7.19	7.43	NBS
E37	accommodation and restaurant GDP	10^8 CNY	1.25	0.46	NBS
E38	financial industry GDP	10^8 CNY	8.99	12.24	NBS
E39	real estate GDP	10^8 CNY	48.73	67.39	NBS
E40	other services GDP	10^8 CNY	11.41	16.04	NBS
E41	investment on environmental pollution	10^8 CNY	1.48	1.08	BMBEP
E42	investment on green construction	10^8 CNY	18.82	38.76	BMBS
E43	investment on energy infrastructure	10^8 CNY	86.40	103.05	BMBS
E44	R&D projects	cases	1.28	0.61	NBS
E45	rural consumption *per capita resident population*	CNY *per capita*	22.75	24.39	BMBS
E46	urban consumption *per capita resident population*	CNY *per capita*	25.01	25.96	BMBS
E47	rural resident net income	CNY *per capita*	25.39	26.90	BMBS
E48	urban disposable income	CNY *per capita*	34.15	39.02	BMBS
E49	CPI of retail products	index of last year =100	1.07	0.07	NBS
E50	index of local consumption *per capita resident population*	index of last year =100	1.05	0.05	NBS
E51	index of rural consumption *per capita resident population*	index of last year =100	1.07	0.07	NBS
E52	index of urban consumption *per capita resident population*	index of last year =100	1.06	0.06	NBS
E53	R&D employee	*per capita*/*per year*	1.13	0.28	NBS
S01	floating population	%	1.12	0.26	Lu (2013)
S02	65 and over population ratio %	%	1.99	4.33	NBS
S03	aging population adopted ratio %	%	1.07	0.13	NBS
S04	infrastructure rise impact	%	1.77	0.47	BMBS
S05	infrastructure investment structure	%	3.79	0.59	BMBS
S06	CO_2 Emission growth rate	%	1.70	0.71	NBS
S07	vehicle parc	10^4 cars	17.98	21.16	BUDY
S08	drain pipe length	10^4 km	1.19	0.38	NBS
S09	street cleaning	10^4 m^2	1.10	0.17	NBS
S10	road area	10^4 m^2	1.15	0.30	NBS
S11	urban daily sewage treatment capacity	10^4 m^3	1.12	0.21	NBS
S12	comprehensive production capacity of water supply	10^4 m^3 daily	1.24	0.44	NBS
S13	private cars	10^4 number	153.69	213.85	NBS
S14	public buses	10^4 number	4.10	3.04	NBS
S15	healthcare beds	10^4 number of beds	2.19	0.79	NBS
S16	total resident	10^4 population	1.55	0.46	NBS
S17	urban resident	10^4 population	1.95	0.40	NBS
S18	rural resident	10^4 population	4.50	1.38	NBS
S19	65 and over population	10^4 population	1.06	0.11	NBS
S20	higher education students	10^4 population	6.16	4.31	NBS

S21	population of water consumption	10^4 population	1.12	0.20	NBS
S22	energy consumption	10^4 ton of standard coal	1.09	0.19	12th BPLAN[5]
S23	fossil fuel EC	10^4 ton	1.09	0.18	12th BPLAN
S24	living EC	10^4 ton	1.17	0.36	12th BPLAN
S25	production CO_2 Emission	10^4 ton	1.06	0.12	12th BPLAN
S26	living CO_2 emission	10^4 ton	1.12	0.26	12th BPLAN
S27	transport EC	10^4 ton	1.23	0.47	BMBS
S28	total CO_2 Emission	10^4 ton	2.69	1.39	NBS
S29	faeces garbage	10^4 ton	1.05	0.09	NBS
S30	energy consumption	10^4 ton of standard coal	2.08	0.98	NBS
S31	living garbage	10^4 ton/per year	1.19	0.30	NBS
S32	total water resource	10^8 m^3	1.08	0.20	NBS
S33	total water supply	10^8 ton	1.04	0.08	NBS
S34	total living water supply	10^8 ton	1.05	0.11	NBS
S35	total production water supply	10^8 ton	1.10	0.20	NBS
S36	number of total traffic accident	cases	2.37	3.03	NBS
S37	*per capita* GDP	CNY *per capita*	3.98	3.90	NBS
S38	roads length	km	1.57	0.60	BUD
S39	water supply pipe length	km	1.14	0.25	NBS
S40	living water consumption daily *per capita*	litre (L)	1.06	0.11	NBS
S41	water resource *per capita*	m^3 *per capita*	1.16	0.29	NBS
S42	hospital beds per ten thousand people	number of beds	1.57	0.46	NBS
S43	urban bridges	number of bridges	1.16	0.30	NBS
S44	cleaning cars	number of cars	1.11	0.23	NBS
S45	public restrooms	number of restroom	1.03	0.06	NBS
S46	urban street lights	number of street lights	1.03	0.07	NBS
S47	CO_2 emission *per capita*	ton *per capita*	1.45	0.33	NBS
EC01	grass land	%	1.01	0.04	Duan & Hu (2015)
EC02	forest	%	1.00	0.01	Duan & Hu (2015)
EC03	cultivated land	%	1.01	0.07	Duan & Hu (2015)
EC04	water	%	1.02	0.11	Duan & Hu (2015)
EC05	unused	%	1.00	0.02	Duan & Hu (2015)
EC06	cucurbitaceae planting	10^3 hectares	2.66	0.93	NBS
EC07	orchard planting	10^3 hectares	5.90	2.53	NBS
EC08	aquiculture production	10^3 hectares	4.24	1.94	NBS
EC09	total afforestation area	10^3 hectares	1.25	0.60	NBS
EC10	3E parameter	10^4 ton	1.06	0.11	12th BPLAN
EC11	COD daily annual average	10^4 ton	1.23	0.37	BMBS
EC12	blue sky days	days	1.13	0.22	BMBS
EC13	ecological tension index	index value	1.01	0.03	Chu et al. (2017)
EC14	ecological occupancy index	index value	1.03	0.09	Chu et al. (2017)
EC15	ecological economic coordination index	index value	1.02	0.08	Chu et al. (2017)
EC16	built-up	landscapepatch	1.13	0.54	Duan & Hu (2015)
EC17	residential sites	landscapepatch	1.01	0.04	Duan & Hu (2015)
EC18	other built-up	landscapepatch	1.10	0.39	Duan & Hu (2015)
EC19	paddy	landscapepatch	1.72	2.63	Duan & Hu (2015)
EC20	dry farmland	landscapepatch	1.06	0.26	Duan & Hu (2015)
EC21	forest	landscapepatch	1.06	0.28	Duan & Hu (2015)
EC22	shrub wood	landscapepatch	1.08	0.29	Duan & Hu (2015)
EC23	woody land	landscapepatch	1.12	0.53	Duan & Hu (2015)
EC24	other woody land	landscapepatch	1.18	0.80	Duan & Hu (2015)
EC25	high coverage grassland	landscapepatch	2.08	3.73	Duan & Hu (2015)
EC26	moderate coverage grassland	landscapepatch	1.08	0.47	Duan & Hu (2015)
EC27	low coverage grassland	landscapepatch	1.06	0.22	Duan & Hu (2015)
EC28	river and canals	landscapepatch	1.06	0.34	Duan & Hu (2015)
EC29	lake	landscapepatch	1.03	0.16	Duan & Hu (2015)
EC30	reservoir pits	landscapepatch	1.07	0.29	Duan & Hu (2015)
EC31	floodplain	landscapepatch	1.04	0.17	Duan & Hu (2015)

EC32	sandy land	landscapepatch	1.00	0.00	Duan & Hu (2015)
EC33	marshland	landscapepatch	1.00	0.00	Duan & Hu (2015)
EC34	bare land	landscapepatch	1.05	0.28	Duan & Hu (2015)
EC35	bare rock gravel land	landscapepatch	1.27	1.46	Duan & Hu (2015)
EC36	ideally ecological land *per capita*	m^2	1.00	0.00	Yu et al. (2009)
EC37	PMs daily annual average	mkg/m^3	1.13	0.21	BMBS
EC38	SO_2 daily annual average	mkg/m^3	2.31	3.12	BMBS
EC39	NO_2 daily annual average	mkg/m^3	1.11	0.18	BMBS

Note: Code marks: Economic indicators (E); Social indicators (S); and Ecological indicators (EC). Data Source marks: 1- P.R. of China National Bureau of Statistics (NBS); 2- Beijing Municipal Bureau of Environmental Protection; 3- Beijing Municipal Bureau of Statistics (BMBS); 4- Beijing Urban Development Yearbook (BUDY); 5- The twelfth five-year plan for energy consumption of Beijing (12^{th} BPLAN).

4 Results

Graphical results from the *non-metric multidimensional scaling analysis* (NMDS) show that sorting chronological changes of all indicators in three temporal stages: 1978-1996, 1997-2002, and 2003-2015 (Figure 4). By comparing the development paths in each set of categorized indicators, economic development is the main driving force of Beijing's SEES. The path of economic indicators in Figure 4b is similar as the path of all indicators in Figure 4a, and their positive scale effects (0.4,0.2) are higher than the scale of all indicators' performance (0.3,0.15). The ecological infrastructure construction for 2008 Olympics does have positive impacts on improving ecological performance in Beijing. Scale effects of ecological indicators during 2000-2007 (0.2,0.2) in Figure 4d are positively higher than the performance of social indicators in Figure 4c. Thus, systematic changes are unbalanced among three sets of indicators. The performance of economic indicators is higher than that of ecological indicators, while the performance of social indicators drags down the systematic performance during 1978-2015.

We reviewed the big events in national strategic plans during 1978-2015. Beijing as the capital city was a strong demonstrative representative. After 1978 to 1991, PRC experienced economic reformation and institutional modifications. During 1992-1996 in the eighth five-year plan, PRC entered in the era of high economic growth rate, over 12% annually. We called this stage during 1978-1996 as "entrance" after the opening policy reformation. In this first stage, the main large state-owned manufactories in Beijing experienced the reformation to modern shareholding enterprises. Many state-owned labors lost their jobs or resigned to run private business. At that time, there was a saying that "swimming in the ocean" (xiàhǎi in Chinese) which is a metaphor to interpret people do not know their prospects because the future of market-based economy is full of uncertainties. At the same time, more opportunities in megacities such like Beijing occurred the first time of rural-urban immigration. In the second stage during 1997-2002 as "soar", the first mid-long-term strategic plan started to be implemented by the ninth five-year plan that designed the development pathway of PRC in the market-based economy reformation. The goal of this plan aimed to "complete the second strategic deployment of the comprehensive modernization" until 2010. Beijing took the leading role in accomplishing this strategic planning, and successfully won the bid of 2008 Olympic summer games in 2002. In the third stage during the stage of 2003-2015 as "coursing", Beijing made great efforts to municipal construction including housing development, transportation construction, and other public service. Thereafter, she becomes a more attractive megacity in PRC.

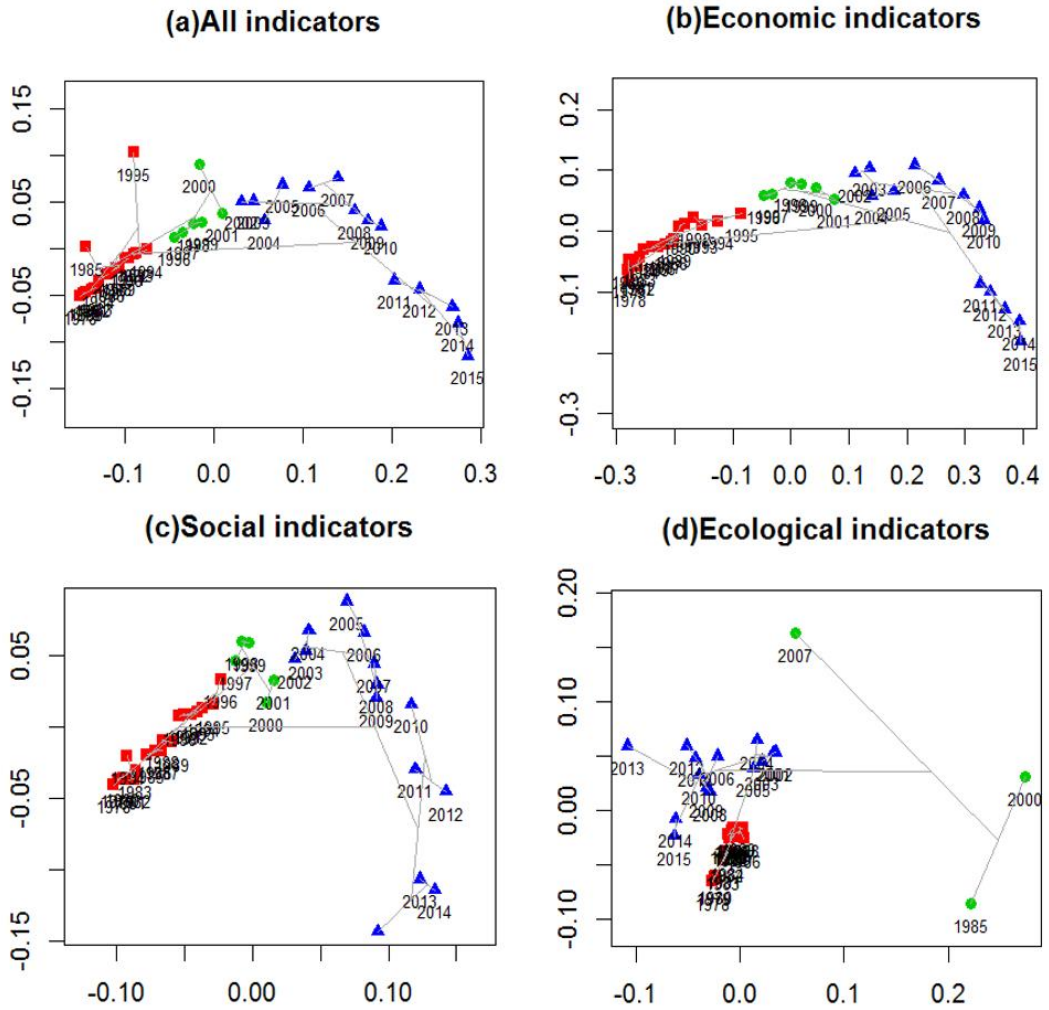

Figure 4. Sorting chronological changes of indicators in Beijing's social-economic-ecological system, 1978-2015.

4.1 Cohesion of all indicators

During 1978-2015, the increase of economic resilience indicators in delivery quantity [E06], road investment [E15], real estate GDP [E39], investment on energy infrastructure [E43], R&D projects [E44], and rural [E45] and urban [E46] consumption *per capita by rural/urban resident population*, with decreasing indicators in chemical and fiber [E09], rolled steel [E11] and forest investment [E04], and the increase of social resilience indicators in vehicle parc [S07] and private cars [S13] distinctively contributed to Beijing's SEES development (Figure 5_right). The performance of these indicators illustrates the industrial transformation in Beijing after the opening policy and reformation. Chairman Mao designed Beijing to be a demonstration of industrial cities. So that, state-owned chemical engineering factories were set up in 1950s, and located outside of the third ring road in the southeast side of Beijing supervised by Beijing municipal government. During the "coursing" stage, most of chemical factories reduced productions and moved out of the fourth ring road. After the reformation of state-owned assets reorganization during 1980s, these chemical factories were the first group reformed to run a modern shareholding enterprise and forming the Beijing Chemical Industry Group CO. LTD which started to transform to serve municipal disposal of solid waste, waste gas, waste water, danger chemical delivery, automotive exhaust purification, and physical material recycling. Such like industrialization in developed countries past, fibers and textile industry were also set up in Beijing during 1950s. Tiantongyuan and Huilongguan are the largest residential communities near to Qinghe area in Haidian District of Beijing, where was used to be the location of fibers and textile factories and some air force and guided missile research institutes before the “coursing” stage. Additionally, because many universities are located at Haidian District of Beijing, R&D projects of high-technology started from Zhongguancun street in 1980s and their knowledge spillover effects contributed to economic growth and industrial transformation significantly. During the “soar” stage, population increased very fast and accelerating built-up area constructed. The *per capita* built-up area increased 71.4 square meter, while *per capita* cultivated land shrunk 65.6 square meter. Some Beijing suburban peasant households got financially compensations from municipal or central planning land development for large construction projects, such as the 2008 Olympic Games, and large residential housing residential communities’ development. These compensations effectively stimulated rural consumption *per capita* during the “coursing” stage.

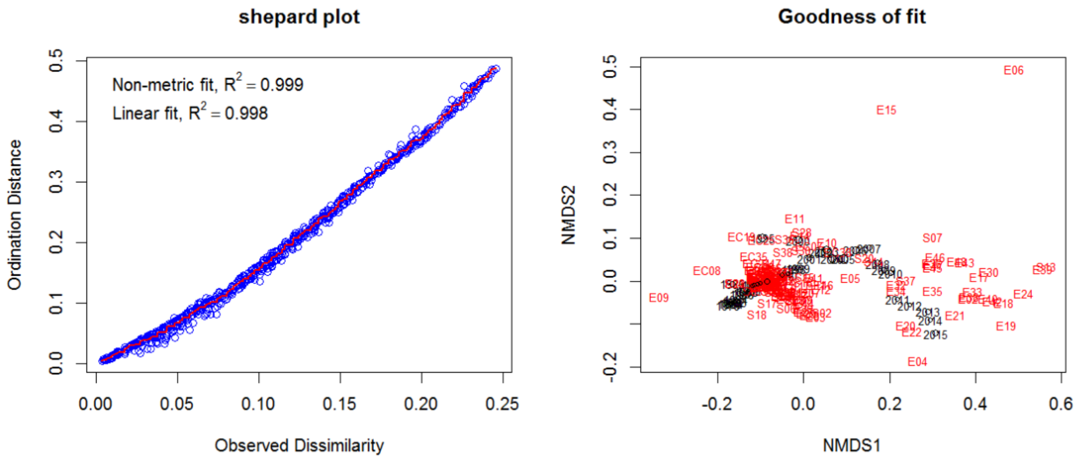

Figure 5. Cohesion of all indicators changes in Beijing’s social-economic-ecological system, 1978-2015.

4.2 Cohesion of economic-ecological indicators

The central government pays attention to ‘ecological construction’ in Beijing after 1949. Although the forest investment [E04] was still relatively low, the cohesion of economic and ecological indicators is almost perfect matched during 1978-2015 (Figure 6_left). Those chemical and fiber factories [E09] contributed to local economy, so that deviated from other indicators (Figure 6_right). With e-commerce booming, the increasing demand of delivery quantity [E06] and road investment [E15] challenged local budget consumption [E24]. With urban population increased, real estate GDP [E39] and investment on energy infrastructure [E43] were distinctively deviated the economic-ecological cohesion path. With increasing rural [E45] and urban [E46] consumption *per capita by rural/urban resident population*, transportation and telecommunication GDP [E36] and total retail sales of consumer goods [E17] also increased significantly.

However, after 2008, scale effects of ecological performance have been much lower than economic performance. Before the “coursing” stage, there were plenty of fishponds for aquiculture production [EC08] at suburban Beijing (Figure 6_right). Fishing at those fishponds was used to the main recreational activities for middleclass at weekends. After won the bid of 2008 Olympics in 2002, those fishponds shrunk fast, so that water/wetland area reduced 4.7 square meter *per capita resident population* during 2000-2008. Furthermore, forest investment [E04] were too low to match the pathway of economic growth. Wang et al. (2016c) and Wang & Deng (2016e; 2017a; 2017b) have proved that the return on ecological investment increases environmental income. Status-seeking effects of conspicuous consumption for better environmental infrastructures such like car use would not directly hurt the individual payment on environmental improvement and can indirectly stimulate the tourism for benefitting to economic growth with environmental quality improvement. By contrast, lower ecological investment may decrease the *per capita* ecological infrastructures, so that increases the risk of economic growth with side-effects of environmental degradation. Therefore, the deviation of forest investment [E04] indicates an increasing trend of risks to economic growth cohered with a downward sliding standard of environmental quality during the “coursing” stage.

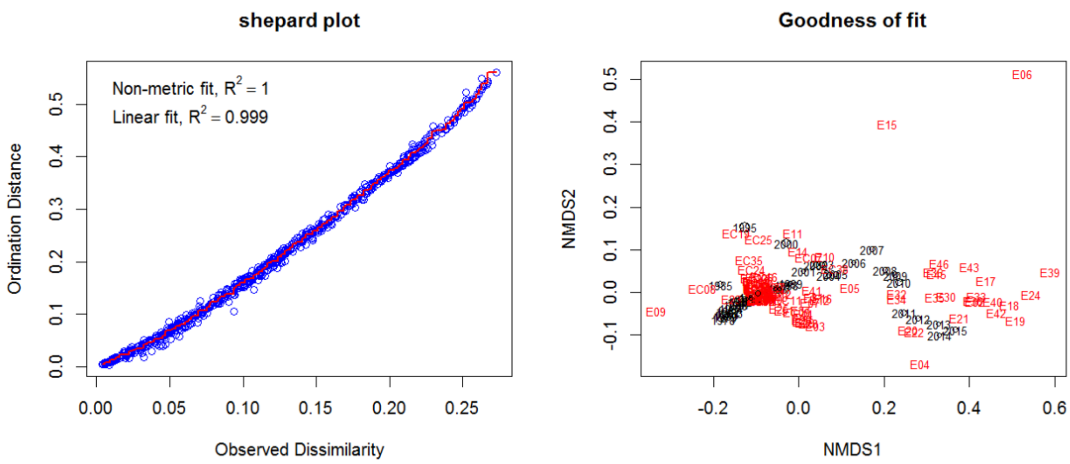

Figure 6. Cohesion of economic and ecological indicators changes in Beijing’s social-economic-ecological system, 1978-2015.

4.3 Cohesion of social-ecological indicators

Most of social indicators show weak positive contributions to the SEES of Beijing development. Several indicators significantly deviate from the social-ecological cohesion path (Figure 7_right). With *per capita* GDP [S37] increased, the vehicle parc [S07], private cars [S13], and public buses [S14] increased to satisfy the increasing transportation demands. Consequently, the number of total traffic accidents [S36] increased. It is very debatable with regard to the concomitant increase of air pollution because CO_2 Emission growth rate [S06] shows a quite slow increasing trend, but the total energy consumption [S30] and total CO_2 Emission [S28] increased obviously deviated from the cohesion area. Furthermore, with low-income population fast increased such as higher education students [S20], key public resources such as water consumption [S21], drain pipe length [S08], and healthcare beds [S15] become scarcer. Urban garbage management also confronted increasing challenges, such like street cleaning [S09] and faeces garbage [S29], so that social performance left behind the increase of social-ecological development due to lack of infrastructure rises [S04].

Before 2005, ecological functional land including aquiculture production [EC08], other woody land [EC24], and bare rock gravel land [EC35] continually decreased in Beijing. Best ecological performance occurred during 2005-2007 just before the 2008 Olympics. However, after 2010, social development fast dragged down the ecological performance continually, so that air pollution indictor such as SO_2 daily annual average [EC38] obviously deviated from the cohesion area.

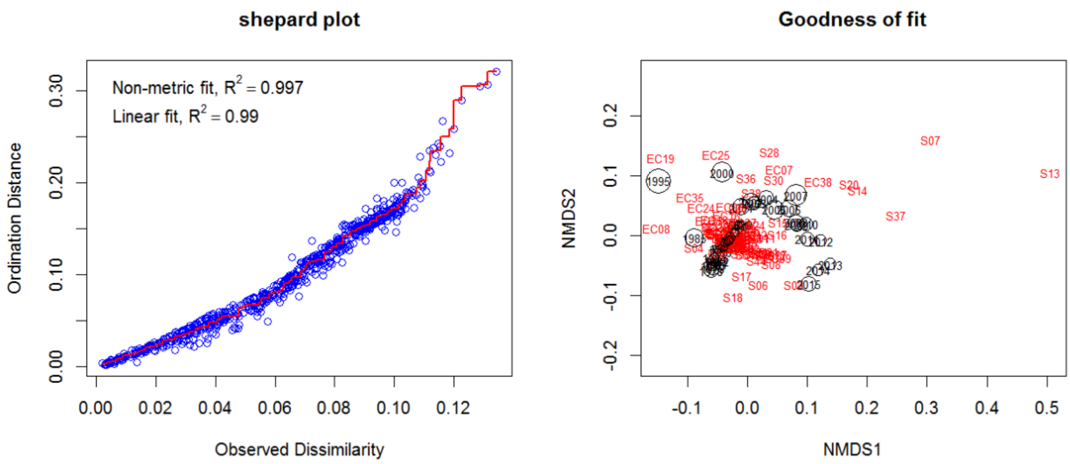

Figure 7. Cohesion of social and ecological indicators changes in Beijing's social-economic-ecological system, 1978-2015.

4.4 Social resilience indicators

Significant increases of total resident [S16], urban resident [S17] and rural resident [S18] brought about a shortage of total water supply [S33], total living water supply [S34] and drain pipe length [S08]. With the increases of 65 and the above years old population ratio [S02], the infrastructure rise impact [S04] and infrastructure investment structure [S05] had weak positive strength to support all other social performance during 1978-2015 (Figure 8_left). In particular, after 2008 Olympic Games, social performance in Beijing in fact was getting worse.

After 2010, total water supply [S33], total living water supply [S34] (Figure 8_left), and water supply pipe length *per capita* [S39] significantly deviated from other indicators by taking calculation of *per capita* indicator changes (Figure 8_right). The drain pipe length *per capita* [S08] negatively deviated from the cohesion center. After 2011, we have experienced twice severe urban inland inundation in Beijing in July of 2012 and 2016. This further proved the municipal infrastructure investment structure [S05] and infrastructure rise impact [S04] lowered the *per capita* systematic social resilience after 2008. By tracing back to Beijing municipal construction planning, the growth of population and economic development have been far beyond the expectations of either governors or planners since 1949. The infrastructure investment structure [S05] relatively lagged behand the demand of municipal facilities when population increased fast. With improving public health care system and higher education opportunities in Beijing, the healthcare beds [S15] and higher education students [S20] increased. However, with income rises, this improvement of public services attracted more population moving into Beijing, so that the energy consumption *per capita* [S30] and CO_2 Emission *per capita* [S28] increased and deviated the cohesion center area after 2011 (Figure 8_right). Meanwhile, the driving force of *per capita* GDP become weak, consequently, that further lowered the social resilience of Beijing.

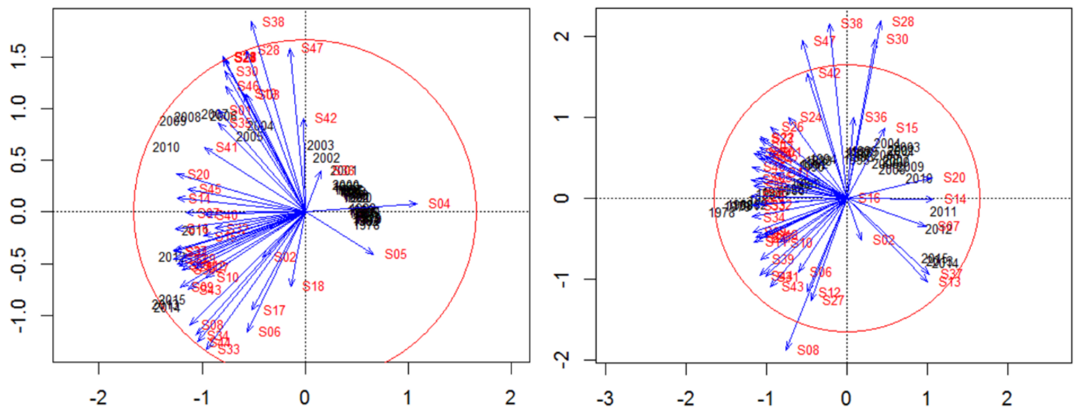

Figure 8. Indicator analysis of social performance in Beijing's social-economic-ecological system, 1978-2015.

4.5 Economic resilience indicators

Economic development benefited from manufacture industry in Beijing before 2002 (Figure 9_left), so that rolled steel [E11] with strong economic scale impact [E08] performed outstandingly. Since the "soar" stage, industrial structure had transformed to low-emission industries, while the increases of the chemical and fiber [E09] and local state-company revenue [E23] still played the principal components to the increased CPI of retail products [E49]. Although *per capita* ecological investment to forest [E04] was too low to cohere with economic development, its driving force in Beijing during 2001-2007 was distinctively (Figure 9_right). Energy structural reformation, such as investment on energy infrastructure [E43], investment on green construction [E42], investment on environmental pollution [E41], and investment on waste gas [E05] contributed to economic growth in significance. It cannot be ignored that the contribution of rolled steel production [E11] with cement [E10] and road investment [E15] supplied to the development of Beijing automobile and transportation industry. The Shougang Group is the second largest steel factory in PRC, and one of the global 500 companies since 2010, which supported Beijing auto production of BAIC Motor, Beijing Hyundai, Foton automobile, BMW Brilliance, and other smaller auto parts factories in PRC. However, the economic scale impacts [E08] become weaker after the 2008 Olympic Games. Even though the growth of third industry GDP [E33] with e-commerce in delivery quantity [E06] distinctively contributed to local industrial transformation, the firm's profit space is getting narrower. Because the increasing consumption in service sectors initiated local wage rise, that increased cost of production, and shrank the profit space.

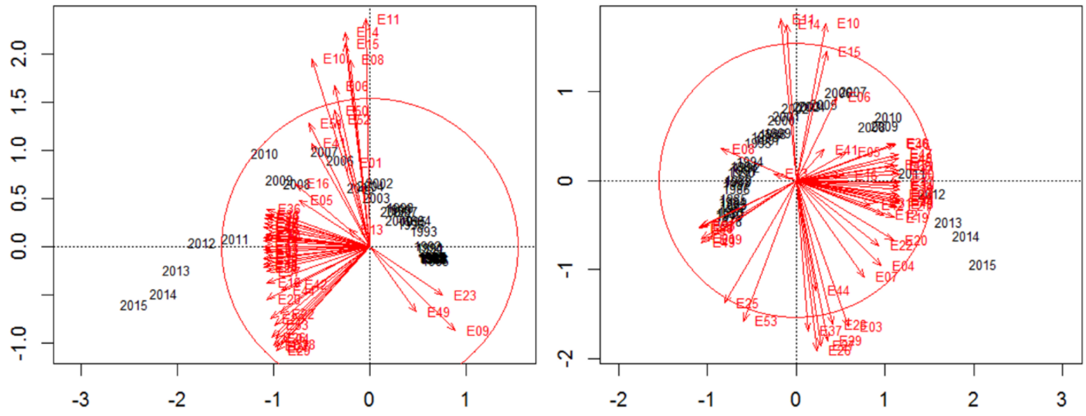

Figure 9. Indicator analysis of economic performance in Beijing's social-economic-ecological system, 1978-2015.

By taking calculation of *per capita* economic resilience indicators changes (Figure 9_right), local public service consumption *per capita* [E25] and full-time equivalent R&D employee *per capita/per year* [E53] become relatively lower after the "soar" stage. In recent five years (2011-2015), public opinions much cared about livable environment with a higher standard of living. We did a survey in summer of 2016 (Wang & Deng et al., 2016e), and found that income rise can efficiently alter the willingness to pay for environmental amenities. Figure 10 shows the comparison of kernel density of willingness to pay [v189] respectively with income level changes [v114] (Figure 10_left) and the income rise changes (Figure 10_right). It indicates that income rise contributed to a higher level of sustainable consumption can balance the cohesion path of a social-economic-ecological system with industrial transformation. Thus, regional production and service are highly likely more efficient than a large amount trade to support status-seeking consumption and enhance economic resilience, such like for cars and other high-quality goods and services benefit to keeping the smooth economic growth with income rises in a large city.

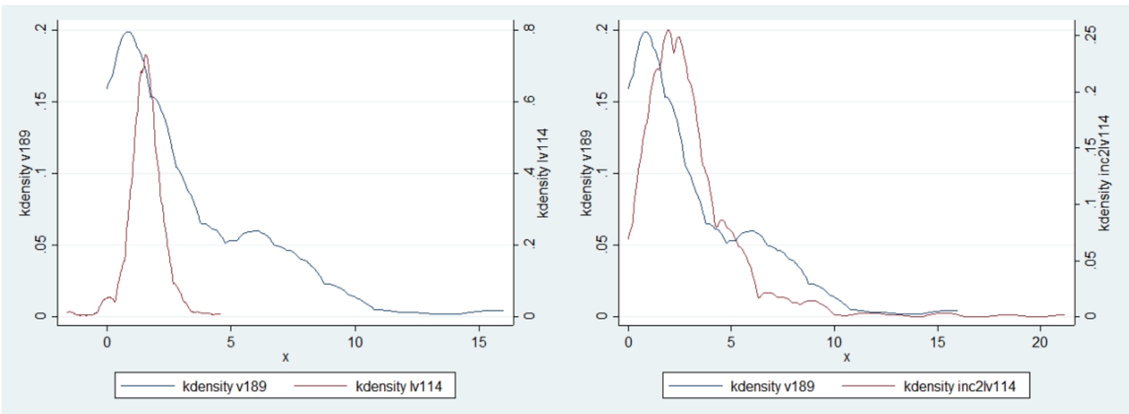

Figure 10. Comparison analysis of kernel density of willingness to pay for environmental infrastructure improvement to environmental quality improvement

with income changes on the left and the income rise changes on the right in Beijing, 2016.

4.6 Ecological resilience indicators

Although all ecological resilience indicators to some extent negatively deviated from the cohesion center (-3,2) (Figure 11_left), forest [EC02], orchard planting [EC07], and total afforestation area [EC09] significantly increased the ecological performance during the “entrance” stage. During the “soar” stage, grass land [EC01] and unused land [EC05] slightly increased the ecological performance (Table 1), but the COD daily annual average [EC11] and blue-sky days [EC12] relatively decreased and deviating from other ecological resilience indicators, and the decreased aquiculture production [EC08] further dragged down the ecological performance. After 2010, the PMs daily annual average [EC37], SO_2 daily annual average [EC38], NO_2 daily annual average [EC39] were increased. After 2012, Beijing municipal bureau of statistics did not publish the annual blue-sky days.

Ecological resilience is supported by the diversity of ecosystem functions *via* various land types. By taking calculation of *per capita* indicator changes (Figure 11_right), ecological performance (-2,1) become much worse after the “entrance” stage. Such like the decreases of bare rock gravel land [EC35], all kinds of grassland [EC25-27], and woody land [EC23-24] significantly lower the *per capita* ecological performance after the “soar” stage. Because urban ecosystem relies on diversified land types, urban biodiversity may highly depend upon landscape architecture. For instance, catkin in springs of Beijing increases the probability of air pollution. To deal with this kind problem, ecological governance may start from ecosystem diversity control in urban planning because it is not only for the beauty of an eco-city but the function of a livable city.

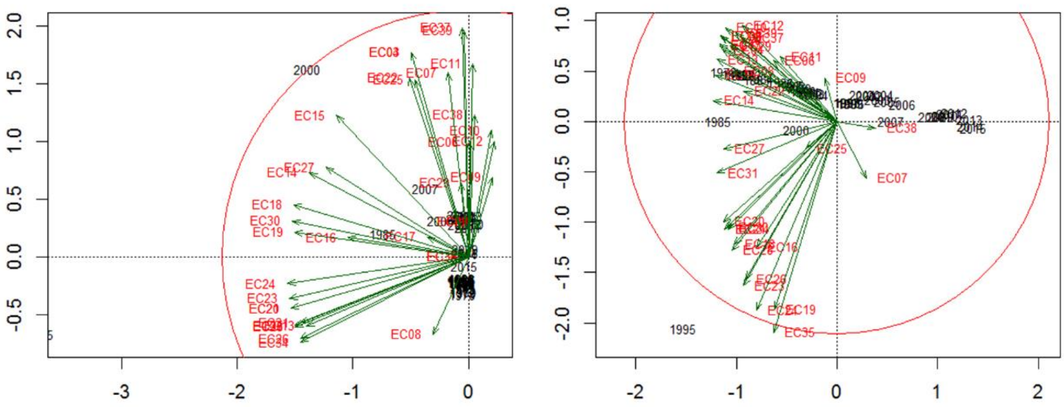

Figure 11. Indicator analysis of ecological performance in Beijing’s social-economic-ecological system, 1978-2015.

5 Discussion and implications

The analytic results are presented in a reversal order of our technical analysis findings. After we did literature reviews about the conceptual framework of sustainable urban resilience, according to the *multi-attribute utility theory* (MAUT), we considered the research methods of systematic analysis by using the *multiple-criteria decision analysis* (MCDA) for serving to *multiple objective decision-making* with *the technique for order of preference by similarity to ideal solution* (TOPSIS), so that we grouped three sub-concepts, in order to study the features of ecological resilience, economic resilience, and social resilience, and their cohesions. We firstly applied the *principal coordinate analysis* (PCoA), the *correspondence analysis* (CA), and the *principal component analysis* (PCA) to figure out key indicators in each set of categorized indicators to evaluate the numerical performance of the same indicator in two most principal components across temporal scales. The results provide evidence that the chronological changes of indicators have structural impacts on each sub-concept. Because the relationship between two sub-concepts is usually assumed to exist in the systematic indicators research. We tested the stress function of all indicators, and separately tested the stress in between economic-ecological resilience indicators, and the stress in between social-ecological resilience indicators. We found ecological resilience indicators show cohesive functions to enhance the cohesion between economic resilience and social resilience. Based on these stress and cohesion among sub-conceptual resilience indicators, the *non-metric multidimensional scaling analysis* (NMDS) sorts the Euclidean distance among the categorized indicators to report three chronological stages. Then, we checked the historical records to test whether the analytic evidence perform as well as the key indicators shown, so that we can reinterpret what we have found in a more readable and logic statement order rather than to explain some technical findings without factual cases.

There are three chronological stages from analytic results categorized in 1978-1996, 1997-2002, and 2003-2015 on the development pathway of Beijing. After reviewed the big events in national strategic plans during 1978-2015, we found Beijing is a strong demonstrative representative to implement all plans. We named the first stage during 1978-1996 as “entrance”, the second stage during 1997-2002 as “soar”, and the third stage during 2003-2015 as “coursing”. Beijing experienced rapid industrialization after 1949. This transformation accumulated the firmest economic base in the “entrance” stage to develop market-based economy. Beijing in the “soar” stage depended upon the advantages of human resources and political resources, provided development opportunities to private enterprises. That further absorbed immigration but challenged social resilience. In the “coursing” stage, Beijing seized the opportunity to hold 2008 Olympic summer games with great efforts to municipal construction including housing development, transportation construction, and other public service. However, by compering her neighborhoods, the urban growth of Beijing has been relatively far beyond them. Thereby, population increased too fast to use enough *per capita* public infrastructure and service, so that urban resilience was challenged when ecological resilience becomes weak to shrink the tensions between social resilience and economic growth.

Beijing as the capital city of PRC demonstrates the outcomes of central planning for sustainable urban policies of China’s context. Since April 1st in 2017, the Xiongan new special zone is designed as the vice capital of PRC in a millennium plan to partake the non-capital function of Beijing in the strategic future. Its growth space is questionable, and its impacts on Beijing's future development are uncertain. Policy options for responses to its future changes in regional resilience thus require insightful discussion. Many cities have existed over millennium years in the long history of China. Some of them were located close to the past capital cities. For instance, Xi'an as the capital city of Shanxi Province is one of firmest historic cities, such like Xianyang and Weinan are near to Xi'an, but their development has been far behind Xi'an in recent millennium years. Nanjing as the capital city of Jiangsu Province is another firmest historic city. Only Yangzhou, one of many cities near to Nanjing, has been well developed because where was a key wharf on the Beijing-Hangzhou Grand Canal[7]. Tianjin close to Beijing, becomes a large city because its location is a large seaport. Such like Shanghai close to Suzhou, has been advanced developed even much larger than Suzhou because of the booming marine technology after the Song Dynasty (A.D. 960−1279). Whereas, other inland small cities take different supportive functions to their close large cities and gradually constrained by the limitation of resources. Because recent rapid growth of Beijing population is caused by a large amount of household migration who follow higher salary and higher education opportunities. Central planning is trying to let Xiongan to lower down the increase of population growth in Beijing and Tianjin. While, the significance of Xiongan is to design a far-sight framework of urban growth for coursing to a demonstrative path of eco-urbanization for the Beijing-Tianjin-Hebei region. Thus, the main function of Xiongan should be clarified firstly depending upon its regional features even if it has been designed as the vice capital in political position.

Beijing as the representative megacity experienced rapid industrialization with abusing environmental capacity after the "entrance" stage during 1990s-2000s. If Xiongan plan has long-term positive contributions to regional development, ecosystem planning with functional landscape architecture is the first line of regional planning for cohering with strict principles, targets, standards, and regulations of environmental assessment and monitoring. An old saying[8] in Chinese history means to develop a nation must depend upon geological and geographical characteristics. Ecological conservation area and local environmental capacity predetermine the growth space of social production. The smart pathway of urban growth relies on minimizing the environmental impacts in advance, by predicting regional dynamic changes of simulated firm location options, and to provide scenario analysis for future development options. For instance, before 1990s, Beijing strategically held some cultivated farm land or bare land around those chemical factories which aimed to segregate environmental impacts directly spreading to urban core. However, rapid urbanized progress even led to renewal on some polluted land in a short period. Thus, urban manufacture is not something horrible, but lack of updated smarter planning schemes is the crux of cities lack of ecological wisdom. For instance, Xiongan includes three counties: Xiong, Anxin, and Rongcheng which are around the Bai-yang Lake, the largest lake in Hebei Province. To protect water quality from degradation,

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[7] This Grand Canal started to construct in 486 B.C. during the Kingdom of Qin (888-221 B.C.) before the Qin Dynasty (221-207 B.C.), and almost completed during the Sui Dynasty (A.D. 581-618).

[8] This is the saying "国必依山川" by a senior official (Boyafu) in the Western Zhou Dynasty (1046-771 BC) and is recorded in the first Chinese national style history book (Guóyǔ, 《国语》 in Chinese).

higher standards of industrial establishments are necessary.

Beijing was used to suffer from sandy storms and severe chemical pollutions before 2010s, but higher standards of industrial establishments enhance environmental regulations to minimize the environmental impacts in advance during the “coursing” stage. Rapid industrialization in Beijing occurred during 1950s-1980s. Because of slack regulations to environmental assessment, some production security events in those chemical factories in fact were used to occur even though there were rarely reported in the information era after 2000. Since those chemical and steel factories moved out of Beijing during the “soar” stage for holding 2008 Olympic Games, ecological construction and advanced criteria of new establishments have benefited to local environmental performance. Although fogs and hazes seemingly decreased the environmental quality of Beijing during the “coursing” stage, the higher standards to lower the environmental impacts of manufacture factories should not be ignored, and their contributions to the economic base of future regional development are significant. This indicates modern industrialization are necessary for lowing environmental impacts in advance rather than close all factories.

The development pathway of Beijing benefited from the increasing accessibility. The construction of high quality roads, plenty parking lots, and possible docks, subways, bridges, airports, etc., these gray infrastructures contributed to enhance the function of local ecosystem (Deng, Gibson & Jia, 2017). Thereby, lack of *per capita* municipal infrastructures lowers the urban resilience level. We have seen the actual economic losses from the environmental losses when natural hazards occurred in Beijing. It implies to the development pathway of surrounding area such like Xiongan to design a smart resource recycling system for regional urban-rural coordinative development. By considering a millennium plan, municipal construction of pipe lines, utilities capacity, and waste quantity need to reserve a growth space to future changes and renewals. In other words, these thresholds of urban resilience are better planned for future growth space. To develop an area on the pathway of eco-urbanization, how large the regional environmental capacity can support future population growth? How much ecological construction can coordinate the economic growth and the population growth to keep an advanced level of the standard of living on the sustainable development pathway? In this urban growth pathway, resource recycling may play a key role, and how to return the benefits back to the area? For instance, waste classification bins have been posited in many communities of Beijing. However, because municipal sanitation department does not have the capability to collect classified garbage, mixed garbage still put into these classified bins. Hopefully in near future, a smart resource recycling system can avoid this kind of lessons from failures to update environmental infrastructures.

Beijing is transforming to a high-tech-centered city for serving more people in the more livable space. Whatever she can be an innovative city, or a smart city, or a green city, or any other kind of city in ideal plans. Her claims for high-technology would not mean to just absorb high-tech industries. As if Beijing relied on manufacture production in the “entrance” stage, transformed to a consumption-centered city in the “soar” stage, and has become a financial and R&D center in the “coursing” stage. In that, multi-sectors crucially contribute to local economic prosperity in a long run.

More importantly, the positive spillover effects of high-techniques on industrial establishments have capacity to control potential environmental impacts by complying with higher standards of environmental regulations. Such as an advanced resource recycling system increases the resource use efficiency to optimize economic efficiency reallocation across various sectors. Thus, a well-designed plan has critical function to serve the market allocation along with a well-implemented system of managerial institutions, and ultimately letting consumer demands drive the economic growth with coherence of a higher standard of environmental quality.

6 Conclusion

We analyzed 139 urban resilience indicators from a social-economic-ecological perspective to deeply understand the systematic cohesion on the development pathway of Beijing during 1978-2015. By comprehensively studying each set of resilience indicators, we figured out the merits and demerits in the past development pathway to draw lessons from the history for learning the implications of a demonstrative pathway to eco-urbanization.

Beijing has experienced over 3000 years in the history of urban development, which has been the center of political geography position in East Asia since the Ming Dynasty in A.D. 1421. Modern Beijing in the New China experienced rapid industrialization during 1950s-1970s by following the Chairman Mao’s strategic urban plan. This laid the foundation of rapid economic growth after opening policy and reformation in 1978. The analytic results show the development pathway in three stages of modern Beijing’s social-economic-ecological system after 1978. We called the first stage during 1978-1996 as “entrance”, the second stage during 1997-2002 as “soar”, and the third stage during 2003-2015 as “coursing”. Those basic industries such like steel and chemical factories supported auto manufactories development, so that had great contribution to regional economic development during the “entrance” stage. However, during the “soar” stage, lax environmental regulations induced environmental degradations in Beijing-Tianjin-Hebei region. With public opinions getting concern about environmental quality, most of highly polluting factories have been moved out of Beijing. With population and income increases, the demand of higher quality of life has driven consumption rise significantly during the “coursing” stage. Consequently, the income inequality has intensified environmental inequality even though Beijing completed industrial transformation to become a financial and R&D center. Over 80 *per cent* of GDP was from the tertiary industry in 2015. However, environmental quality had been getting worse since 2010 because *per capita* ecological infrastructures construction and the quality of public service were lowered during this stage. Thus, the development pathway of Beijing indicates that her sustainable consumption doesn’t mean to limit individual consumption, but to provide more options to consume goods and services and concomitantly lower negative environmental impacts.

In the context of the “Xiongan new special zone” strategic plan released on April 1st in 2017, this research implies to the places surrounding Beijing in the Beijing-Tianjin-Hebei region for coursing to a demonstration pilot path of eco-urbanization in five aspects in the current new stage: 1) to clarify ecological function of an area contributing to a region based on scenarios analysis of population growth for identifying the strategic growth space; 2) to design functional landscape architecture with taking consideration of an environmental capacity for supporting the urban growth path; 3) to update advanced regulations of environmental assessment and monitoring for enhancing the standards of industrial establishments; 4) to adopt high-technology in environmental infrastructures for constructing a smart resource recycling system, and supporting multi-sectors development in a long run; and 5) to optimize a well-designed planning system to dynamically serve market allocation, and let strict implementation of institutions and regulations guarantee consumption demands being the main drive to accomplish the multi-targets of regional development.

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Conflicts of Interest

The authors declare no conflict of interests.

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