Evaluation of urban development quality of the coastal cities around the Bohai Rim

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Abstract. The quality of urban development is an important symbol reflecting the level national modernization. Here, we examine the cities in the Bohai Rim coastal area and establish an urban development quality index system based on four aspects of urban development: residents living, humanistic environment, environmental protection, and economic development. We then used the CRITIC-TOPSIS analysis method to evaluate the coastal node cities. Based on our results, we found that the quality of urban development in the Bohai Rim coastal can be represented by a “pyramid”, the distribution of urban development quality is unequal, and the node cities are divided into five grades. We hope that our novel approach could be helpful for the assessment of urban development quality.

1. Introduction
The term “urbanization” describes the urban agglomeration of non-agricultural industry and the redistribution of the rural population to cities. Furthermore, urbanization is considered an important symbol of modernization for a society. In the past 20 years, China’s urbanization rate has continued to grow by about 1% a year [1]. However, this transformation has been accompanied with increasingly prominent issues including traffic congestion and serious environmental pollution. The quality of city development becomes the focus of the whole society. In March 2014, the CPC Central Committee and the State Council officially issued the “National Plan on New Urbanization (2014-2020)” (hereinafter referred to as “The Plan”) which proposes to promote the coordinated development of cities and small towns, based on improving the spatial layout of eastern city clusters. This strategy aligns with the promotion of “quality” as a point of emphasis for city development. Therefore, it serves as a practical guide to explore how to achieve quality urban development.

2. Literature review
Domestic and foreign scholars have conducted extensive research on urban development quality at both the macroscopic (region, province domain) and microscopic (city, county) levels. Researchers have mainly focused on the evaluation of urban development quality, scale, and spatial difference analyses. For example, LiLei and Zhang Guixiang [2] constructed an index system to explore the quality of urban development in Beijing-Tianjin-Hebei region. They discovered that uneven urbanization between the groups resulted in a “double core”, in which Beijing and Tianjin exhibit prominent radiation effects and attracting effects. Ma Jing et al. [3] explored and analyzed spatial spillover effects and regional differences of city cluster in the middle reaches of the Yangtze River. Yang Lulu [4] analyzed the spatial evolution of urbanization quality in six provinces in central China focusing on urban development level, urban development efficiency, and urban-rural coordinated
development. Liu Jianguo [5] evaluated the urbanization quality in Chinese provinces, and found that the decisive factors were the levels of economic and infrastructure development. Yang Haotian et al. [6] used inner Mongolia as an example and studied urban development quality based on two factors: urban development level and degree of city development coordination. Yang wen [7] constructed an index system using five dimensions which included economic development, infrastructure, social development, residential life, and habitat environment. They then analyzed the development quality of the 288 cities, at prefecture level and above, in China. They found that the quality of urban development had regional characteristics and was influenced by the level of economic development. Yu Tao et al. [8] constructed an evaluation index system at the county level which aimed to study the problems encountered in the late stages of urban development. The results of this study were used to propose future overall development strategies.

When evaluating the quality of urban development, most scholars use different index systems, for example, an index system based on “economy, life, society, infrastructure, ecology” to study urban modernization and urban-rural integration [2, 4, 7], an index system based on “material, cultural and ethical, and ecological” to evaluate the urban civilization [9], and an index system based on “population, economy, resources, and environment” to examine development from an internal and multisystem perspective. Each index system is designed with its own emphases in mind, but in general these systems overlook the internal driving forces of innovation. However, “The Plan” promotes the construction of new cities with aims to “promote the development of green cities and smart cities”.

Here, we have designed an index system encompassing four aspects of “people-oriented” aspects of residents living, humanistic environment, environmental protection, and economic development. We examine the objective data as a whole to study increases and decreases in a city’s “quantity” of urbanization as well as the change in “quality” of urbanization in the Bohai Rim coastal area. We then evaluated the quality of the development of cities in this region.

3. Research methods

3.1. Methods overview

Evaluating the quality of urban development has yielded fruitful results. In general, these analyses mainly use subjective weighting, such as Delphi method, Analytic hierarchy process, and objective weighting like principal component analysis, factor analysis, entropy, data envelopment analysis, and the fuzzy comprehensive evaluation etc. A weakness of the subjective weighting method is that it has too many subjective factors. Principal component analysis or factor analysis methods condense the index, which leads to the problem of information loss, and the results of entropy analysis are difficult to compare across studies. The data envelopment analysis method is limited by the input and output factors, and the index coverage is relatively narrow. The fuzzy comprehensive evaluation method employs greater subjectivity in the determination of weights assignment.

Therefore, in order to measure the quality of urban development scientifically, we chose to use criteria importance though intercriterial correlation method [10] and technique for order preference by similarity to an ideal solution method [11] (hereinafter referred to as “CRITIC-TOPSIS”). The central idea of the CRITIC method uses the contrast between evaluation indicators to reflect the objective weight. The contrast intensity reveals the difference between indicators; larger values indicate a greater difference between the schemes. This method can solve the problem of multi-attribute decision making, and it meets the requirements of weight calculation in this paper. The TOPSIS method is a multi-objective decision making analysis proposed by Hwang and Yoon in 1981. This method is used to identify the virtual positive and negative ideal solutions. CRITIC-TOPSIS method can solve the problem of multi-attribute decision making, and it meets the requirements of weight calculation in this paper.
3.2. Specific steps

Here, we assigned \( m \) as the evaluation object with \( n \) evaluation indicators, \( t_1, t_2, \ldots, t_3 \) refer to the original data matrix of the corresponding evaluation index of each year in chronological order.

\[
X = x_{ij}(t_k) (i = 1, 2, \ldots, m; n = 1, 2, \ldots, n; k = 1, 2, \ldots, k)
\]

(1)

The first step is to process the raw data in a dimensionless way. \( Y = y_{ij} \):

\[
y_{ij} = \begin{cases} 
\frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}, & \text{The bigger the optimal type indicator} \\
\frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}, & \text{The smaller type indicator}
\end{cases}
\]

(2)

In the second step, the correlation coefficient between the characteristic values \( R_{ij} \) is calculated using SPSS to analyze the correlations of the dimensionless processing indicators.

In the third step, the contrast intensity between indicators is calculated by measuring the difference of data between indicators. The contrast between indicators is expressed by the difference coefficient:

\[
h_j = \frac{\sigma_j}{x_j}
\]

(3)

The fourth step is to calculate the amount of information, \( G_j \), contained in the \( j \) indicators:

\[
G_j = h_j \sum_{j=1}^{\infty} (1 - R_{ij})
\]

(4)

The fifth step is to calculate the weight value of evaluation indicators: \( w_j \)

\[
w_j = \frac{G_j}{\sum_{j=1}^{\infty} G_j}
\]

(5)

The sixth step is to calculate the weighted normalized matrix \( F \):

\[
F = f_{ij}(t_k) = w_j y_{ij}(t_k)
\]

(6)

The seventh step is to calculate positive and negative ideal solutions:

\[
F^* = (\max_{1 \leq i \leq m} \max_{1 \leq k \leq N} f_{ij}(t_k)) = (f_1^*, f_2^*, \ldots, f_n^*)
\]

\[
F^- = (\min_{1 \leq i \leq m} \min_{1 \leq k \leq N} f_{ij}(t_k)) = (f_1^-, f_2^-, \ldots, f_n^-)
\]

(7)

The eighth step is to calculate the distance between the positive ideal and the negative ideal solution.

The distance to the positive ideal solution is:

\[
d^*_i(t_k) = \sqrt{\sum_{j=1}^{\infty} (f_{ij}(t_k) - f_j^*)^2}
\]

(8)

The distance to the negative ideal solution is:

\[
d^-_i(t_k) = \sqrt{\sum_{j=1}^{\infty} (f_{ij}(t_k) - f_j^-)^2}
\]

(9)
The ninth step is to calculate the relative closeness of each scheme:

\[ C_i^*(t_k) = \frac{d_{i+}(t_k)}{d_{i+}(t_k)+d_{i-}(t_k)} \]  \hspace{1cm} (10)

To take into account the increase in the metric value, we followed these steps:

The first step is to calculate the growth coefficient matrix: \( b_{ij}(t_k) \)

\[ b_{ij}(t_k) = f_{ij}(t_k) - f_{ij}(t_{k-1}) \]  \hspace{1cm} (11)

In the second step, we calculate the weighted growth coefficient matrix: \( \Delta F \)

\[ \Delta F = \Delta f_{ij}(t_k) = w_jb_{ij}(t_k) \]  \hspace{1cm} (12)

In the third step, we calculate the positive ideal and negative ideal solution of the growth coefficient matrix:

Positive ideal solution:

\[ \Delta F^+ = \max_{1 \leq i \leq m} \max_{1 \leq j \leq nN} (\Delta f_{ij}^*(t_k)) = (\Delta f_{1+}^*, \Delta f_{2+}^*, \ldots, \Delta f_{n+}^*) \]  \hspace{1cm} (13)

Negative ideal Solution:

\[ \Delta F^- = \min_{1 \leq i \leq m} \min_{1 \leq j \leq nN} \Delta f_{ij}(t_k) = (\Delta f_{1-}^*, \Delta f_{2-}^*, \ldots, \Delta f_{n-}^*) \]  \hspace{1cm} (14)

The fourth step is to calculate the distance between the positive ideal solution and the negative ideal solution.

The distance to the positive ideal solution is:

\[ \Delta d_i^*(t_k) = \sqrt{\sum_{j=1}^{n}(\Delta f_{ij}^*(t_k) - \Delta f_j^*)^2} \]  \hspace{1cm} (15)

The distance to the negative ideal solution is:

\[ \Delta d_i^-(t_k) = \sqrt{\sum_{j=1}^{n}(\Delta f_{ij}(t_k) - \Delta f_j^-)^2} \]  \hspace{1cm} (16)

The fifth step is to calculate the closeness of the evaluated object:

\[ \Delta C_i^* = \frac{\Delta d_i^*(t_k)}{\Delta d_i^*(t_k)+\Delta d_i^-(t_k)} \]  \hspace{1cm} (17)

The sixth step is calculate the comprehensive evaluation value of each scheme in time \( t_k \) (taking into account the degree of difference and the degree of increase of the index value)

\[ u_i(t_k) = \alpha C_i^*(t_k) + \beta \Delta C_i^*(t_k) (0 \leq \alpha, \beta \leq 1, \alpha + \beta = 1) \]  \hspace{1cm} (18)

In order to compare the overall situation of the rated object in the \( t_1 \) to \( t_k \) time period, we attempt to weighted two times, and the synthetic evaluation value of the \( i \) evaluated object is:

\[ g_i = \sum_{k=2}^{N} w_k u_i(t_k) \left( \sum_{k=2}^{N} w_k = 1, w_k > 0, w_k = \frac{k}{\sum_{k=2}^{N} k} \right) \]  \hspace{1cm} (19)
4. Model and index system

4.1. Model building
Here, the urban development quality system encompasses four aspects of residents living, humanistic environment, environmental protection, and economic development. The quality of residents living is the basic condition of urban development. A good living quality is conducive to the steady development of the city. This relationship is the foundation for evaluating the quality of urban development. High quality of humanistic environment is a precondition for urban development. Environmental protection quality is another key factor because sustainable development is the only way for the residents to improve their living conditions and enjoy a healthy way of life. Economic development is the fundamental approach to improve the quality of urban development, the improvement of urban development quality cannot be separated from economic support. Based on this premise, we propose the following urban development quality model (figure 1).

![Quality model of urban development](image)

**Figure 1.** Quality model of urban development.

4.2. Index system construction

4.2.1. Quality of residents living. The quality of the residents living is mainly manifested in the following three ways:

*Living environment:* Living environment refers to the public infrastructure related to living conditions. The basis for urban development is to allow residents to experience good living conditions and thus speed up the improvement of urban development quality. Therefore, the better the living environment, the better the quality of urban development.

*Public service:* Urban public service could directly promote population influx to city [12]. The improvement of public service is conducive to the steady development of urban quality.

*Living security:* Living security refers to the basic privileges and amenities that city-dwellers are entitled to, and it affects the speed of urbanization [13].
4.2.2. Quality of humanistic environment. Humanistic environment is an important factor which drives city formation and development. It is mainly judged on the basis of population growth and cultural resources.

Population growth: The driving force and aim of urban development is to serve the people and satisfy the needs of residents. The larger the population, the higher the rate of urbanization, and the greater the ability to provide a stable workforce to support further urban development [14].

Cultural resources: Culture is the crystallization of human wisdom and the vehicle for human progress. The more culture progresses, the more innovative it is, and the more willing city-dwellers is to stay in the city.

4.2.3. Quality of environmental protection. To take a sustainable development approach requires to strengthen the quality of environmental protections [15].

Environmental remediation: New urbanization and construction of ecological cities are two of China’s current goals. However, these goals do not always align. Rapid advancement of urbanization will increase environmental pollution in China, and resource conservation will restrict the development of urbanization.

Environmental protection: Environmental protection refers to providing appropriate protection for the environment to ensure human survival and sustainable urban development.

4.2.4. Quality of economic development. The quality of economic development refers to the degree that a city is able to meet the economic needs of the society it serves. High-quality economic development improves regional economic benefits and optimizes the economic structure [16].

Efficiency and benefits: The efficiency of economic development refers to the relationship between input and output in the process of economic development, while maintaining an appropriate pace.

Coordination and sharing: Coordination is a basic requirement for sustainable economic development. Sharing is the fundamental aim of economic development, and the coordination and sharing of economic development reflects successful transformation to an advanced mode of development.

Innovation: Scientific and technological innovation promotes an increase of the urban economy. Furthermore, innovation influences people’s mindsets and values by changing the environment in which they live. These changes affect how social organizations form, which is capable of penetrating into all spheres of life and subsequently affecting the urbanization process [17]. All indicators and the related interpretation are shown in table 1 as follows.

| Table 1. Construction of quality Index system for urban development. |
|---------------------------------------------------------------|
| First-level indicators | Secondary indicators | Third indicators | Indicator interpretation | Property |
|------------------------|----------------------|------------------|-------------------------|----------|
| Living Environment     | Road surface area per capita (sq. m) | To characterize the population’s stress on the road | Positive |
|                        | Area of land used for urban construction (sq. m) | To characterize the utilization of urban land space | Positive |
|                        | Number of bridges (unit) | To characterize the construction of urban bridge facilities | Positive |
| Quality of residents living | Number of regular secondary schools and primary schools | To characterize the construction of urban compulsory education schools | Positive |
|                        | Proportion of full-time teachers to regular secondary schools and primary schools | To reflect the adequacy of teacher strength in primary education | Positive |
| Public Service         | Proportion of full-time teachers in regular institution of higher education | To reflect the adequacy of teachers’ strength in higher education | Positive |
|                        | Number of hospital beds per 10000 persons | To reflect the adequacy of urban medical and health resources | Positive |
| Category                                      | Indicator                                                                 | Purpose                                                                 | Sign  |
|-----------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------|-------|
| Life Security                                 | Number of doctors per 10000 persons                                       | To reflect the adequacy of rural medical and health resources           | Positive |
|                                               | Proportion of tertiary industry employees (%)                             | Reflecting employment in the service sector                              | Positive |
|                                               | Average wage of employed staff and workers (yuan)                         | Representation of workers’ remuneration                                  | Positive |
|                                               | Number of employees joining urban basic pension insurance (person)        | To characterize the security of employees’ endowment insurance          | Positive |
| Population Growth                             | Number of employees joining urban basic medical care system (person)      | To characterize medical insurance                                       | Positive |
|                                               | Registered unemployment rate in urban areas (%)                           | To characterize the level of urban unemployment                          | Negative |
|                                               | Persons covered of unemployment insurance (person)                       | To characterize unemployment Insurance                                   | Positive |
|                                               | Permanent resident (10000 persons)                                       | To reflect the living conditions of the urban population                 | Positive |
|                                               | Population density (people/sq km)                                        | To reflect the static pressure of the population on the environment     | Positive |
| Quality of Humanistic Environment             | Student enrollment of regular institution of higher education per 10000 persons (person) | To reflect the adequacy of high-end human resources                      | Positive |
|                                               | Natural growth rate (%)                                                  | To reflect the dynamic pressure of the population on the environment   | Positive |
|                                               | Number of public libraries (unit)                                        | To characterize the adequacy of public cultural facilities             | Positive |
|                                               | Number of theatres and cinemas (unit)                                    | To characterize the development level of the cultural industry          | Positive |
| Cultural Resources                            | Collection of public libraries per 100 persons (copy, piece)              | To characterize the development scale of public culture                 | Positive |
|                                               | Volume of industrial waste water (10000 tons)                            | To reflect the emission of pollutants from urban industrial wastewater  | Negative |
| Environmental Remediation                     | Volume of sulfur dioxide emission (ton)                                  | To reflect air pollutant emissions                                      | Negative |
|                                               | Volume of industrial soot (dust) emission (ton)                          | Characterization of sewage treatment strength                           | Positive |
| Quality of Environmental Protection           | Ratio of Waste water Centralized Treated of Sewage Work(%)               | Characterization of water saving level                                  | Positive |
|                                               | Environmental Protection Wastewater treatment rate (%)                    | Characterization of urban landscaping and ecological environmental protection | Positive |
|                                               | Green covered area as % of completed area (%)                            | To characterize the harmless treatment strength of domestic waste      | Positive |
|                                               | Ratio of consumption waste treated (%)                                   | To reflect the level of enterprise economic activity                     | Positive |
| Efficiency and Benefits                       | Social labor productivity                                                | To reflect the level of economic development                           | Positive |
| Quality of Economic Development               | Ratio of per capita GDP growth (%)                                       | To reflect the efficiency of investment                                  | Positive |
|                                               | Input-output ratio (%)                                                   | To characterize the degree of optimization of urban industrial structure | Positive |
|                                               | Tertiary industry as percentage to GRP (%)                               | To characterize the degree of optimization of urban industrial structure | Positive |
| Coordination and Sharing                      | Per capita disposable income as percentage of GDP per capita (%)         | To characterize the degree of optimization of urban industrial structure | Positive |
|                                               | Per capita disposable income ratio of urban and rural households         | To characterize the income gap between urban and rural residents        | Positive |
5. Empirical evaluation and comparative analysis

5.1. Data sources
The Bohai Rim coastal cities include Beijing, Tianjin, Hebei, Liaoning, and Shandong province. In 2015, 14 coastal cities achieved a production value of 13.4511 trillion yuan, accounting for 19.52% of the GDP of China. This demonstrates that the Bohai Rim coastal area is an important driving force for China’s economic development. From 2011 to 2015, the average population of these areas increased by 6.682 million. Here, we ask what problems will emerge through the process of urbanization and economic development?

We will analyze data for the node cities in the coastal cooperation zone to objectively evaluate the key indexes influencing the quality of urban development. Our aims in this study are to facilitate the evaluation of urban development quality, explore new ways to promote the development of urbanization, and to provide some support for solving the increasing “urban disease” phenomenon. Therefore, we selected the Bohai Rim coastal area as our research subject, and all index data are obtained from “China Urban Statistical Yearbook” (2012-2016), “China Urban Construction Statistical Yearbook” (2011-2015), “Shandong Province Statistical Yearbook” (2012-2016), “Liaoning Statistical Yearbook” (2012-2016), “Hebei Economic Yearbook” (2012-2016), and the national Economic and Social Development Statistics Bulletin. To compensate for missing data, we used Excel data prediction to facilitate evaluation and analysis.

5.2. Analysis of results
For the industry innovation data from 2011-2015, we used the CRITIC-TOPSIS method to calculate the weight and evaluation value of each index (see table 2, figure 2 and figure 3).

Table 2. Weight of urban development quality index in Bohai Rim coastal area.

| First-level indicators                        | Weight value | Secondary indicators            | Weight value |
|-----------------------------------------------|--------------|---------------------------------|--------------|
| Quality of residents living                   | 0.4063       | Living environment              | 0.1433       |
|                                               |              | Public service                  | 0.0967       |
|                                               |              | Life security                   | 0.1663       |
| Quality of humanistic environment             | 0.1997       | Population growth               | 0.0928       |
|                                               |              | Cultural resources              | 0.1069       |
| Quality of environmental protection           | 0.0654       | Environmental remediation       | 0.0235       |
|                                               |              | Environmental protection        | 0.0419       |
|                                               |              | Efficiency and benefits         | 0.0508       |
| Quality of economic development               | 0.3286       | Coordinated and sharing         | 0.0751       |
|                                               |              | Innovation                      | 0.2027       |
Figure 2. Comprehensive evaluation value of urban development quality in the Bohai Rim coastal area.

Figure 3. Comprehensive evaluation value of the indexes of the Bohai Rim coastal cities.

Table 2 shows that currently the urban development quality of the Bohai Rim coastal area is greatly influenced by the quality of residents living and economic development. These are the two most important factors affecting the development of the city, which strongly influences the quality of urban development. The influence of humanistic environment is relatively weaker. Since the influence of population growth and the cultural resources are similar, it indicates that the quality of humanistic environment is in a relatively stable state. Figure 2 and figure 3 show respectively comprehensive evaluation value and the status of each index of urban development quality.

Cluster analysis is a frequently used applied statistical technique that helps to reveal hidden structures and "clusters" found in data sets [18]. Entities or objects of interest are grouped together based on attributes that make them similar, with the final goal being to distinguish these entities or objects by clustering them into comparable groups and to separate them from differing groups. To clearly see the development status of the urban quality, we used SPSS to conduct a cluster analysis
based on the comprehensive evaluation values for each node city in figure 2. The results were divided into the following five grades (figure 4).

**Regional Grade I:** Highest quality of urban development. This division contains only Beijing. The indicators are almost in the position of leading shown in figure 2 and figure 3.

**Regional Grade II:** Higher quality of urban development. This division contains only Tianjin. This city, located near Beijing, has a unique geographical advantage. Both its economic development quality and environmental protection quality are high. However, an imbalance exists in the quality of residents living and humanistic environment, which lowers the overall urban development quality of the city.

**Regional Grade III:** The quality of urban development is mid-range. This division contains three coastal cities: Dalian, Jinan, and Qingdao. Environmental development quality is relatively high, while the quality of residents living, economic development, and humanistic environment are all mid-range.

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**Figure 4.** Hierarchical diagram of the urban development quality of the node cities.
Regional Grade IV: The quality of urban development is lower. This division includes five cities: Handan, Baoding, Shijiazhuang, Weifang, Shenyang. These cities have lower economic development quality, humanistic environment quality, and residents living quality.

Regional Grade V: The quality of urban development is low. This division includes the rest 21 cities. Environmental protection quality of these areas is mostly in the middle and lower ranges. The quality of economic development is insufficient, the quality of humanistic environment and the quality of residents living are also poor.

In conclusion, the quality of urban development in the node cities of the Bohai Rim Coastal Cooperation Zone can be described by a “pyramid”: very little of the urban development quality is high, while more than two-thirds of the urban development quality is at a low level, revealing a clear gap in development quality between cities.

6. Conclusions
This paper analyzes the concepts of a “Green City”, “Smart City”, and “Humanistic City” for promoting the construction of new cities as proposed by “The Plan”. Here, we have constructed a “people-oriented” index system encompassing four aspects of urban development including residents living, humanistic environment, environmental protection, and economic development. We have unified the objective data to study changes in both “the quality” and “the quantity” of city development in the Bohai Rim Coastal Cooperation Zone. We systematically analyzed four years of data from 2012 to 2015 using the CRITIC-TOPSIS method based on evaluation objects and evaluation index. Our results show that: 1) the quality of urban development in the Bohai Rim coastal can be represented by a “pyramid”: only a few cities have high quality urban development, whereas most cities exhibit low quality urban development; 2) The residents living quality plays a central role in the development of cities. Comparatively speaking, the quality of environmental protection plays a smaller role in urban development for the Bohai Rim coastal area, but it is generally greater than the other factors that were evaluated; 3) The distribution of urban development quality in Bohai Rim coastal area is unequal. The growth range for urban development in each major city quality exhibits a non-linear relationship, with clear differences between cities. Currently, this restricts the amount of quality urban development in the region.

Comparing with other research about urban quality, the difference of the growth for each city is considered here, instead of static evaluation in most papers. Development of the cities is paid more attention to. That is, the urban development quality is investigated from dynamic perspective. To further improve the urban development quality, it is necessary to maintain steady development focused on developing quality humanistic environment and economic development, and to strengthen the residents living quality. Furthermore, we should increase the overall support to improve cities that have low urban development quality to minimize the differences in quality urban development between cities.

Acknowledgements
This paper is supported by the National Natural Science Foundation of China (Grant No. J1624001), Beijing Nova Program Interdisciplinary Cooperation Project (Z181100006218123), BWU Program for Cooperative Research Team (2017GG06).

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