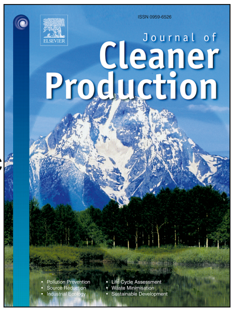

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Credit Author Statement

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Title

Multiscale assessment of the coupling coordination between innovation and economic development in resource-based cities: A case study of Northeast China

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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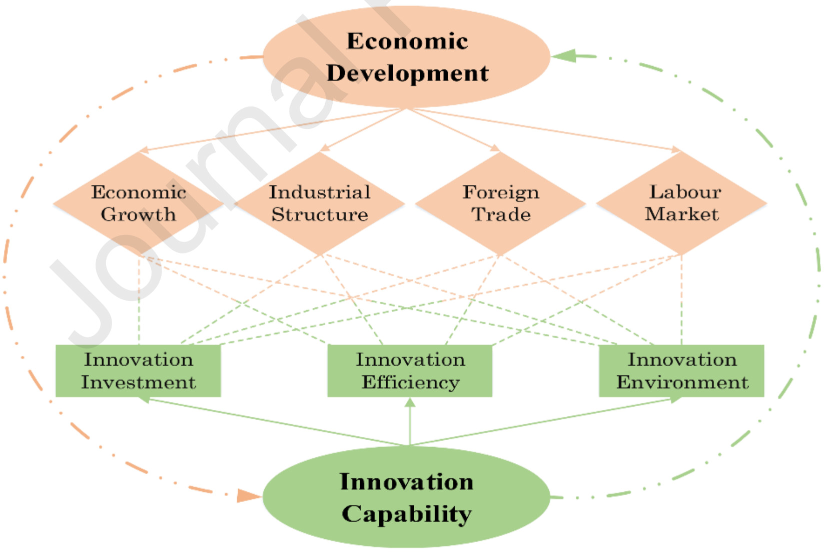
Multiscale assessment of the coupling coordination between innovation and economic development in resource-based cities: A case study of Northeast China

Abstract: The coordinated advancement of innovation and economic development is an inevitable problem for urban areas in China, among which resource-based cities confront more complex difficulties because of the continuous depletion of natural resources. However, little work has been done to measure the coupling coordination between innovation capability (IC) and economic development (ED) in resource-based cities. This study, therefore, calculated the coupling coordination degree (CCD) between IC and ED of resource-based cities in Northeast China from different regions with different resource types at different development stages. Moreover, the geographical detector further was employed to distinguish the influencing factors of CCD. The empirical results show that from 2013 to 2018, the coordinated development between ED and IC performed poorly in northeastern resource-based cities and experienced an obvious decoupling phenomenon. For the different regions, different resource types, and different development stages, the difference in CCD performance was significant among the northeastern resource-based cities. By comparing the influencing factors, the spatial heterogeneity of each indicator varied greatly, and the indicators of IC collectively had a stronger power determinant than ED in stimulating coordinated development.

Graphical Abstract:



Keywords: Coupling coordination degree; Innovation capability; Economic development; Geographical detector; Resource-based cities

Highlights:

(1) Coupling coordination of economic development and innovation capability is assessed.

(2) Geographical detector is used to identify the heterogeneous influence of indicator.

(3) Coordinated development of resource-based cities performs poorly.

(4) Innovation capability has a stronger power determinant than economic development.

(5) Coupling coordination is varied in different resource types or development stages.

Abbreviations			
IC	innovation capability	MC	moderate coordination
ED	economic development	RC	reluctant coordination
CCD	coupling coordination degree	II	imminent imbalance
WAO	weighted arithmetic operator	MI	moderate imbalance
EC	extreme coordination	SI	serious imbalance
		PD	power determinants

1. Introduction

Resource-based cities are defined as those for which economic growth mainly depends on the exploitation and processing of natural resources (Yu et al., 2015), and resource-intensive industries are the dominating part of their economic structure (Li and Dewan, 2017). In the last few decades, resource-based cities, accounting for 17.8% of all cities, have provided abundant resources and made tremendous contributions to economic development in China (Liu et al., 2021). However, with the excessive depletion of natural resources, a shrinking city characterized by population loss, a serious imbalance between innovation and economic development, and a trend of ecological deterioration are common phenomena observed throughout resource-based cities (Martinez-Fernandez et al., 2012; Hoekveld, 2012). In 2013, the State Council issued the *Plan on the Sustainable Development of Resource-based Cities in China (2013-2020)* (State Council, 2013), and more than a quarter of cities (25.58%) were divided into the recession stage (Yu et al., 2016). Presently, in the context of the profound adjustment of innovation-driven development, a series of structural problems that emerged in resource-based cities have been considered the stumbling block of the comprehensive transition in China (Zhang et al., 2021). Thus, the structural transformation and sustainable development of resource-based cities have become the focal point, and a series of measures have been taken by the Chinese government to move to the intensive growth model (Liu et al., 2020). One of the major strategies is to leverage advances in innovation and enhance labor quality (Huang et al., 2012). Thus, measuring the coordinated relationship of economic development and innovation develops an important research direction to fulfill the national strategic requirements for the sustainable development of resource-based cities.

As the earliest exploitation of the industrial base, Northeast China, dominated by the metal, coal, and oil mining industries, is the most profoundly influenced by the planned economic system. Due to diminishing natural resources provoking the bankruptcy of many state-owned enterprises, the economic growth and social development of resource-based cities in Northeast China have experienced a pronounced decline since 1990. For example, the proportion of gross regional products in the northeast, including Liaoning, Jilin, and Heilongjiang, was 11.27% in 1990, and it dramatically dropped to 5.08% in 2019 (China Statistics Bureau, 2020). To mitigate these issues, a revitalizing strategy of the Northeast Old Industrial Base (NOIB) was proposed by the Chinese central government to achieve sustainable development in 2003 and 2016. It is time to estimate whether northeastern resource-based cities have obtained a coordinated relationship between economic development and innovation. Hence, this study selected resource-based cities as the research objectives to explore the coordinated development between the economy and innovation in Northeast China.

Given the above analysis, the main purpose of this study is to demonstrate the coupling coordination between the economic development and innovation capability of resource-based cities in Northeast China from 2013 to 2018 in different regions utilizing different resource types at different development stages scales. Then, the special objectives of this study are proposed through four levels: 1) to construct a practical index system for evaluating CCD; 2) to employ a weighting method based on the coordinated status of indicators among cities; 3) to explore the CCD of northeastern resource-based cities in different regions, different resource types, and different development stages; and 4) to distinguish the spatial heterogeneity of the influence of factors on CCD. Compared with the existing literature, the main contributions of this study are proposed from three aspects. First, this study evaluates the coordinated relationship between economic development and innovation in resource-based cities from a multiscale comparison. Second, the indicator weight based on the coordinated status of indicators among cities is calculated. Third, this study enriches the analysis of CCD in resource-based cities by exploring the spatial heterogeneity of influencing factors from a multiscale perspective.

The remainder of this study is arranged as follows. The existing studies are reviewed in Section 2. Section 3 provides an overview of the study area and data collection. The research methods are introduced in Section 4. Section 5 presents the results of this study. The discussion is described in Section 6. The conclusion and future works are provided in Section 7.

2. Literature review

Regarding the relationship between innovation and economic development, a series of studies have recognized that innovation directly or indirectly fosters economic growth, and economic development, in turn, stimulates innovation activities through knowledge accumulation and learning effects (Maurseth and Verspagen, 2002; Santacreu, 2015). Howells (2005) theoretically analyzed the relationship between innovation and regional economic development from a “top-down” and “bottom-up” perspective. In addition, Hasan and Tucci (2010) and Zhou et al. (2020) empirically confirmed that innovation is the main driving force of economic development. As Li and Du (2021) pointed out, economic development has a positive influence on green innovation efficiency (GIE) in China. Zhang and Cui (2020) revealed that the crowding-out effect of resources on innovation performance is key in resource-based cities. Furthermore, by using Granger causality, Maradana et al. (2019) conceded a back-and-forth relationship between economic development and innovation in the 19 European Economic Areas. From the review mentioned above, we can discover that most of the existing studies have explored the unidirectional effect between economic development and innovation, that is, the impact of innovation on economic development or the role of economic development on the improvement of innovation. However, less attention has been given to the interactive relationship between economic development and innovation, especially in resource-based cities. To compensate for these deficiencies, this study concentrates on the coupling coordination of economic development and innovation in resource-based cities.

Coupling coordination, which originated from the field of physics, refers to a close linkage between two or more subsystems (Yang et al., 2020). It emphasizes the interactive relationship of internal and external subsystem elements. Given the existence of multiple advantages, coupling coordination has been introduced into the coordinated analysis of different subsystems in the process of sustainable urban development, such as the socioeconomic and ecological environment (Xiao et al., 2021), urbanization and environment (Ariken et al., 2021), and resource utilization and environment carrying capacity (Wang et al., 2017). For the evaluation method of coupling coordination, the coupling coordination degree model has been widely used in many fields (Li et al., 2021; Zhao et al., 2017). Therefore, this study also selected this model to evaluate the interactive relationship between economic development and innovation. Furthermore, an in-depth analysis of the coordinated development between the economy and innovation would provide an effective reference for facilitating sustainable urban development.

In the real world, only if economic development and innovation capability are calculated can their coordinated relationship be assessed, and then bottlenecks can be supported across various policy adjustments. Existing studies have used many methods to evaluate the performance of economic development and innovation from either a single or integrated perspective. Regarding the assessment of innovation, Chen et al. (2009) selected the application activities of patents to evaluate the technological innovation capability of eight economic regions of China. Paas and Poltimäe (2012) and Kaynak et al. (2017) compared the innovation performance of different nations in Europe by using factor analysis and entropy-based TOPSIS, respectively. Chen et al. (2020) assessed the performance of city innovation capability in Liaoning Province, China, by using the TOPSIS-based order relation method. In terms of the measurement of economic development, Dong and Ma (2011) employed super-efficiency data envelopment analysis (DEA) model to evaluate the economic development efficiency of Shandong Province, China. Jokanović et al. (2017) used different science and technology indicators and then applied an artificial neural network approach to estimate economic development. Based on a review of the relevant studies, it appeared that most of the studies mainly concentrated on the performance of economic development and innovation capability at national, provincial, and urban levels, and less attention was given to resource-based cities. Additionally, the weighting method was widely based on the distribution characteristics of the indicator itself and ignored the coordinated relationship of the indicator among different evaluation objectives. To compensate for these deficiencies, this study followed the principle of weight calculation; that is, the more coordinated the indicator is among cities, the greater the weight is. Then, the weight of each indicator was calculated and used to aggregate the evaluation values of economic development and innovation capability.

3. Study area and data source

3.1. Study area

Northeast China is located between 38°43′N — 53°33′N and 118°53′E — 135°05′E, covering 36 cities. It covers an area of 787,300 km^2 and is abundant in natural resources. However, the exhaustion of natural resources leads to a sharp conflict between urban development and resource supply. According to the *Plan on the Sustainable Development of Resource-based Cities in China (2013−2020)*, 19 northeastern resource-based cities (accounting for 15.08%) have been cataloged by the State Council and divided into four categories based on the development stage: growth (5.26%), mature (31.58%), recession (42.11%), and regeneration (21.05%) (He et al., 2017) (column 8 of Table 1). The geographical location is shown in Fig. 1 and the soc-economic information is illustrated in Table 1. Specifically, Anshan, Benxi, Fushun, Fuxin, Huludao, and Panjin are located in Liaoning Province. The five cities in Jilin Province include Baishan, Jilin, Liaoyuan, Songyuan, and Tonghua. Daqing, Hegang, Hehei, Jixi, Mudanjiang, Qitaihe, Shuangyashan, and Yichun are situated in Heilongjiang Province. Additionally, the main resources of these cities are iron, copper, graphite, oil, magnetite, coal, natural gas, woodland, and molybdenum. Furthermore, based on the different resource-based types, this study divided 19 resource-based cities into oil&gas-based, forestry-based, coal-based, ferrous metal-based, and nonferrous metal-based cities (Chen et al., 2019) (column 7 of Table 1).

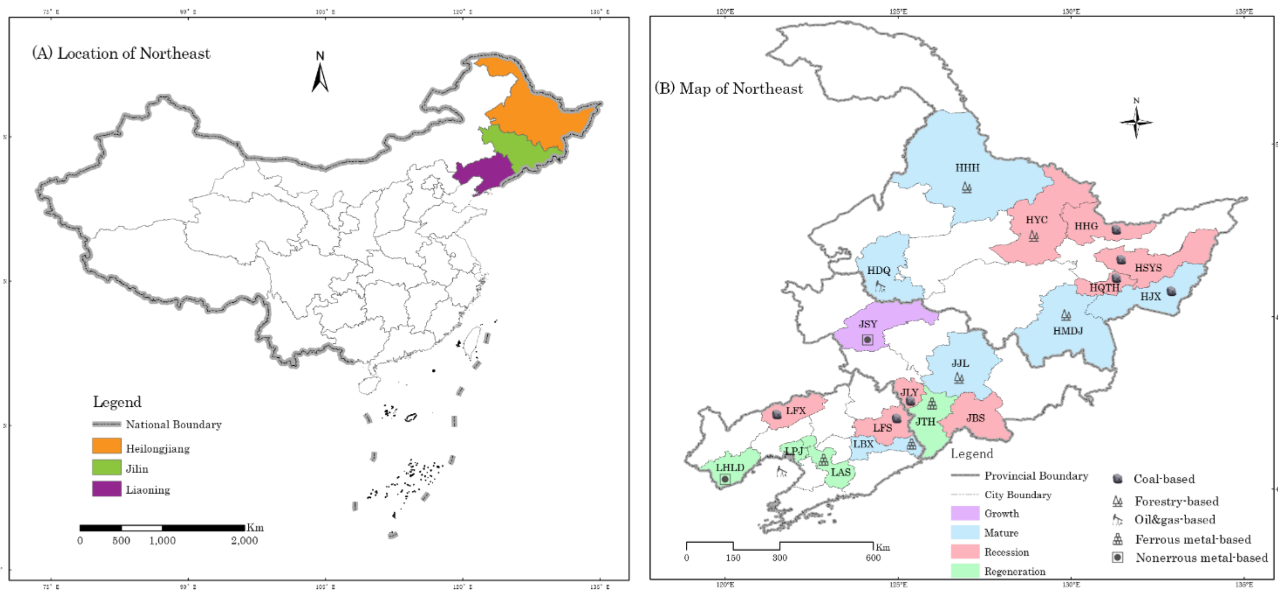


Fig. 1. The geographical location of resource-based cities in Northeast China.

Table 1

The soc-economic information of 19 resource-based cities in Northeast China.

Province	City (Abbreviation)	Per-capita GDP (USD)	Population (10^4)	Area (km^2)	Main Resource	Resource Type	Development Stage
Liaoning (LN)	Fushun (LFS)	7795.2	209	11271	coal, iron, zinc, copper, gold, silver, nickel, lead	Coal-based	Recession
	Fuxin (LFX)	3876.9	185	10355	coal, oil, gold, silica sand, iron, marble, natural gas	Coal-based	Recession
	Anshan (LAS)	7858.1	342	9263	iron, talc, limestone, granite, jade, magnesite	Ferrous metal-based	Regeneration
	Benxi (LBX)	7484.5	146	8414	iron, copper, gypsum, marble, zinc	Ferrous metal-based	Mature
	Huludao (LHLD)	4897.6	276	10416	zinc, molybdenum, iron, copper, manganese	Nonferrous metal-based	Regeneration
	Panjin (LPJ)	12943.6	130	4103	oil, natural gas, well salt, coal, sulfur	Oil&gas-based	Regeneration
Jilin (JL)	Liaoyuan (JLY)	8087.4	117	5140	coal, iron, copper, lead, gold, silver, peat, zinc	Coal-based	Recession
	Tonghua (JTH)	5859.2	216	15612	iron, chromium, copper, lead, zinc, nickel, cobalt	Ferrous metal-based	Regeneration
	Jilin (JJL)	8177.8	414	27711	woodland, oil shale, diatomite, iron, gold	Forestry-based	Mature
	Baishan (JBS)	8572.4	118	17505	woodland, quartz sand, silica, talc, iron ore	Forestry-based	Recession
	Songyuan (JSY)	7636.2	275	21089	sand, quartz sand, glass sand, refractory soil	Nonferrous metal-based	Growth
Heilongjiang (HLJ)	Jixi (HJX)	4709.8	173	22531	coal, graphite, feldspar, marble, mineral water, silica	Coal-based	Mature
	Hegang (HHG)	4420.2	100	14665	coal, uranium, rock gold, placer gold, iron, copper	Coal-based	Recession
	Shuangyashan (HSYS)	5435.4	141	22682	coal, iron, tungsten, gold, graphite, feldspar, peat	Coal-based	Recession
	Qitaihe (HQTH)	4900.1	78	6190	coal, graphite, gold, marble, limestone	Coal-based	Recession
	Yichun (HYC)	3646.9	114	32800	woodland, gold, silver, iron, lead, copper, limestone	Forestry-based	Recession
	Mudanjiang (HMDJ)	7374.5	252	38827	woodland, coal, gold, marble	Forestry-based	Mature
	Heihe (HHH)	4833.4	159	69345	woodland, iron, copper, lead, tungsten, molybdenum	Forestry-based	Mature
	Daqing (HDQ)	15703.2	273	21219	oil, geothermal energy, wetlands	Oil&gas-based	Mature

Source: China City Statistical Yearbook in 2019.

3.2. Data source

This study assembled the relevant data of the northeastern resource-based cities from the China City Statistical Yearbook (NBSC, 2013-2018). In this study, the studied period is 2013-2018 because the resource-based city was first defined in 2013, and the most updated data were only obtained in 2018.

4. Methods

Fig. 2 shows the key steps in the CCD evaluation. An indicator system is established, and the original data are then normalized in Data Preparation. The evaluation subindex applies the order relation method (ORM), based on the principle that the more coordinated the indicator is among cities, the greater the weight is, to calculate the indicator weight and aggregate the evaluation values of ED and IC. A coupling coordination degree model is selected to calculate the interactive relationship between ED and IC in Calculation CCD. The influencing factor uses the geographical detector to distinguish the influencing indicators.

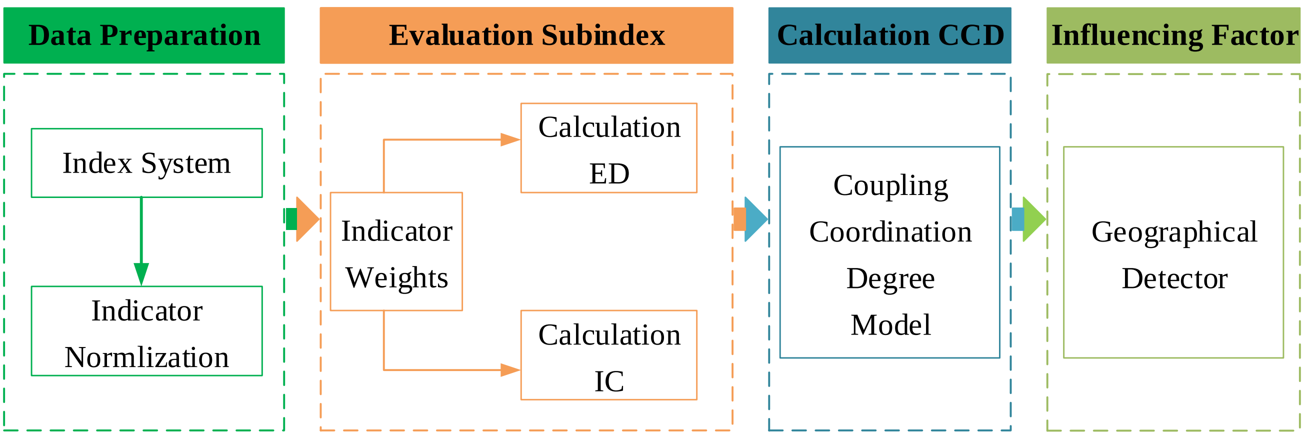


Fig. 2. Theoretical framework for evaluating coupling coordination degree between innovation and economic development.

4.1. Construction of index system

This study followed the following criteria to select appropriate indicators: (1) The raw data of indicator are continuous, without missing data; (2) The raw data of indicator can be measured and accessed; (3) The indicators have an indirect or direct relationship with ED and IC (Chen and Zhang, 2020). Then, an index system covering a set of 12 indicators was constructed to interpret ED and IC, as shown in Table 2. Strictly speaking, due to missing and unmeasurable data, the index system constructed in this study cannot fully interpret the implications of ED and IC. Taking IC as an example, innovation culture is an important factor for stimulating innovation activities within a city (Chen and Zhang, 2021). However, due to missing data, this study excluded innovation culture from the index system. From a data availability perspective, constructing an index system for ED and IC is the best choice in this study.

Table 2

Index evaluation system of economic development and innovation capability.

Dimension	Indicator (Code)	Unit	Property	Weight
Economic Development (ED)	GDP growth rate (C_{11})	%	+	0.1509
	proportion of service industry in GDP (C_{12})	%	+	0.1522
	proportion of import and export in GDP (C_{13})	%	+	0.1312
	per capita FDI (C_{14})	USD/person	+	0.1273
	registered rate of unemployment (C_{15})	%	—	0.1523
	per capita added value of mining industry (C_{16})	Yuan/person	+	0.1450
	per capita investment in fixed asset (C_{17})	Yuan/person	+	0.1410
Innovation Capability (IC)	proportion of R&D expenditure (C_{21})	%	+	0.1935
	per capita collection of public libraries (C_{22})	1000 copies	+	0.2136
	patent application per 10,000 people (C_{23})	Piece	+	0.2017
	proportion of scientific expenditure (C_{24})	%	+	0.2008
	proportion of R&D personnel in population (C_{25})	%	+	0.1903

4.2. Data normalization

Due to the difference in the unit and magnitude of indicators, these indices cannot be directly used for aggregation and comparison. Therefore, the raw data must be standardized, and the range method used in this study transformed the raw data. Eq. 1 and Eq. 2 were used to normalize the positive and negative indicators, respectively.

$$X_{ij}^{t} = \frac{x_{ij}^{t} - \underset{\forall i,t}{Min}(x_{ij}^{t})}{\underset{\forall i,t}{Max}(x_{ij}^{t}) - \underset{\forall i,t}{Min}(x_{ij}^{t})} \tag{1}$$

$$X_{ij}^{t} = \frac{\underset{\forall i,t}{Max}(x_{ij}^{t}) - x_{ij}^{t}}{\underset{\forall i,t}{Max}(x_{ij}^{t}) - \underset{\forall i,t}{Min}(x_{ij}^{t})} \tag{2}$$

where x_{ij}^{t} is the raw data of the j-th indicator of the i-th city in the t-th year; X_{ij}^{t} represents the normalized result of x_{ij}^{t}, such that $X_{ij}^{t} \in [0, 1]$; i is $1, 2, \cdots\cdots, 19$, representing the number of resource-based cities; j is $1, 2, \cdots\cdots, 12$, representing seven and five indicators for ED and IC, respectively; t is $1, 2, \cdots\cdots, 6$, representing the investigated period from 2013 to 2018; $\underset{\forall i,t}{Min}(x_{ij}^{t})$ and $\underset{\forall i,t}{Max}(x_{ij}^{t})$ represent the minimum and maximum of the j-th indicator cross all years, respectively.

4.3. Calculation of economic development and innovation capability

To synthesize the n-dimensional data and corresponding weight into one-dimensional values, this study selected the weighted arithmetic operator (WAO) to aggregate the ED and IC (Wang, 2014). Then, Eq. 3 and Eq. 4 were used for ED and IC, respectively.

$$ED_i^t = \sum_{j=1}^{7} X_{ij}^t w_j \tag{3}$$

$$IC_i^t = \sum_{j=8}^{12} X_{ij}^t w_j \tag{4}$$

where ED_i^t and IC_i^t are the evaluation value of the *i-th* city in the *t-th* year, respectively; w_j is the *j-th* indicator weight, hence $0 \le w_j \le 1$, and $\sum_{j=1}^{7} w_j = 1$ and $\sum_{j=8}^{12} w_j = 1$.

The main principle of calculating weight is that the more coordinated the indicator is among cities, the greater the weight is. When the indicator is equal in all cities, the entropy value obtains its maximum. Then, this study followed the maximum entropy principle to calculate the coordinated status of each indicator, and ORM was used to calculate the indicator weight. Hence, the indicator entropy was calculated by Eq. 5, and Eqs. 6−7 were used to compute the indicator weight.

$$E_j = -\frac{\sum_{t=1}^{6}\sum_{i=1}^{19} p_i^t(j)\ln(p_i^t(j))}{6} \tag{5}$$

where E_j is the entropy value of the *j-th* indicator, representing the coordinated status of the indicator among cities. The greater the E_j is, the higher the indicator coordination is; $p_i^t(j) = x_{ij}^t \Big/ \sum_{i=1}^{19} x_{ij}^t$ denotes the proportion of the *j-th* indicator of the *i-th* city in the *t-th* year.

$$\begin{cases} w_7^*(ED) = \left[1 + \sum_{k=2}^{7}\prod_{u=k}^{7} r_u(ED)\right]^{-1} \\ w_5^*(IC) = \left[1 + \sum_{k=2}^{5}\prod_{v=k}^{5} r_v(IC)\right]^{-1} \end{cases} \tag{6}$$

$$\begin{cases} w_{u-1}^*(ED) = w_u^*(ED) \times r_u(ED), \ u = 7,6,5,4,3,2 \\ w_{v-1}^*(IC) = w_v^*(IC) \times r_v(IC), \ v = 5,4,3,2 \end{cases} \tag{7}$$

where $w_7^*(ED)/w_5^*(IC)$ is the weight coefficient of the indicator corresponding to minimum entropy in ED/IC, such that $0 \le w_7^*(ED)/w_5^*(IC) \le 1$; $r_u(ED) = H_{u-1}(ED)/H_u(ED)\ (u = 7,\cdots,2)$ / $r_u(IC) = H_{v-1}(IC)/H_v(IC)\ (v = 5,\cdots,2)$ represents the descending ratio of entropy, hence $r_2(ED) \ge \cdots \ge r_7(ED) \ge 1 / r_2(ED) \ge \cdots \ge r_5(ED) \ge 1$; $H_u(ED)/H_v(IC)$ is the u-th / v-th largest entropy value corresponding to the ED/IC indicator.

Example: Taking IC as an example illustrates the calculation process of weight. The entropy value of IC calculated by Eq. 5 is $E_{21} = 0.8696, E_{22} = 0.9598, E_{23} = 0.9062, E_{24} = 0.9024,\ and\ E_{25} = 0.8550$. The descending order of IC weight is $w_1^*(C_{22}) \succ w_2^*(C_{23}) \succ w_3^*(C_{24}) \succ w_4^*(C_{21}) \succ w_5^*(C_{25})$, and then $r_2 = H_{22}/H_{23} = 0.9598/0.9062 = 1.0592$, $r_3 = H_{23}/H_{24} = 0.9062/0.9024 = 1.0042$, $r_4 = H_{24}/H_{21} = 0.9024/0.8696 = 1.0377$, and $r_5 = H_{21}/H_{25} = 0.8696/0.8550 = 1.0171$. Hence, $w_5^* = w_{25} = 0.1903$, $w_4^* = w_{21} = w_5^* * r_5 = 0.1903 \times 1.0171 = 0.1935$, $w_3^* = w_{24} = w_4^* \times r_4 = 0.1935 \times 1.0377 = 0.2008$, $w_2^* = w_{23} = w_3^* \times r_3 = 0.2008 \times 1.0042 = 0.2017$, and

$w_1^* = w_{22} = w_2^* \times r_2 = 0.2017 \times 1.0592 = 0.2136$.

4.4. Calculation and classification of coupling coordination degree

This study selected the coupling coordination degree model to calculate the coupling coordination degree between economic development and innovation capability. It can be expressed by Eq.8.

$$CCD_i^t = \left[\frac{2 \times (ED_i^t \times IC_i^t)^{\frac{1}{2}}}{ED_i^t + IC_i^t} \times (\alpha ED_i^t + \beta IC_i^t) \right]^{\frac{1}{2}} \quad (8)$$

where CCD_i^t represents the CCD of the *i-th* city in the *t-th* year, such that $CCD_i^t \in [0,1]$. The closer CCD_i^t is to 0, the lower the coordination level is, and vice versa. The value of α and β indicates the contribution comprehensive coefficient of ED and IC, respectively, with $\alpha, \beta \in [0,1]$ and $\alpha + \beta = 1$. In this study, ED is considered to be as important as IC, and α, β can be set to 0.5. According to the classification of MA et al. (2020), this study divided CCD into coordination development, transformation development, and imbalance development including 15 subclassifications, as shown in Table 3.

Table 3

Classification criterion of coupling coordination degree.

Stage	Classification	Criteria	Systematic Comparison	Sub-classification
Coordination Development	Extreme Coordination (EC) [I]	$0.8 < D \le 1$	$0 \le \lvert IC - ED \rvert \le 0.1$	Systematic Balanced EC (I-1)
			$IC - ED > 0.1$	Sluggish Economic EC (I-2)
			$ED - IC > 0.1$	Lagging Innovation EC (I-3)
	Moderate Coordination (MC) [II]	$0.6 < D \le 0.8$	$0 \le \lvert IC - ED \rvert \le 0.1$	Systematic Balanced MC (II-1)
			$IC - ED > 0.1$	Sluggish Economic MC (II-2)
			$ED - IC > 0.1$	Lagging Innovation MC (II-3)
Transformation Development	Reluctant Coordination / Imminent Imbalance (RC/II) [III]	$0.4 < D \le 0.6$	$0 \le \lvert IC - ED \rvert \le 0.1$	Systematic Balanced RC/II (III-1)
			$IC - ED > 0.1$	Sluggish Economic RC/II (III-2)
			$ED - IC > 0.1$	Lagging Innovation RC/II (III-3)
Imbalance Development	Moderate Imbalance (MI) [IV]	$0.2 < D \le 0.4$	$0 \le \lvert IC - ED \rvert \le 0.1$	Systematic Balanced MI (IV-1)
			$IC - ED > 0.1$	Sluggish Economic MI (IV-2)
			$ED - IC > 0.1$	Lagging Innovation MI (IV-3)
	Serious Imbalance (SI) [V]	$0 \le D \le 0.2$	$0 \le \lvert IC - ED \rvert \le 0.1$	Systematic Balanced SI (V-1)
			$IC - ED > 0.1$	Sluggish Economic SI (V-2)
			$ED - IC > 0.1$	Lagging Innovation SI (V-3)

4.5. Geographical detector

Many methods have been adopted to explore the influencing factors, such as decomposition analysis (Ajayi and Reiner, 2018) and econometric analysis (Xie and Lin, 2019). However, the spatial heterogeneity of different variables in most studies has been neglected, and the influencing coefficient of each variable is set to be equal in different geographical units. In the real world, a remarkable characteristic of CCD between ED and IC in resource-based cities is the spatiotemporal heterogeneity. Then, the influence of the same factor in different cities is significantly heterogeneous, which is attributed to the difference in absorbing the spillover effect. To capture the spatial heterogeneity of an indicator's influence, a geographical detector was applied in this study. As a spatial statistical tool, geographical detector can investigate the influencing factors in different geographical strata (Wang et al., 2010) and have been used in many fields, such as housing price (Wang et al., 2017), $PM_{2.5}$ concentration (Ding et al., 2019), and sustainable development prediction (Zhao et al., 2021). In this study, the power determinants (PD) are defined as the influencing coefficient of different factors on CCD to analyze spatial heterogeneity to a certain degree. The formula of the geographical detector used in this study was expressed by Eq. 9:

$$PD_j = 1 - \frac{\sum_{h=1}^{L} n_h \sigma_h^2}{n\sigma^2} \tag{9}$$

where PD_j measures the influence of the j-th indicator; $h = 1, 2, \cdots L$ is the strata of the j-th indicator; n_h and n represent the number of cities in strata h and the whole studied area, respectively; σ_h^2 and σ^2 are the variances of CCD at strata h and the whole studied area, respectively. The value of PD_j ranges from 0 to 1. The larger the PD_j of the j-th indicator, the stronger the impact is (Cao and Yuan, 2019). Note that if the j-th indicator completely controls the spatial differentiation of CCD, then $PD_j = 1$.

5. Results

5.1. Coupling coordination in different cities

The evaluation values of CCD, ED, and IC are shown in Appendix 1, Appendix 2, and Appendix 3, respectively. Additionally, Fig. 3 shows the changing trend of CCD on a graph, and the time evolution of CCD classification is illustrated in Table 4.

From 2013 to 2018, the CCD between ED and IC of the resource-based cities in Northeast China performed poorly and experienced a slight decline. The mean value of CCD within the whole research area decreased from 0.5245 in 2013 to 0.5064 in 2018, a decrease of 3.45%, thus indicating that ED and IC experienced a serious decoupling problem in resource-based cities. In general, the provincial order of CCD in Northeast China was Liaoning ≻ Jilin ≻ Heilongjiang. Notably, the CCD of resource-based cities in Liaoning Province obtained the best performance, with an average value of 0.6096 (0.5855−0.6506), which was significantly higher than the average value of Northeast China (0.5118). The range in parentheses indicates the maximum and minimum CCD. In contrast, the CCD of Heilongjiang Province was only 0.4275 (0.4167−0.4376). In detail, among the 19 resource-based cities, LPJ, LBX, and LAS (the abbreviations of cities are shown in Table 1) performed the best, with average values of 0.6602, 0.6487, and 0.6381, respectively. Unexpectedly, the three cities with the lowest CCD were HSYS (0.4203), HQTH (0.4080), and JSY (0.4080). Among the three provinces, the CCD of Liaoning Province declined the most, with a negative growth rate of 1.59% (from 0.6058 in 2013 to the lowest point of

0.5208 in 2016 and returned to 0.5591 in 2018). That of Jilin Province increased slightly from 0.4839 to 0.4860, with a growth rate of 0.08%, thus indicating that the coupling development of ED and IC slightly improved. Regarding resource-based cities, eight resource-based cities (accounting for 42.11%) displayed a clear upward trend in 2018 compared to 2013, whereas 11 cities (accounting for 57.89%) significantly decreased. For example, from 2013 to 2018, the CCD of HDQ dropped significantly, by 3.22%, from 0.6484 to 0.5505, followed by LBX (3.00%), and LFS (2.62%). During the same period, the CCD of the HQTH grew slowly from 0.3776 to 0.4243 between 2013 and 2018, representing a growth rate of 2.36%, followed by JSY (1.79%), and JBS (1.24%).

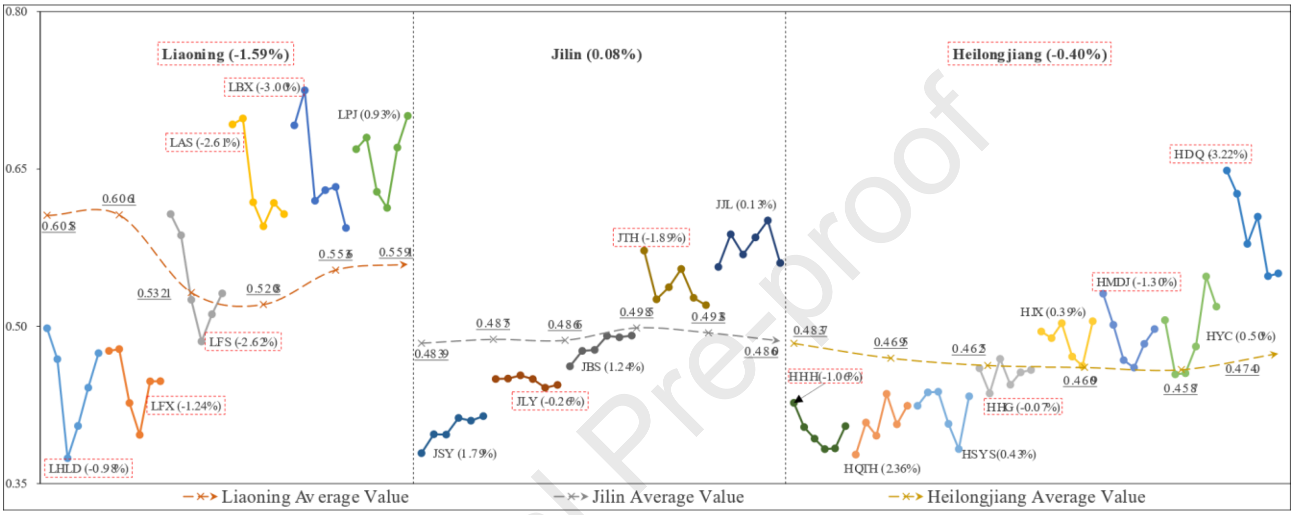


Fig. 3. Trend change of coupling coordination degree in resource-based cities from 2013 to 2018.

Note: The red rectangle represents the negative growth rate.

From the perspective of CCD evolution, Table 4 shows that the CCD of resource-based cities in Northeast China has different changing trends, and most cities are in a stable state. Compared with 2013, LFS, LBX, and HDQ (accounting for 15.79% of total resource-based cities) degraded to RC/II (level III) from MC (level II), JSY and HQTH (accounting for 10.53%) upgraded from MI (level IV) to RC/II (level III), and the CCD classification of 14 cities (accounting for 73.68%) were remaining RC/II (level III) or MC (level II) in 2018 (eight cities for steady, six cities for fluctuation). For example, LAS degraded to RC/II from MC in 2016, and then returned to RC/II in 2017. In addition, the CCD classification of LPJ was always MC (level II) during the studied period. From Table 4, the RC/II (level III) of CCD in Northeast China is widely distributed from 2013 to 2018. Compared with the classification of CCD in different cities, taking into account these 19 resource-based cities over six years, among the 114 points (19 cities times six years), 83 sample points (accounting for 72.81% of total sample points) belonged to the RC/II (level III), only 11 sample points (accounting for 9.65%) were MI (level IV), and 20 sample points (accounting for 17.54%) were MC (level II). This fact indicates that degradation and upgradation are the evolution directions of CCD in resource-based cities. If appropriate measures are taken, the balanced development of ED and IC can be achieved. Combined with Table 3, 63 sample-points (accounting for 55.26%) have been in the state of an innovation lag since 2013—2018, with 59 points (accounting for 42.98%) in a balanced state and only 2 points (accounting for 1.76%) in the state of economic sluggish. This indicates that the enhancement of innovation capability in resource-based cities keeps no pace with economic growth, and the coordinated development of ED and IC is hardly obtained.

Table 4

The classification evolution of coupling coordination degree from 2013 to 2018.

City	2013	2014	2015	2016	2017	2018
LAS	II-3	II-3	II-1	III-1	II-1	II-1
LFS	II-3	III-3	III-3	III-1	III-1	III-1
LBX	II-1	II-1	II-1	II-1	II-1	III-1
LFX	III-3	III-3	III-1	IV-1	III-3	III-1
LPJ	II-3	II-3	II-3	II-1	II-1	II-1
LHLD	III-3	III-3	IV-3	III-3	III-3	III-1
JJL	III-3	III-3	III-3	III-3	II-1	III-1
JLY	III-3	III-3	III-3	III-3	III-3	III-3
JTH	III-1	III-1	III-3	III-1	III-1	III-3
JBS	III-3	III-3	III-3	III-3	III-3	III-3
JSY	IV-3	IV-3	IV-3	III-3	III-3	III-3
HJX	III-1	III-1	III-1	III-1	III-1	III-1
HHG	III-2	III-1	III-1	III-1	III-1	III-1
HSYS	III-3	III-1	III-3	III-3	IV-3	III-3
HDQ	II-1	II-1	III-1	II-1	III-3	III-3
HYC	III-1	III-1	III-1	III-1	III-2	III-1
HQTH	IV-1	III-3	IV-3	III-1	III-3	III-3
HMDJ	III-3	III-3	III-3	III-3	III-3	III-3
HHH	III-3	III-3	IV-3	IV-3	IV-3	III-3

Note: denotes MC; denotes RC/II; denotes MI.

5.2. Coupling coordination of different resource types

As illustrated in Fig. 4, resource-based cities with different resource types exhibited diverse CCD trends in Northeast China during the investigated period of 2013−2018. Generally, the CCD between ED and IC of oil&gas-based cities was in the best state (reached the lowest point of 0.603 in 2015 from 0.659 in 2013, decreasing by 8.39%, and returned to increasing by 3.68% to 0.626 in 2018, with an average of 0.6264), and the CCD of nonferrous metal-based cities obtained the lowest value with an average of 0.4227, which indicates that ED and IC were in an uncoordinated development. Regarding the changing trend, only the CCD of nonferrous metal-based cities showed an upward trend and displayed a V-shaped increasing pattern over time with a growth rate of 1.29%; that is, the CCD reached the lowest point in 2015 (decreasing by 12.12% from 0.439 in 2013 to 0.386 in 2015 and increasing by 15.25% to 0.444 in 2018). These changes reflected that with the continuous improvement of innovation (going from 0.110 in 2013 to 0.143 in 2018, with an increase of 30.63%), the interactive relationship between ED and IC became more balanced. In contrast, the average CCD of ferrous metal-based, oil&gas-based, coal-based, and forestry-based cities decreased from 2013 to 2018 by 12.03%, 5.02%, 1.40%, and 0.40%, respectively, for the same time frame. In particular, the CCD classification of ferrous metal-based cities has degenerated from MC (level II) to RC/II (level III) as a result of the continuous decline of innovation capability. For example, the evaluation value of IC in ferrous metal-based cities was 0.391 in 2013 and 0.307 in 2018, declining by

21.55%.

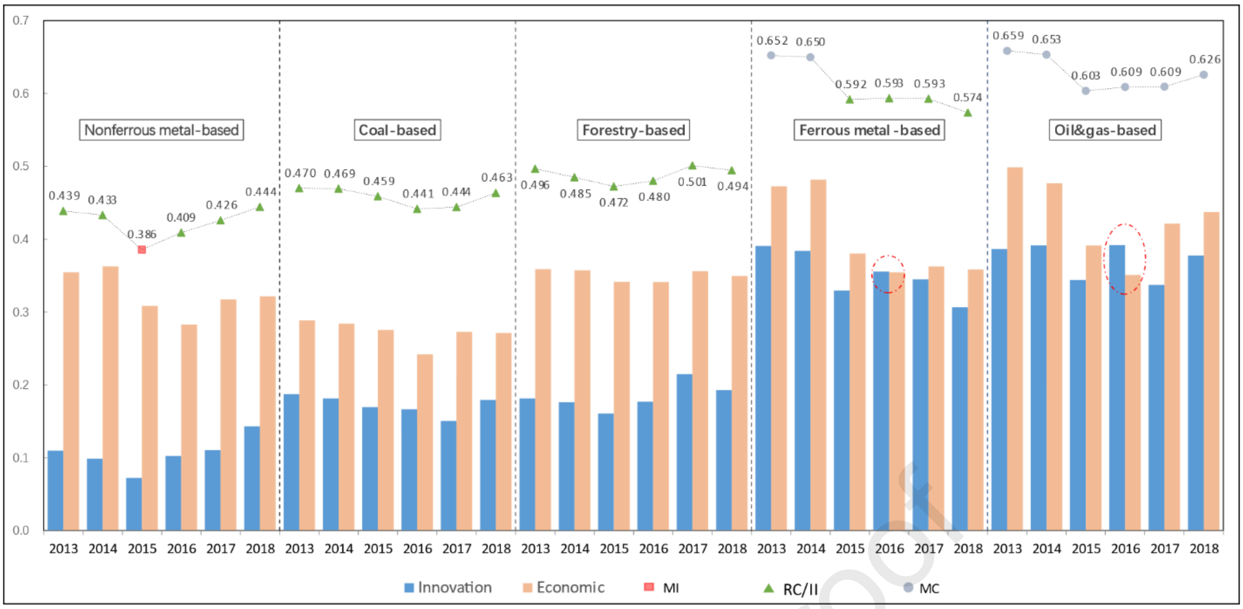


Fig. 4. Coupling coordination degree in different resource types of resource-based cities from 2013 to 2018.

Note: X-axis is the year and Y-axis is the evaluation value of coupling coordination degree.

5.3. Coupling coordination at different development stages

Fig. 5 illustrates the changing trend of resource-based cities from the perspective of different development stages. Given the differences in their resource supporting capabilities, the CCD of resource-based cities belonging to different development stages showed different characteristics. In detail, the evaluation values of CCD in the regeneration stage were the highest in all years, with an average of 0.570, reaching the lowest point of 0.540 in 2015 from 0.608 in 2013, decreasing by 11.18%, and then increasing by 6.67% to 0.576 in 2018, with a negative rate of 5.35% throughout the whole research period. Moreover, faced with unprecedented pressure on industrial transformation, the CCD in the growth stage obtained the lowest value of 0.4017 with a positive growth rate of 9.29%. This fact indicates that resource-based cities in the growth stage face the serious problem of unbalanced development. Nevertheless, they have huge potential for improving the coupling coordination of ED and IC. In terms of CCD classification, CCD in the recession and mature stages with RC/II (level III) had mean values of 0.4615 and 0.5325, decreasing by 0.38% and 7.11%, respectively. Additionally, the CCD of the resource-based cities in the regeneration stage degraded to RC/II (level III) in 2014 from MC (level II) in 2013 and remained stable. Fortunately for the resource-based cities in the growth stage, the classification of CCD upgraded from MI (level IV) to RC/II (level III) in 2016, increasing from 0.379 in 2013 to 0.414 in 2018. The main reason for the upgradation of CCD is that economic development has achieved sustained growth, increasing by 35.63% from 0.300 in 2013 to 0.406 in 2018. However, as the foundation of CCD, IC kept no pace with ED in the research period and performed poorly, only increasing by 5.07% from 0.069 in 2013 to 0.073 in 2018.

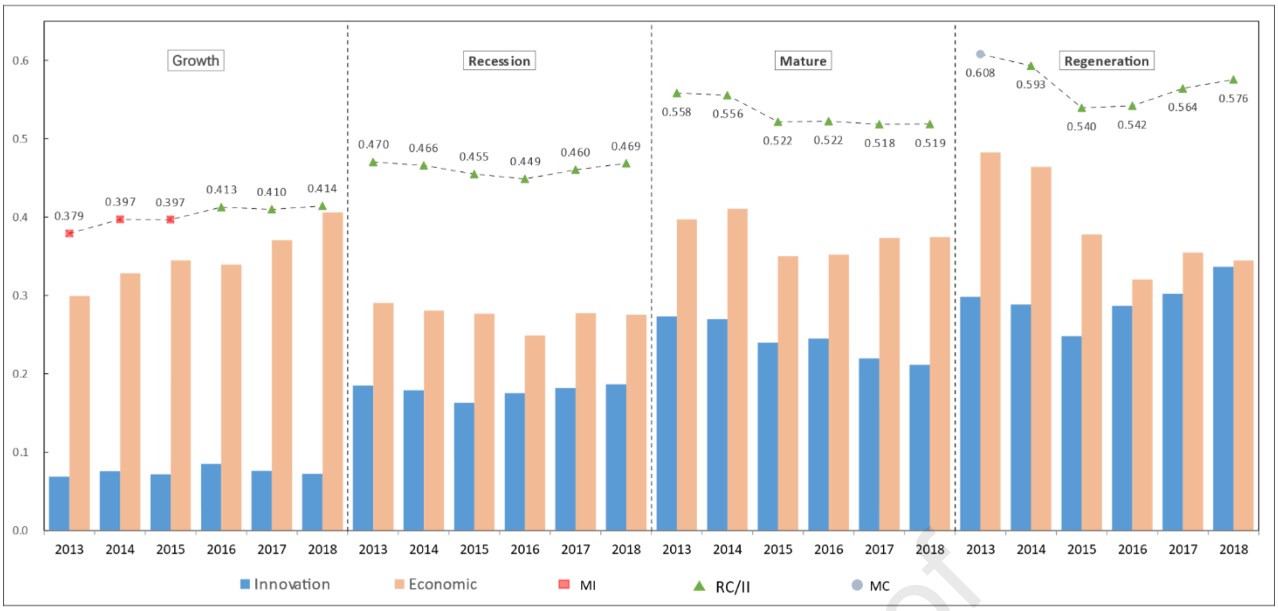


Fig. 5. Coupling coordination degree at different development stages of resource-based cities from 2013 to 2018.

Note: X-axis is the year and Y-axis is the evaluation value of coupling coordination degree.

5.4. Influencing factors of coupling coordination

Using Eq. 9, the special impact of each indicator on CCD was calculated in the resource-based cities. Given the small sample size, nonferrous metal-based and ferrous metal-based cities were merged into metal type cities, oil&gas-based and coal-based cities were merged into fossil energy cities, and growth and mature cities were merged into growth&mature cities. Then, Fig. 6 and Fig. 7 depict the PD of ED and IC and the associated indicator on different scales, respectively.

Through the influencing factors of CCD throughout the whole research area (Fig. 6 illustrated by the "Overall" row), IC and ED make substantial contributions to improving the CCD in resource-based cities. Nevertheless, IC collectively has a stronger power determinant than ED (0.3742 vs 0.1364). Concretely, the results reveal that IC plays a dominating role in improving the coupling coordination between ED and IC, indicating that the CCD of resource-based cities is characterized by lagging innovation. These results confirm the findings reported in Table 4, in which the classification of CCD in most sample points belongs to the innovation lag (with label 3). To further explore the influence of each indicator (as shown in Fig. 7), the proportion of R&D personnel in population (C_{25}) is the most influential indicator for CCD in resource-based cities, with a PD value of 0.6503. One possible reason is that under the continuous depletion of natural resources, the population, especially highly skilled labor, massively outflows from Northeast China, and these indicators hinder coordinated development. The per capita collection of public libraries (C_{22}) and proportion of R&D expenditure (C_{21}) are the second and third most important factors among the indicators, with PD values of 0.4169 and 0.4111, respectively. Additionally, the most important factor among ED indicators is the per capita added value of mining industry (C_{16}, 0.2291), and the proportion of import and export in GDP (C_{13}, 0.2190) ranks second. However, the PD of the proportion of service industry in GDP (C_{12})

is only 0.0102, which indicates that this indicator has the lowest effect on CCD, followed by the GDP growth rate (C_{11}) and patent application per 10,000 people (C_{23}), with influencing coefficients of 0.0339 and 0.0975, respectively.

As seen from Fig. 6, the influencing coefficients of IC are still stronger than ED in different provinces utilizing different resource types at different development stages, which indicates that IC plays a more significant role in determining CCD. Compared with the different scales, the resource-based cities in Jilin Province, under the metal type at the growth&mature stage, have the highest PD of 0.4955, 0.5679, and 0.5555, respectively, which is higher than the average (0.3742). In particular, the power determinants of ED and IC in recessing resource-based cities are lower than the average, with PD values of 0.1260 and 0.2067, respectively. These findings suggest that the recessing resource-based cities in Northeast China face more complex structural problems, and one-sided measures cannot improve the CCD. From Fig. 7, a major difference in the influencing coefficient of different indicators at multiple scales can be observed, which indicates that the influence of indicators on coordinated development exhibits spatial heterogeneity in different cities. In detail, the proportion of R&D personnel in population (C_{25}) of resource-based cities constitutes the top factor of the total indicators in Heilongjiang Province, in fossil energy and forestry-based cities at the regeneration stage. This result indicates that the most common way to improve CCD is to energetically foster scientific talent. The most influencing factor of the other scales belongs to IC indicators, for example, proportion of scientific expenditure (C_{24}) in Jilin (0.6652), per capita collection of public libraries (C_{22}) in metal type (0.7725), and recession stage (0.3553), and proportion of R&D expenditure (C_{21}) in growth&mature stage (0.7731). The only exception is that the driving factor of Liaoning Province is the per capita added value of mining industry (C_{16}), with a PD of 0.7594. The reason can be attributed to the overall transformation of Liaoning's economic structure, which makes the proportion of the mining industry in GDP continue to decline.

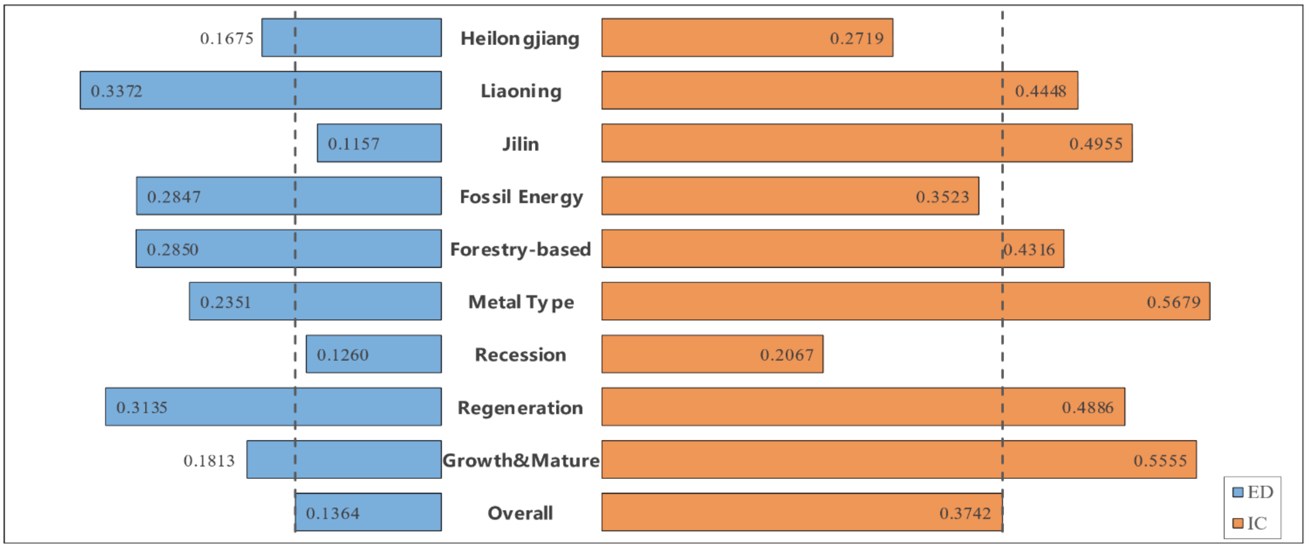


Fig. 6. The power determinants of economic development and innovation capability on different scales.

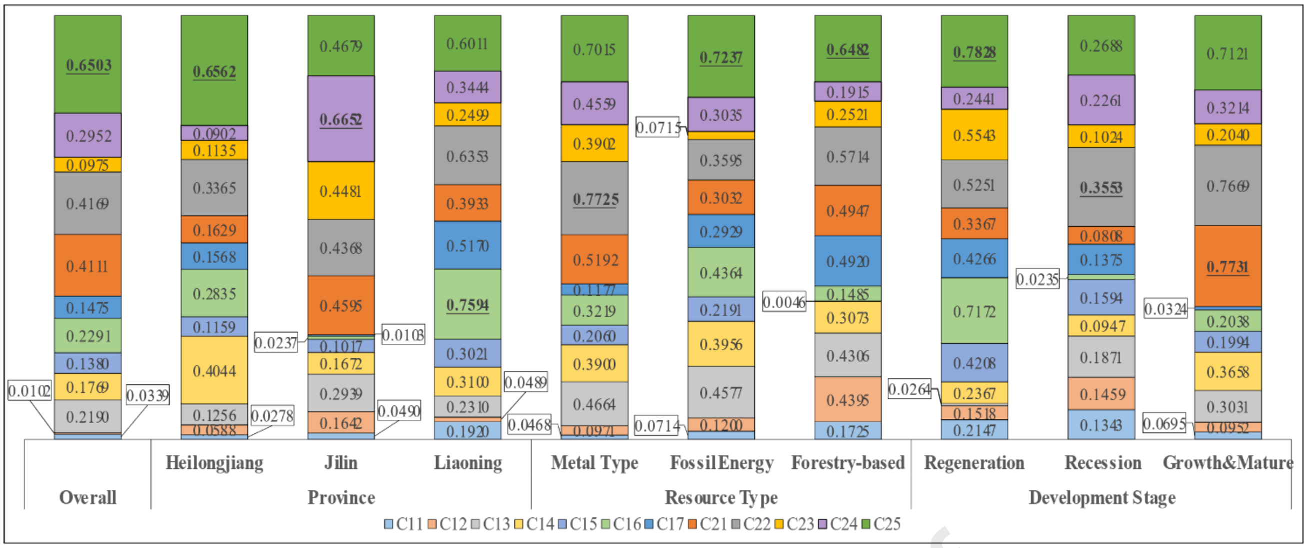


Fig. 7. The power determinants of each indicator on different scales.

6. Discussion

6.1. Uncoordinated development of innovation capability and economic development

In the process of comprehensively revitalizing the old industrial base in the northeast resource-based cities face the enormous challenge of how to achieve coordinated development by balancing the relationship between the economy and innovation. In this study, the coupling coordination degree model was applied to measure the interaction between economic development and innovation capability of resource-based cities in Northeast China. The results suggest that most resource-based cities, especially nonferrous metal-based cities in the growing stage, were in serious uncoordinated development between economic development and innovation capability, mainly caused by lagging innovation. Over the past few decades, northeastern resource-based cities have experienced rapid urbanization and industrialization (Li et al., 2017), with many serious issues behind their process, such as the depletion of natural resources, "brain drain", lack of sufficient funds, and inefficient technology (Yang and Song, 2019). In particular, the continuous loss of highly skilled talent has weakened the foundation of innovation capability of northeastern resource-based cities. Therefore, the urban innovation capability performed poorly and experienced an obvious drop, which corroborated the previous research obtained by Chen et al. (2020b). Additionally, the social development of northeastern resource-based cities has been deeply influenced by the planned economic system and the "resource curse" phenomenon (Song et al., 2021). Coupled with the imperfect policies of heavy industry transformation, resource-based cities are confronted with a bottleneck of industrial development (Fu et al., 2020). Therefore, innovation capability is poor, and the pressure to industrial transformation is considerable in northeastern resource-based cities. These intertwined factors cause an unbalanced development between economic development and innovation capability.

6.2. Coupling coordination in different development stages or resource types

For the resource-based cities in different development stages or resource types, the CCD performance of ED and IC varied greatly. One potential reason is that the mechanism contradiction limits the synchronization of economic development and innovation (Sueyoshi and Yuan, 2015). For the different resource types, the serious imbalance of ED and IC in nonferrous metal-based cities indicates that overexploitation has led to the exhaustion of nonferrous metals with low technical requirements, and the original industrial enterprises in these cities are continuously shrinking. Furthermore, the existing circumstances aggravate all kinds of social problems, such as unemployment, social instability, and population outflow (Xing et al., 2018). Coupled with the continuous enhancement of environmental regulation, the industrial technology for exploitation fails to meet the technical requirements in nonferrous metal-based cities, which leads to economic decline and aggravates the imbalance. For resources based in the growth stage, with a strong resource maintenance ability and policy support strategy, the coordinated development of ED and IC has been significantly promoted. However, the slow transformation of the industrial structure dominated by natural resources is the key reason for the serious imbalance between economic development and innovation of resource-based cities in the growth stage.

6.3. Heterogeneity of influencing factors

This study confirms that the innovation capability of resource-based cities performed poorly, especially in nonferrous metal-based or growth stage cities. To further analyze the influencing factors, the indicators of IC play a dominant role in improving the CCD, such as the proportion of R&D personnel in population, per capita collection of public libraries, and proportion of R&D expenditure. A possible reason is that the innovation infrastructure of resource-based cities is extremely poor and lacks industrial support, and enhancing innovation capability can greatly improve coordinated development. Given its political position in the national energy system, resource-based cities in Northeast China thus draw more national and provincial attention and obtain more policy-oriented investment projects (Tan et al., 2020). However, the traditional development approach relying on increasing investment causes relatively weak innovation accumulation. In general, innovation capability is influenced by the industrial structure characterized by peripheral factors and is less marketized (Zweimüller and Brunner, 2005) and requires the long-term accumulation of knowledge. However, the overall transformation and upgrading of the natural-resource-based industry is generally longer and restricts the construction of the urban innovation system. Additionally, the continuous outflow of different skilled talent undermines the foundation of the innovation system. To achieve coordinated development of ED and IC, the enhancement of innovation capability is needed.

6.4. Policy recommendations

The findings confirm that the lagging innovation of resource-based cities was the main obstacle to nonideal coordinated development. It is suggested that the resource-based cities in Northeast China first need to simulate innovation activities. On the one hand, the local government can boost innovation capability at the firm level, including innovation introduction, assimilation, and renovation, by increasing public expenditure. In addition, the corresponding policies should be formulated to solve the brain drain phenomena, such as increasing the salary of highly skilled talent, optimizing the innovation environment, improving the ability of talent service, and attracting the inflow of talent. On the other hand, enterprises can reform the incentive mechanism of technical personnel and recruit domestic first-class experts to stimulate innovation activities. In addition, industry-university research collaboration should be encouraged and an innovation-oriented social environment needs to be gradually created in northeastern resource-based cities. For special resource-based cities, Liaoning Province, including Fushun, Fuxin, Panjin, Huludao, Benxi, and Anshan, should gradually adapt to economic transformation, and establish an innovation-driven development model for improving natural resource efficiency. The local government should change the industrial structure dominated by heavy industries, transferring to energy-conserving and environmentally friendly industries. Meanwhile, the education and training of highly skilled workers should be of major focus.

7. Conclusions

Most of the existing literature concentrated on the unidirectional effect between economic development and innovation and the coordinated relationship of their subsystems has been ignored, especially in resource-based cities. Therefore, the coupling coordination degree model was employed to assess the interactive relationship between economic development and innovation capability of the resource-based cities in Northeast China from 2013 to 2018. Additionally, a geographical detector was used to explore the spatial heterogeneity of their indicators on CCD. The main conclusions are drawn as follows: (1) From 2013 to 2018, the coupling coordination between economic development and innovation capability in northeastern resource-based cities performed poorly and experienced an obvious decoupling phenomenon, which can be attributed to lagging innovation. (2) In different regions, different resource types, and different development stages, the coordinated development of ED and IC showed a significant difference. (3) By comparing the influencing factors, IC collectively has a stronger power determinant than ED, and the influence of each indicator exhibits spatial heterogeneity.

This study contributes to understanding the coupling coordination between economic development and innovation capability in resource-based cities and further illustrates the spatial heterogeneity of influencing factors from a multiscale perspective. However, like most studies, this study has some limitations. First, the selection of indicators is inevitably subjective (Su et al., 2010). This study constructed an index system based on the data availability, which cannot fully interpret the real ED and IC. Then, the index system needs to be updated in future research. Second, the evaluation results of ED and IC would change in different geographical units (Turner et al., 1989). Then, matching the appropriate scale to obtain accurate results is an issue to be explored in future work.

CRediT authorship contribution statement

××: Conceptualization, Methodology, Software, Visualization, Writing—original draft, Writing—review & editing. ×××: Conceptualization, Validation, Writing—review & editing, Supervision.

Declaration of competing interest

The authors have no conflict of interest.

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Appendix

Appendix 1

The evaluation value of coupling coordination degree between economic development and innovation capability from 2013 to 2018.

City	Evaluation Value						Average	Ranking	Grow Rate
	2013	2014	2015	2016	2017	2018			
LPJ	0.6689	0.6799	0.6282	0.6129	0.6705	0.7007	0.6602	1	0.93%
LBX	0.6915	0.7249	0.6197	0.6298	0.6328	0.5938	0.6487	2	-3.00%
LAS	0.6925	0.6982	0.6183	0.5953	0.6176	0.6069	0.6381	3	-2.61%
HDQ	0.6484	0.6264	0.5786	0.6045	0.5478	0.5505	0.5927	4	-3.22%
JJL	0.5566	0.5877	0.5685	0.5848	0.6009	0.5603	0.5765	5	0.13%
LFS	0.6069	0.5867	0.5253	0.4855	0.5115	0.5314	0.5412	6	-2.62%
JTH	0.5722	0.5257	0.5372	0.5547	0.5272	0.5201	0.5395	7	-1.89%
HYC	0.5059	0.4542	0.4553	0.4808	0.5475	0.5188	0.4937	8	0.50%
HMDJ	0.5311	0.5014	0.4677	0.4605	0.4832	0.4974	0.4902	9	-1.30%
HJX	0.4950	0.4888	0.5029	0.4711	0.4622	0.5048	0.4875	10	0.39%
JBS	0.4618	0.4766	0.4774	0.4909	0.4896	0.4911	0.4812	11	1.24%
HHG	0.4600	0.4361	0.4690	0.4443	0.4560	0.4584	0.4540	12	-0.07%
JLY	0.4499	0.4502	0.4532	0.4497	0.4414	0.4441	0.4481	13	-0.26%
LFX	0.4765	0.4782	0.4268	0.3965	0.4475	0.4476	0.4455	14	-1.24%
LHLD	0.4982	0.4687	0.3742	0.4050	0.4416	0.4743	0.4437	15	-0.98%
HSYS	0.4242	0.4370	0.4376	0.4070	0.3829	0.4333	0.4203	16	0.43%
HQTH	0.3776	0.4082	0.3957	0.4356	0.4065	0.4243	0.4080	17	2.36%
JSY	0.3791	0.3971	0.3968	0.4126	0.4100	0.4143	0.4016	18	1.79%
HHH	0.4270	0.4039	0.3929	0.3830	0.3835	0.4048	0.3992	19	-1.06%
Liaoning	0.6441	0.6506	0.5898	0.5855	0.5969	0.5906	0.6096	–	-1.59%
Jilin	0.5132	0.4893	0.4881	0.4916	0.5019	0.5064	0.4984	–	0.08%
Heilongjiang	0.4366	0.4349	0.4183	0.4167	0.4212	0.4376	0.4275	–	-0.40%
Northeast	0.5245	0.5210	0.4937	0.4934	0.5020	0.5064	0.5068	–	-3.45%

Appendix 2

The evaluation value of innovation capability from 2013 to 2018.

City	Evaluation Value						Average	Ranking	Growth Rate
	2013	2014	2015	2016	2017	2018			
LBX	0.4707	0.4837	0.4020	0.4461	0.4097	0.3276	0.4233	1	-6.99%
LPJ	0.3406	0.3648	0.3341	0.4076	0.4390	0.5400	0.4043	2	9.66%
LAS	0.3947	0.4298	0.3591	0.3552	0.3620	0.3709	0.3786	3	-1.23%
HDQ	0.4322	0.4185	0.3539	0.3759	0.2356	0.2145	0.3384	4	-13.08%
HYC	0.2511	0.2306	0.2190	0.2652	0.4145	0.3054	0.2810	5	4.00%
JJL	0.2504	0.2965	0.2477	0.2806	0.3182	0.2840	0.2796	6	2.55%
LFS	0.2958	0.2853	0.2296	0.2627	0.2405	0.2926	0.2678	7	-0.22%
JTH	0.3076	0.2379	0.2271	0.2653	0.2631	0.2217	0.2538	8	-6.34%
HJX	0.2287	0.2215	0.2459	0.1909	0.1720	0.2358	0.2158	9	0.62%
HHG	0.2755	0.2042	0.2069	0.1907	0.1843	0.1893	0.2085	10	-7.23%
LFX	0.1731	0.1692	0.1443	0.1404	0.1560	0.1642	0.1579	11	-1.05%
JBS	0.1482	0.1549	0.1477	0.1630	0.1591	0.1686	0.1569	12	2.61%
LHLD	0.1502	0.1215	0.0722	0.1192	0.1444	0.2139	0.1369	13	7.32%
HSYS	0.1153	0.1579	0.1457	0.1184	0.0878	0.1412	0.1277	14	4.15%
HMDJ	0.1614	0.1272	0.1148	0.1054	0.1105	0.1226	0.1236	15	-5.34%
HQTH	0.1115	0.1144	0.1019	0.1548	0.1120	0.1242	0.1198	16	2.19%
JLY	0.1091	0.1159	0.1114	0.1083	0.1002	0.1077	0.1088	17	-0.25%
HHH	0.0954	0.0723	0.0747	0.0710	0.0725	0.0844	0.0784	18	-2.42%
JSY	0.0690	0.0757	0.0719	0.0853	0.0762	0.0725	0.0751	19	1.00%
Liaoning	0.3042	0.3091	0.2569	0.2885	0.2919	0.3182	0.2948	−	0.91%
Jilin	0.1769	0.1762	0.1611	0.1805	0.1833	0.1709	0.1748	−	-0.68%
Heilongjiang	0.2089	0.1933	0.1828	0.1840	0.1736	0.1772	0.1867	−	-3.24%
Northeast	0.2511	0.2463	0.2151	0.2386	0.2316	0.2399	0.2371	−	-4.44%

Appendix 3

The evaluation value of economic development from 2013 to 2018.

City	Evaluation Value						Average	Ranking	Growth Rate
	2013	2014	2015	2016	2017	2018			
LPJ	0.5878	0.5856	0.4663	0.3461	0.4603	0.4464	0.4821	1	-5.36%
HMDJ	0.4931	0.4971	0.4168	0.4267	0.4934	0.4993	0.4711	2	0.25%
LAS	0.5828	0.5529	0.4071	0.3537	0.4018	0.3657	0.4440	3	-8.90%
LBX	0.4856	0.5708	0.3668	0.3527	0.3914	0.3794	0.4245	4	-4.82%
JJL	0.3832	0.4023	0.4216	0.4169	0.4097	0.3470	0.3968	5	-1.96%
HDQ	0.4090	0.3680	0.3166	0.3551	0.3824	0.4280	0.3765	6	0.91%
JLY	0.3756	0.3543	0.3785	0.3776	0.3788	0.3610	0.3710	7	-0.79%
JSY	0.2995	0.3285	0.3451	0.3396	0.3709	0.4062	0.3483	8	6.29%
JBS	0.3069	0.3333	0.3517	0.3563	0.3611	0.3449	0.3424	9	2.36%
JTH	0.3487	0.3212	0.3668	0.3569	0.2937	0.3300	0.3362	10	-1.09%
LFS	0.4587	0.4154	0.3316	0.2115	0.2846	0.2726	0.3291	11	-9.88%
HHH	0.3486	0.3678	0.3190	0.3029	0.2986	0.3181	0.3258	12	-1.81%
LHLD	0.4101	0.3969	0.2715	0.2257	0.2633	0.2367	0.3007	13	-10.41%
HJX	0.2625	0.2578	0.2601	0.2580	0.2652	0.2754	0.2632	14	0.96%
LFX	0.2977	0.3090	0.2298	0.1760	0.2571	0.2444	0.2523	15	-3.87%
HSYS	0.2808	0.2309	0.2517	0.2319	0.2449	0.2496	0.2483	16	-2.33%
HQTH	0.1823	0.2428	0.2406	0.2326	0.2438	0.2610	0.2338	17	7.44%
HYC	0.2609	0.1846	0.1962	0.2016	0.2167	0.2371	0.2162	18	-1.89%
HHG	0.1625	0.1772	0.2340	0.2043	0.2346	0.2333	0.2076	19	7.50%
Liaoning	0.4705	0.4718	0.3455	0.2776	0.3431	0.3242	0.3721	−	-7.18%
Jilin	0.3428	0.3479	0.3727	0.3694	0.3628	0.3578	0.3589	−	0.86%
Heilongjiang	0.3000	0.2908	0.2794	0.2766	0.2974	0.3127	0.2928	−	0.84%
Northeast	0.3945	0.3924	0.3392	0.3141	0.3459	0.3475	0.3556	−	-11.93%

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.