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Exploration on sustainable new infrastructure green development pattern: coupling coordination measurement and evaluation of China's new infrastructure investment intensity and green technology innovation

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Abstract: In the context of China's new infrastructure construction developing rapidly, this paper explores the sustainable new infrastructure green development pattern. We establish qualitative and quantitative indicators for green technology innovation (GTI) at both the societal macro level and enterprise micro level, capturing the multidimensional nature of China's green innovation dynamic. Additionally, we create an indicator system for China's new infrastructure investment intensity (NTI) across three areas: information infrastructure, integration infrastructure, and innovation infra-structure. Using provincial panel data from 2010 to 2020, we construct a coupling coordination degree model (CCDM) to examine the level of coordination between NTI and GTI. Our findings reveal that: the degree of coordination between NTI and GTI follows a U-shaped curve, with both sub-systems remaining far from highly coordinated during rapid development; the coupling level of NTI and GTI in China is currently at a near dissonance level overall; the degree of coupling and coordination between NTI and GTI is mainly influenced by policies, and the coupling level is higher on the enterprise side than on the societal side; the two parameters (α-NTI and β-GTI) widely used in prior studies have less of an effect on the coordinated coupling system than other factors considered herein.

Introduction

According to the "China's New Infrastructure Development Report (2022)" published by the Chinese Academy of Social Sciences and other departments on January 8, 2023, the construction of new infrastructure has become a crucial driver for promoting high-quality economic development in the post-epidemic period. The concept and content of the new infrastructure were officially explained by China's National Development and Reform Commission (NDRC) on April 20, 2020, covering information infrastructure, converged infrastructure, and innovation infrastructure. Although the new infrastructure is a relatively cutting-edge concept, it is essentially an extension of the technological end of traditional infrastructure, with a focus on the digital and information economy. Unlike traditional infrastructure, which has raised environmental concerns (Doyle and Havlick 2009, Zhu et al 2014, Allenby and Chester 2018, Chester et al 2019), new infrastructure is widely considered to be beneficial to both economic and environmental improvement. In the context of global green and low-carbon, sustainable development, and digital transformation (Pan and Gu 2022, Luo et al 2022), the role of new infrastructure in environmental protection, innovation development, and digital transformation has become the focus of disciplinary research. Studies have shown that new infrastructure investment can stimulate local innovation and development (Gu and Liao 2022), while simultaneously promoting the quantity and quality of local green innovation (Song et al 2021).

As the development of new infrastructure advances to a new stage, the sustainable green development model of new infrastructure has garnered increased attention from researchers and policymakers alike. At a press conference on January 18, 2023, Jin Xiandong, director of China's NDRC Policy Research Office, announced that in 2023, NDRC will collaborate with relevant stakeholders to further support the construction of new infrastructure, while guiding and encouraging social capital to increase investment in related fields. As new infrastructure investment is poised for rapid growth, green new infrastructure is being increasingly valued by various sectors of society. On December 16, 2022, the first IFCE Green New Infrastructure Forum opened in Beijing, where various government departments, industry associations, enterprises, and research institutions discussed the future development of the green new infrastructure industry. Although the government and research departments have highly valued green new infrastructure, few research reports exist on the status quo of new infrastructure investment and green development. With the rapid growth of new infrastructure investment, relevant departments must pay attention to issues related to green innovation and new infrastructure investment, which are crucial to promoting the sustainable green development of new infrastructure.

Since the green development of new infrastructure gains momentum, it is crucial to urgently expand research on the coupling of new infrastructure investment and green technology innovation. New infrastructure construction is the backbone of the new generation of the economy, and promoting green technology innovation can undoubtedly enhance the sustainability of the new economy. Therefore, promoting the coupling and coordinated development of new infrastructure and green technology innovation is an important research proposition. Despite the ongoing research on new infrastructure investment and the coupled development of new infrastructure investment and technological innovation, which has achieved preliminary results (Gu and Liao 2022), there remains a gap in the research on the coordinated development of new infrastructure investment and green technology innovation. Based on the existing theoretical foundation of new infrastructure construction, this paper studies the coupling coordination between the investment intensity of new infrastructure construction and green technology innovation from macro and micro perspectives using a coupling coordination degree approach.

The interplay between new infrastructure investment and green technology innovation, and the degree of their coupling and coordination, are key indicators of the green and sustainable development potential of local new infrastructure construction. Prior research suggests that new infrastructure investment can facilitate technological innovation (Kuang et al 2021), including green technological innovation (Song et al 2021, Wen et al 2022, Yu and Xu 2023). From a relational standpoint, while new infrastructure investment stimulates green technology innovation, green technology innovation in turn provides technical guidance for environmental protection in new infrastructure investment, and a solid technical foundation for future green-oriented development. For instance, data centers and 5G construction are strategic resources and public infrastructure essential for future economic and social development. They are also key links for energy conservation and reduction of new infrastructure consumption. Green technology innovation can promote new infrastructure investment in greener and more environmentally friendly fields, offering a critical path towards sustainable development. Thus, promoting mutual promotion and a virtuous circle between new infrastructure investment and green technology innovation is critical for localities to explore a more sustainable green development model for new infrastructure.

Literature Review

Currently, researchers have focused mainly on the one-way transmission mechanism of new infrastructure and its impact on regional development. The existing studies show relatively positive results regarding the economic, environmental, and social impacts of new infrastructure. The literature on new infrastructure investment has examined its multiplier effect (Jiang et al. 2020,Wang and Li 2022), productivity impact (Wan and Zhang 2018, Shang 2020), impact on high-quality economic development (Chao 2020, Wan and Tang 2020, Liu and Su 2021, Li 2022, Du et al. 2022, Gong et al. 2022), impact on industrial structure (Pan and Gu 2022, Wang and Li 2022, Du et al. 2022, Guo et al. 2020, Liu and Li 2020, Sheng and Shi 2021, He and Zhao 2021, Zhang and Ru 2021, Lyu and Bi 2022), impact on the digital economy (Kuang et al. 2021, Fan and Wu 2022), impact on innovation promotion (Gu and Liao 2022, Song et al. 2021, Kuang et al. 2021, Yu and Xu 2023, Zhao 2022), impact on environmental protection (Wen et al. 2022, Wen et al 2021, Wang and Li 2022), and other related topics. These studies have provided a theoretical foundation for the development of the new infrastructure theory that has yet to be formulated.

However, there are relatively few coupling coordination studies related to new infra-structure construction, and the most relevant literature related to this paper focuses more on the coupling relationship research related to new infrastructure investment. Gu & Liao (2022) found in their research on the coupling of new infrastructure investment and techno--logical innovation that the comprehensive index of China's new infrastructure investment and technological innovation capability has increased year by year, showing a gradient distribution pattern from east to west. At the same time, the index has gradually in-creased and decreased in various provinces and cities, but more than half of the provinces and cities belong to the coupling disorder type, and a good coupling development trend has not yet been formed. The study also found a certain spatial relationship between new infrastructure investment and the comprehensive index of technological innovation. Wu et al. (2021) conducted a study on the coordinated development of information infrastructure and converged infrastructure within the subdivision of new infrastructure. The re-search findings indicate that the coupling coordination level of information infrastructure and integrated infrastructure is generally in a state of favorable coupling, but there is a risk of misalignment that may expand. Additionally, the distribution of the comprehensive index of the two exhibits a certain characteristic of the Matthew effect at the national level. In a similar vein, Xu et al. (2022) studied the coupling and coordination of new infra-structure and traditional infrastructure, revealing that the coupling and coordination level of China's new and old infrastructure has been increasing year by year and displays a spatial layout characteristic of strong east and weak west.

The current literature has yet to explore the coupling relationship between new infrastructure investment and green technology innovation. This paper aims to address this gap by introducing a comprehensive index of coupling coordination between the two, which is an innovative aspect of this study. The paper presents an integrated research framework to investigate the utility of green technology innovation resulting from new infrastructure investment. By coupling and coordinating new infrastructure investment with green technology innovation in a reasonable manner, the two can promote and guide each other towards achieving sustainable development. The study can aid governments in formulating green innovation-oriented new infrastructure investment policies and can serve as a basis for considering the effectiveness of green innovation in the differential allocation of new infrastructure investment across regions. Furthermore, the paper provides a useful indicator and quantitative basis for other developing countries looking to adopt a green development model for new infrastructure investment.

Materials & Methods

Data Pre-processing

The investment intensity data for new infrastructure in this paper are sourced from the "China Fixed Assets Investment Statistical Bulletin" and "China Fixed Assets Investment Statistical Yearbook" (2011–2021). Meanwhile, the green invention patent data are obtained from the Chinese Research Data Services (CNRDS). To account for the effect of price changes, all nominal value variables in this paper are deflated using 2010 as the base year. To standardize the data, this paper utilizes data preprocessing. For the coupling coordination results, the normalization method is used.

Methods

The Indexes for Evaluation of NTI & GTI

This paper has developed a comprehensive coupling framework for new infrastructure investment and green technology innovation by constructing NTI and GTI indicators based on previous research findings. A general system of coupling factors has been established by incorporating these indicators. As indicated in previous studies (Song et al. 2021, Kuang et al. 2021, Wen et al. 2022, Yu and Xu 2023), there is a mutual interaction between NTI and GTI, and their relationship structure is illustrated in Fig. 1. The ultimate aim of this system is to establish a sustainable new infrastructure green development model. After clarifying the relationship between the indicators, this paper analyzes their coupling coordination level and evaluates the new infrastructure investment-green technology innovation system (NGC). To ensure accuracy, all variables involving nominal value have been deflated with 2010 as the base year, and standardization and normalization methods have been used for data preprocessing and analysis.

In previous research by scholars, infrastructure investment has typically been measured through fixed investment and variable investment, such as the amount invested in fixed assets and the number of specific roads, cables, and servers (Wan and Zhang 2018, Wang and Li 2022, Bougheas et al. 1999). However, given the three subcategories of new infrastructure investment (Information Infrastructure Investment, Integrated Infrastructure Investment, and Innovation Infrastructure Investment) and the differences in regional layout and equipment dimensions in physical investment (e.g., 5G base stations, network equipment, UHV, intercity high-speed rail), this paper does not use physical infrastructure investment as new infrastructure investment data. Instead, following Du et al. (2022), this paper uses the intensity of new infrastructure investment to measure the level of local new infrastructure investment. Table 1 shows the specific criteria for the composition of new infrastructure investment intensity in this paper.

The investment intensity of new infrastructure is comprised of three subcategories: investment intensity of information infrastructure, investment intensity of integrated infrastructure, and investment intensity of innovative infrastructure. As existing policies do not show bias towards any of the three subcategories, this study assigns equal weight of 0.333 to each subcategory. The investment intensities of information infrastructure and innovative infrastructure are calculated by selecting the corresponding fixed asset investment intensity based on previous literature (Du et al. 2022, Guo et al. 2020, Wang and Li 2022, Zhu et al. 2023). For the investment intensity of integrated infrastructure, it is difficult to determine the weights of each item in the integrated infrastructure project, so this study uses the global principal component analysis (GPCA) method to reduce dimensionality and obtain the value of investment intensity of integrated infrastructure. Moreover, as the investment intensity

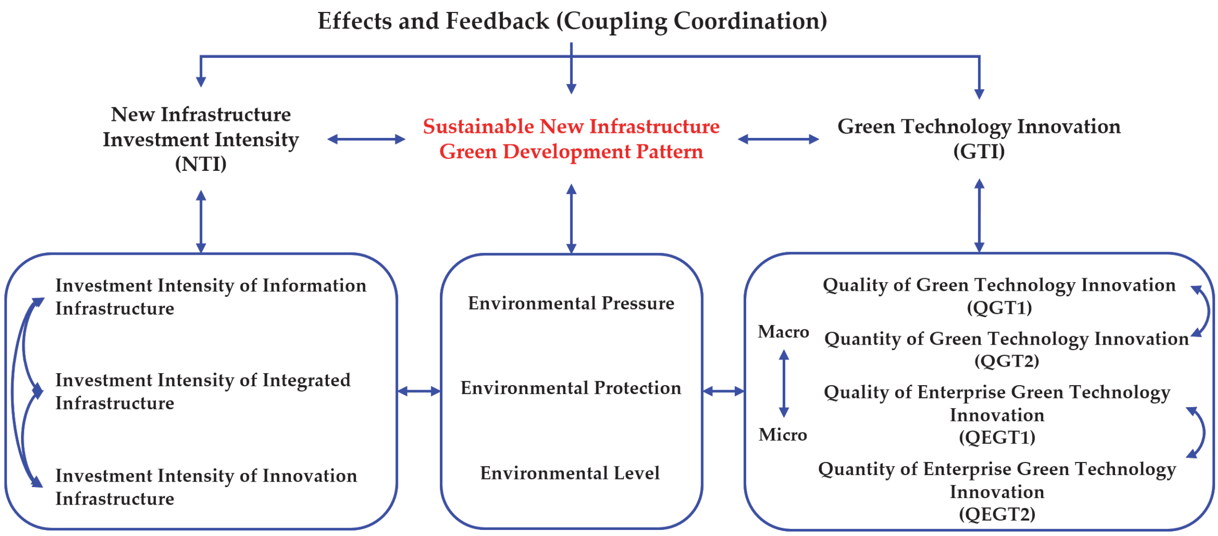

Fig. 1. Relationship of coupling coordination between NTI and GTI

of converged infrastructure is an extension of new infrastructure in traditional industries, this study calculates it by multiplying the investment intensity of fixed asset projects in traditional industries by the ratio of information & innovation investment in new infrastructure investment (TI). Finally, this study adds up the three subcategory investment intensities, each weighted 0.333, to obtain the new infrastructure investment intensity (NTI).

Numerous scholars have recognized the crucial role of green innovation in promoting environmental governance (Aguilera--Caracuel et al. 2013, Arenhardt et al. 2016, Chen 2008, Chen et al. 2012, Rehman et al. 2021, Wang and Liao 2022, Zhang et al. 2022). As a significant concept of sustainable development, green innovation has been extensively researched across various disciplines. However, due to the broad scope of green innovation, the dimensions used to measure the level of green technology innovation are diverse (Chen et al. 2012, Oduro et al. 2022, Takalo and Tooranloo 2021). After reviewing a large number of green technology innovation studies, this paper selects the number of green invention patents as the index to measure the level of green technology innovation based on source authority, social recognition, and data availability. Table 1 presents the specific classification criteria used. To account for the delay in the review and authorization of invention patents by institutions, this paper uses the number of green invention patent applications as the number of green technology innovations (QGT2). Moreover, since the granting of green invention patents is more difficult than general utility model and design patents, the number of green invention patents granted in the year is chosen to represent the quality of green technology innovation (QGT1). The indicators are measured from the macro and micro perspectives, considering the different meanings expressed by the green technology innovation index in various dimensions. The micro-level enterprise group is selected from Chinese listed companies, and the CNRDS database is used as the data source. To account for the workload in patent statistics and the reliability of the data, the paper assigns a value of 1 to each party for multi-party cooperation green patents with a larger workload. Finally, the paper takes the average of the macro and micro green technology innovation indicators to obtain the corresponding macro and micro green technology innovation level data.

Table 1. The coupling and coordination system of new infrastructure investment intensity and green technology innovation

Subsystem	Criterion layer	Distinction	Index layer	Sym.
New infrastructure investment intensity system (NTI)	Investment intensity of information infrastructure	0.333	(A1) Fixed assets investment intensity of information technology service industry	+
	Investment intensity of integrated (converged) infrastructure (Dimensionality reduction was performed by GPCA)	0.333	(A2) Fixed assets investment intensity of mining industry * TI	+
			(A3) Fixed assets investment intensity of manufacturing * TI	+
			(A4) Fixed assets investment intensity of construction industry * TI	+
			(A5) Fixed assets investment intensity of health and social work * TI	+
			(A6) Fixed assets investment intensity of transportation, storage, and postal services * TI	+
			(A7) Fixed assets investment intensity of water conservancy, environment, and public facilities management industry * TI	+
			(A8) Fixed assets investment intensity of the production and supply of electricity, heat, gas, and water * TI	+
			(A9) Fixed assets investment intensity of public administration, social security, and social organizations * TI	+
	Investment intensity of innovation infrastructure	0.333	(A10) Fixed assets investment intensity of scientific research and technology services	+
Green technology innovation system (GTI)	Quality of green technology innovation (QGT1)	Macro	(B1) Number of green invention patents obtained (per 10,000 people)	+
	Quantity of green technology innovation (QGT2)		(B2) Number of green invention patent applications (per 10,000 people)	+
	Quality of enterprise green technology innovation (QEGT1)	Micro	(B3) Number of enterprise green invention patents obtained (per listed company)	+
	Quantity of enterprise green technology innovation (QEGT2)		(B4) Number of enterprise green invention patent applications (per listed company)	+

* TI: Information and innovation investment proportion.

The Indexes for Evaluation of NTI & GTI

This paper adopts the GPCA method in the measurement of the investment intensity of the integrated infrastructure in the new infrastructure investment intensity. Since the integrated infrastructure itself is a new infrastructure extension of traditional industries (Du et al. 2022), and there is a possibility of collinearity between the investment intensities of traditional industries, this paper needs to perform GPCA dimensionality reduction operations on the investment intensity of the integrated infrastructure. First, the Bartlett test (1950) and the Kaiser Meyer Olkin test (1974) were carried out on the data of integrated infrastructure investment intensity A2~A9. The test found that the KMO was greater than 0.5 and the significance of the Bartlett sphericity test was 0.009. The results show collinearity among indicators (Rasheed and Abadi 2014), so global principal component analysis can be performed (Namlu and Odabasi 2007, Hou et al. 2021). After extracting the principal components of the A2~A9 data, this paper selects 4 principal components as F1, F2, F3, and F4 based on the cumulative contribution of 85% as the standard. The cumulative contribution of the four principal components reaches 86.13%, that is, the selected four principal components can cover 86.13% of the original information. Therefore, the score of integrated infrastructure investment intensity can be calculated by the following formula (1):

$$F_{ki} = (\frac{59.35}{86.13}) * F_{c1} + (\frac{11.45}{86.13}) * F_{c2} + (\frac{8.52}{86.13}) * F_{c3} + (\frac{6.82}{86.13}) * F_{c4} \quad (1)$$

F_{ki} is the score of city i's integrated infrastructure investment intensity in year k, and F_{c1}, F_{c2}, F_{c3} and F_{c4}, are the scores of each factor. After obtaining the investment intensity score of integrated infrastructure in each province and city, its value is assigned a weight of 0.333 and added to the intensity of information infrastructure and innovation infrastructure with the same weight. The new infrastructure investment intensity index is obtained by adding the indices of the three categories.

The Coupling Coordination Degree Model (CCDM)

This paper uses CCDM to calculate the coupling coordination level between new infrastructure investment intensity (NTI) and macro-micro green technology innovation (GTI). The specific formula is as follows:

$$C_n = \left\{ \frac{f(X) \cdot g(Y)}{\left[\frac{f(X) + g(Y)}{2}\right]^2} \right\}^K \quad (2)$$

$$T = \alpha f(X) + \beta g(Y) \quad (3)$$

$$D = \sqrt{C \cdot T} \quad (4)$$

C is the coupling degree, K is the regulation factor ($K \geq 2$), f(X) is the new infrastructure investment intensity subsystem level (NTI), and g(Y) is the green technology innovation subsystem level (GTI). When the sum of f(X) and g(Y) is constant, C represents the degree of coupling between new infrastructure investment intensity and green technology innovation, and its goal is to maximize the product of f(X) and g(Y). D is the degree of coupling coordination, and T reflects the overall effect or effect level of new infrastructure investment intensity and green technology innovation. α and β represent the contribution of urbanization and environment, respectively. Considering that China has no obvious policy preference for new infrastructure investment intensity and green technology innovation, this paper sets the sum of α and β as 1 and both are 0.5.

Results and Discussion

Results of the Development of Coupling

Fig. 2, 3, and A1 illustrate the distribution of new infrastructure investment in-tensity across various provinces and cities in China between 2010 and 2020. As the data has been standardized, only the charts depicting new infrastructure investment intensity for each province and city, as well as the eastern, middle, and western regions are included. The results of these charts reveal significant regional disparities in new infra--structure investment in China. Specifically, the intensity of new infrastructure investment in the eastern region has been on a steady decline and is expected to continue to fall in the future. In contrast, the intensity of new infrastructure investment in the central region has been consistently increasing. The intensity of new infrastructure investment in the west-ern region has fluctuated up and down and has not yet stabilized, indicating that China's various regions have not yet formed a relatively stable proportion of new infrastructure investment. From the perspective of the average new infrastructure investment intensity of various provinces and cities from 2010 to 2020, Heilongjiang, Jilin, Qinghai, Tianjin, and Shaanxi exhibit the highest investment intensity in new infrastructure, while Shanghai, Zhejiang, Guangdong, Henan, and Chongqing have the lowest investment in-tensity. In terms of the three categories of new infrastructure investment (as shown in Fig. A2), Jilin, Hainan, Heilongjiang, Qinghai, and Guangxi exhibit the highest investment intensity in information infrastructure. For integrated infrastructure, Heilongjiang, Jilin, Qinghai, Gansu, and Shaanxi exhibit the highest investment intensity. Finally, Heilongjiang, Shandong, Tianjin, Jilin, and Shaanxi exhibit the highest intensity of innovative infrastructure.

Fig. A2 presents the kernel density distribution map of new infrastructure investment intensity in China from 2010 to 2020. It is observed that the peak of the distribution fluctuated from 2010 to 2017 but has significantly increased since 2018, indicating that China's new infrastructure investment has become more concentrated in recent years. Moreover, there is no significant horizontal shift in the curve distribution across the research years, indicating that the investment intensity of new infrastructure is relatively stable. Additionally, the curve's shape is wider in 2010–2017 compared to 2018–2020, which suggests a decrease in regional differences in the level of new infrastructure investment over time.

Fig. 4, 5, and A3 display the distribution of green technology innovation across various provinces and cities in China from 2010 to 2020. It can be observed that the overall level of green technology innovation quality and quantity increases over the study period. However, the overall level of the two declined after 2018–2019, followed by a rebound. Among the specific provinces and cities, the top five regions in the macro green technology innovation index are Beijing, Shanghai, Jiangsu, Tianjin, and Zhejiang, while the last five are Inner Mongolia, Xinjiang, Qinghai, Jiangxi, and Guizhou. The top five regions in the micro green technology innovation index are Beijing, Guangdong, Xinjiang, Henan, and Chongqing, and the last five are Ningxia, Hainan, Jilin, Gansu, and Shanxi. Regarding the sub-indicators of green technology innovation, the macro GTI in the east-ern region shows a certain U-shaped trend, with a significant fluctuation and a bottoming out in 2014–2015. On the other hand, the micro GTI sub-indicators in the eastern region present a divergent trend: the quality of green innovation of enterprises in the eastern region is relatively stable but began to decline after 2018, while the data on green innovation of enterprises in the eastern region experienced an increase for several years after 2016. The central region's overall trend of micro and macro GTI is similar, fluctuating upward and remaining relatively stable. The macro GTI in the western region displays a certain inverted U-shaped trend, with a peak in 2014, while the micro GTI sub-indices in the western region fluctuate and stabilize overall, with a peak in 2015 and 2019.

From 2010 to 2020, there were notable regional disparities in the investment intensity of new infrastructure and the level of green technology innovation across various provinces and

Subsystem	*New infrastructure investment intensity system (NTI)*												
Region	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Average*	*Rank*
Heilongjiang	0.43	0.47	0.75	0.83	0.58	0.51	0.62	0.66	0.84	0.89	1	0.689	1
Jilin	0.56	0.33	0.56	0.51	0.59	0.64	0.63	0.78	0.79	0.48	0.9	0.615	2
Qinghai	0.16	0.19	0.07	0.09	0.33	0.97	0.96	0.75	0.81	0.99	0.41	0.521	3
Tianjin	0.29	0.47	0.5	0.48	0.61	0.43	0.6	0.76	0.4	0.34	0.37	0.477	4
Shaanxi	0.7	0.48	0.61	0.55	0.72	0.46	0.4	0.34	0.36	0.27	0.28	0.470	5
Gansu	0.55	0.64	0.53	0.62	0.56	0.46	0.51	0.25	0.28	0.21	0.22	0.439	6
Inner Mongolia	0.46	0.61	0.52	0.6	0.89	0.31	0.29	0.37	0.28	0.28	0.22	0.439	7
Hunan	0.28	0.42	0.29	0.28	0.29	0.43	0.37	0.42	0.6	0.7	0.64	0.429	8
Guangxi	0.41	0.45	0.4	0.46	0.37	0.35	0.38	0.36	0.42	0.44	0.5	0.413	9
Hainan	0.28	0.51	0.46	0.33	0.24	0.35	0.45	0.43	0.3	0.32	0.34	0.365	10
Shandong	0.13	0.33	0.39	0.5	0.38	0.51	0.38	0.34	0.34	0.35	0.34	0.363	11
Ningxia	0.35	0.33	0.15	0.22	0.38	0.43	0.49	0.58	0.36	0.31	0.3	0.355	12
Liaoning	0.71	0.57	0.6	0.51	0.53	0.44	0.06	0.08	0.06	0.09	0.09	0.340	13
Anhui	0.37	0.25	0.39	0.38	0.36	0.41	0.39	0.29	0.28	0.23	0.3	0.332	14
Xinjiang	0.39	0.43	0.3	0.23	0.32	0.32	0.37	0.4	0.35	0.28	0.25	0.331	15
Hebei	0.1	0.25	0.25	0.32	0.29	0.23	0.33	0.38	0.43	0.54	0.48	0.327	16
Beijing	0.44	0.42	0.48	0.42	0.25	0.17	0.11	0.16	0.21	0.2	0.2	0.278	17
Jiangsu	0.16	0.31	0.33	0.36	0.37	0.33	0.25	0.25	0.23	0.22	0.23	0.276	18
Jiangxi	0.38	0.18	0.2	0.16	0.17	0.24	0.28	0.28	0.32	0.36	0.43	0.273	19
Fujian	0.31	0.28	0.25	0.22	0.17	0.22	0.22	0.23	0.29	0.23	0.21	0.239	20
Sichuan	0.23	0.19	0.14	0.12	0.12	0.25	0.18	0.17	0.23	0.31	0.27	0.201	21
Yunnan	0.22	0.36	0.27	0.27	0.16	0.08	0.24	0.18	0.17	0.12	0.14	0.201	22
Hubei	0.21	0.2	0.24	0.18	0.12	0.15	0.13	0.19	0.22	0.27	0.19	0.191	23
Shanxi	0.22	0.14	0.19	0.26	0.19	0.3	0.3	0.09	0.09	0.12	0.13	0.185	24
Guizhou	0.42	0.1	0	0.04	0.04	0.1	0.13	0.23	0.3	0.28	0.3	0.176	25
Chongqing	0.34	0.19	0.24	0.23	0.11	0.11	0.09	0.13	0.09	0.15	0.19	0.170	26
Henan	0.06	0.02	0.07	0.1	0.12	0.16	0.18	0.22	0.28	0.25	0.33	0.163	27
Guangdong	0.19	0.22	0.22	0.18	0.17	0.14	0.11	0.14	0.12	0.14	0.13	0.160	28
Zhejiang	0.15	0.15	0.1	0.12	0.14	0.13	0.13	0.14	0.15	0.2	0.19	0.145	29
Shanghai	0.19	0.2	0.19	0.13	0.1	0.07	0.06	0.09	0.09	0.11	0.1	0.121	30

Fig. 2. Trends of criterion la yer levels in NTI sub-system

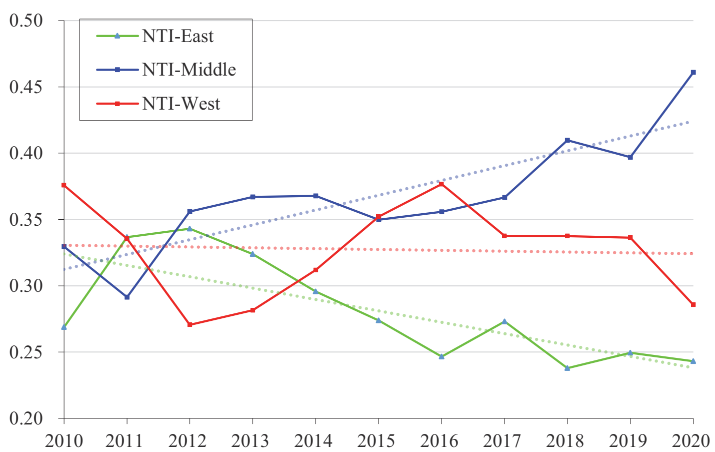

Fig. 3. Trends of criterion layer levels in NTI sub-system by region

cities in China. Specifically, the central region had a higher new infrastructure intensity compared to the western and eastern regions, with the eastern region exhibiting a further downward trend. On the other hand, the western region had a higher level of green technology innovation compared to the eastern and central regions, with a significant gap already present. Although no close correlation was found between the trends of these two subsystems, the following chapter will further investigate the coupling and coordination of the two subsystems.

Coupling Results of the Different Values of NTI (α) & NTI (β)

To investigate the effects of new infrastructure investment intensity (NTI) and green technology innovation (GTI) on the degree of coupling coordination, we conducted an analysis of three cases (Case1-3) with varying NTI and GTI. Tables 6 and 7 present the results of this analysis, which illustrate the degree of coupling between NTI and GTI from 2010 to 2020. Specifically, D1, D2, D3, and D4 denote the coupling coordination levels between NTI and qgt1, qgt2, qegt1, and qegt2, respectively. D1 and D2 pertain to the coupling coordination level at the macro level, while D3 and D4 correspond to the coupling coordination level at the micro level.

When comparing the coupling results of the three groups, we found that the overall trend was consistent, with some minor differences (as shown in Fig. 6, 7, and Fig. A5). These findings suggest that the weights of the NTI and GTI indicators do not significantly affect the degree of coupling.

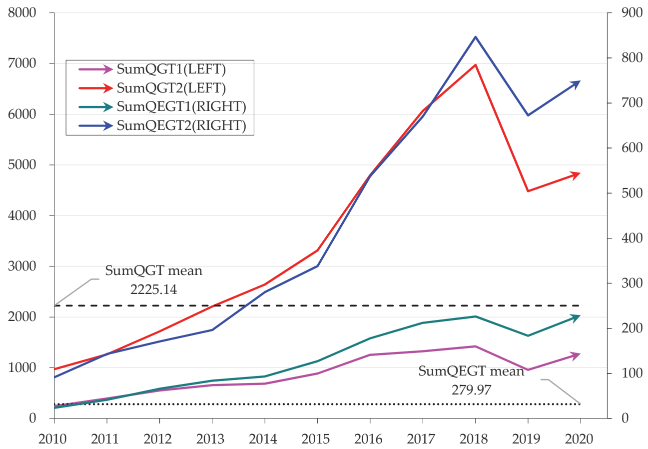

Fig. 4. Trends of criterion layer levels in GTI sub-system (total value)

Green technology innovation system(GTI)

	Macro													Micro												
region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Avg.	Rank	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Avg.	Rank
Beijing	0.96	0.96	0.96	0.98	1	0.99	0.97	0.97	0.97	0.98	0.98	0.972	1	0.985	0.97	0.98	0.96	0.98	0.93	0.88	0.9	0.84	0.65	0.72	0.889	1
Tianjin	0.24	0.24	0.25	0.25	0.23	0.24	0.27	0.23	0.22	0.2	0.16	0.227	4	0.19	0.16	0.15	0.11	0.12	0.1	0.09	0.12	0.19	0.16	0.11	0.135	17
Hebei	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.024	23	0.11	0.14	0.19	0.18	0.15	0.16	0.16	0.22	0.23	0.15	0.16	0.166	12
Shanxi	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.03	0.027	21	0.115	0.12	0.12	0.12	0.11	0.08	0.08	0.06	0.06	0.05	0.04	0.085	25
Inner Mongolia	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.013	30	0.11	0.08	0.1	0.12	0.09	0.12	0.08	0.09	0.12	0.1	0.105	0.100	21
Liaoning	0.1	0.1	0.1	0.1	0.08	0.08	0.07	0.06	0.07	0.07	0.05	0.077	10	0.14	0.14	0.14	0.15	0.12	0.12	0.09	0.1	0.09	0.12	0.15	0.121	18
Jilin	0.06	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.04	0.04	0.037	18	0.085	0.09	0.09	0.09	0.07	0.06	0.06	0.06	0.03	0.07	0.135	0.074	28
Heilongjiang	0.07	0.06	0.05	0.06	0.06	0.06	0.04	0.04	0.04	0.04	0.04	0.049	16	0.12	0.09	0.13	0.14	0.1	0.09	0.09	0.08	0.05	0.09	0.065	0.092	22
Shanghai	0.45	0.44	0.4	0.35	0.32	0.33	0.34	0.34	0.34	0.36	0.35	0.363	2	0.225	0.24	0.21	0.18	0.19	0.22	0.2	0.19	0.18	0.2	0.19	0.200	8
Jiangsu	0.19	0.22	0.25	0.25	0.24	0.24	0.24	0.26	0.25	0.23	0.22	0.232	3	0.175	0.18	0.21	0.26	0.23	0.25	0.27	0.25	0.25	0.19	0.175	0.219	6
Zhejiang	0.15	0.15	0.16	0.15	0.15	0.16	0.17	0.19	0.22	0.2	0.24	0.172	5	0.14	0.14	0.14	0.13	0.12	0.12	0.11	0.1	0.1	0.11	0.125	0.119	19
Anhui	0.05	0.05	0.05	0.06	0.08	0.1	0.13	0.13	0.14	0.1	0.11	0.089	8	0.125	0.14	0.15	0.19	0.18	0.21	0.23	0.25	0.27	0.17	0.205	0.190	10
Fujian	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.08	0.09	0.08	0.08	0.070	13	0.12	0.14	0.13	0.12	0.13	0.12	0.14	0.13	0.17	0.2	0.24	0.147	16
Jiangxi	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.019	27	0.125	0.1	0.11	0.08	0.1	0.09	0.14	0.13	0.12	0.08	0.05	0.100	20
Shandong	0.07	0.07	0.08	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.079	9	0.16	0.14	0.14	0.16	0.18	0.21	0.21	0.25	0.23	0.23	0.225	0.191	9
Henan	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.026	22	0.17	0.17	0.16	0.21	0.24	0.33	0.41	0.36	0.42	0.22	0.3	0.270	4
Hubei	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.072	11	0.175	0.18	0.19	0.16	0.18	0.2	0.22	0.22	0.25	0.25	0.32	0.211	7
Hunan	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.055	15	0.14	0.18	0.19	0.22	0.21	0.22	0.15	0.13	0.12	0.11	0.13	0.162	13
Guangdong	0.14	0.13	0.13	0.13	0.12	0.12	0.14	0.16	0.17	0.17	0.16	0.140	6	0.245	0.3	0.28	0.27	0.3	0.32	0.33	0.34	0.37	0.28	0.275	0.299	2
Guangxi	0.03	0.02	0.03	0.04	0.06	0.06	0.08	0.06	0.03	0.02	0.02	0.040	17	0.1	0.08	0.09	0.09	0.09	0.06	0.06	0.07	0.06	0.11	0.125	0.084	26
Hainan	0.03	0.04	0.03	0.05	0.04	0.02	0.03	0.02	0.02	0.03	0.03	0.029	20	0.08	0.07	0.07	0.08	0.07	0.06	0.06	0.04	0.04	0.08	0.075	0.062	29
Chongqing	0.07	0.08	0.08	0.07	0.07	0.1	0.07	0.06	0.07	0.08	0.08	0.072	11	0.275	0.3	0.34	0.34	0.21	0.22	0.19	0.21	0.15	0.17	0.12	0.228	5
Sichuan	0.05	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.06	0.06	0.06	0.055	14	0.265	0.22	0.18	0.16	0.16	0.18	0.16	0.16	0.15	0.19	0.17	0.180	11
Guizhou	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.019	26	0.105	0.14	0.12	0.09	0.1	0.1	0.08	0.08	0.07	0.07	0.06	0.090	23
Yunnan	0.03	0.03	0.03	0.03	0.03	0.01	0.02	0.02	0.02	0.03	0.03	0.024	24	0.135	0.14	0.12	0.14	0.12	0.58	0.12	0.11	0.1	0.09	0.07	0.155	15
Shaanxi	0.1	0.11	0.12	0.12	0.1	0.08	0.07	0.1	0.08	0.09	0.09	0.095	7	0.18	0.19	0.17	0.15	0.25	0.12	0.15	0.16	0.16	0.14	0.12	0.161	14
Gansu	0.04	0.03	0.03	0.03	0.04	0.03	0.02	0.01	0.01	0.02	0.02	0.023	25	0.09	0.1	0.1	0.09	0.12	0.08	0.07	0.05	0.05	0.07	0.06	0.077	27
Qinghai	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.017	28	0.085	0.1	0.1	0.06	0.09	0.11	0.13	0.08	0.07	0.12	0.07	0.089	24
Ningxia	0.03	0.03	0.03	0.05	0.05	0.04	0.03	0.03	0.04	0.03	0.04	0.034	19	0.105	0.07	0.09	0.08	0.07	0.07	0.05	0.04	0.02	0.04	0.01	0.058	30
Xinjiang	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.01	0.02	0.01	0.016	29	0.11	0.14	0.12	0.14	0.19	0.24	0.28	0.27	0.31	0.75	0.575	0.281	3

Fig. 5. Trends of macro & micro criterion layer levels in GTI sub-system

Therefore, our main focus is on the general trend of the results.

Despite some improvement, the degree of coupling coordination between NTI and GTI remains at a level of near-dissonance overall. Furthermore, the coordination and coupling between NTI and GTI at the micro level is higher than at the macro level, with D3 and D4 significantly outperforming D1 and D2 from 2010–2020. This indicates that the coupling level of the NTI-GTI system at the micro level is better than its performance at the macro level.

To analyze the development of coupling between NTI and GTI, we divided the period from 2010 to 2020 into two stages and examined them based on the degree of coordination and coupling, as well as the comprehensive system level of new infrastructure investment intensity and green technology innovation. Our findings indicate that the degree of coordination and coupling initially decreased and then increased, forming a U-shaped curve:

(1) During the period from 2010 to 2015, the degree of coupling between NTI and GTI demonstrated a consolidating trend, with relatively stable fluctuations. Throughout this period, both the NTI sub-system and GTI subsystem exhibited significant fluctuations. These findings suggest that the intensity of investment in new infrastructure and the overall level of green innovation in society both exhibit relatively unstable fluctuations. Taking into account that new infrastructure investment is predominantly financed by the government, while green innovation is influenced by corresponding policies, we posit that the government allocated a certain degree of attention to both new infrastructure and green technology innovation, without exhibiting a marked preference towards either.

(2) From 2015 to 2020, the degree of coordination between NTI and GTI exhibited a U-shaped trend. Between 2015 and 2017, the coupling and coordination degree of NTI and GTI macro indicators experienced a sharp

Coupling Coordination Degree under Different Weights

Case	Case 1: α=1/3; β=2/3				Case 2: α=β=1/2				Case 3: α=2/3; β=1/3			
Angle	Macro		Micro		Macro		Micro		Macro		Micro	
Year	D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3	D4
2010	0.31	0.36	0.40	0.46	0.34	0.39	0.43	0.48	0.37	0.42	0.45	0.50
2011	0.31	0.36	0.39	0.46	0.34	0.39	0.42	0.48	0.37	0.42	0.44	0.50
2012	0.31	0.35	0.39	0.45	0.34	0.38	0.41	0.47	0.37	0.41	0.44	0.48
2013	0.31	0.36	0.40	0.46	0.34	0.39	0.42	0.47	0.37	0.41	0.45	0.49
2014	0.31	0.36	0.39	0.45	0.35	0.39	0.42	0.47	0.38	0.41	0.44	0.48
2015	0.31	0.35	0.40	0.46	0.35	0.38	0.43	0.48	0.38	0.41	0.45	0.49
2016	0.31	0.34	0.38	0.45	0.34	0.36	0.41	0.46	0.37	0.39	0.43	0.47
2017	0.30	0.33	0.38	0.45	0.34	0.36	0.41	0.46	0.36	0.38	0.43	0.48
2018	0.29	0.34	0.36	0.45	0.32	0.37	0.38	0.46	0.34	0.39	0.40	0.48
2019	0.30	0.35	0.39	0.45	0.33	0.38	0.42	0.47	0.35	0.41	0.44	0.48
2020	0.31	0.35	0.38	0.44	0.34	0.38	0.41	0.46	0.37	0.41	0.43	0.47

Coordination Degree Standard	Date Range
Extreme Disorder Level	0~0.1
Severe Disorder Level	0.1~0.2
Moderate Level of imbalance	0.2~0.3
Mild Disorder Level	0.3~0.4
Near-disorder Level	0.4~0.5
Barely Coordinated	0.5~0.6
Primary Level of Coordination	0.6~0.7
Intermediate Level of Coordination	0.7~0.8
Good Level of Coordination	0.8~0.9
Excellent Level of Coordination	0.9~0.10

Fig. 6. Degree of coordinated coupling of NTI and GTI in China

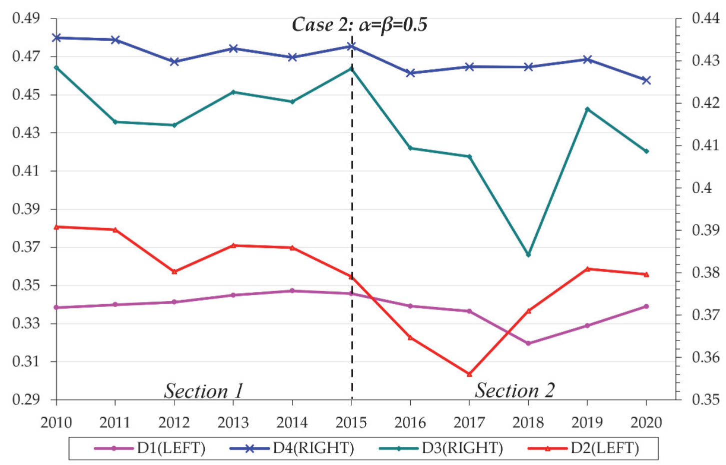

Fig. 7. Degree of coordinated coupling of NTI and GTI in China (Case2: α=β=0.5)

drop, hitting the lowest level during the research period. While the NTI subsystem gradually increased during this period, the GTI macro indicators experienced a rapid decline. This indicates that at this stage, the government was more focused on investing in and constructing new infrastructure, with green technology innovation taking a backseat to infrastructure investment. This trend aligns with actual national policy, as in 2015, the NDRC of the State Council of China issued the "Made in China 2025" plan for future infrastructure, and launched a series of projects on the Internet and smart manufacturing, such as the famous "Internet Plus Plan of Action", which provided important policy guidelines for new infrastructure investment. From 2017 to 2020, the degree of coupling and coordination between NTI and GTI rebounded, as the level of green technology innovation continued to rise and investment in new infrastructure remained relatively stable. This shows that after 2017, the government attached more importance to green innovation, and the emphasis on new infrastructure investment became more normalized. This is closely related to a series of environmental protection policies of the government during this period, such as the "Thirteenth Five-Year Plan for Ecological and Environmental Protection" issued by the State Council on November 24, 2016, and the "Thirteenth Five-Year Plan" related to the environmental protection industry, which provided direction for industrial development. In addition, on December 25, 2016, the National People's Congress passed the Environmental Protection Tax Law of the People's Republic of China, which marked the withdrawal of the original sewage charging system from the stage of history and was of great significance to China's environmental protection. 2017 was also the assessment year for the first phase of China's Air Pollution Prevention and Control Action Plan, and the degree to which the government improved the environment was directly linked to government performance. These policies provided policy-side evidence for the sharp rebound in GTI levels.

The coupling coordination degree model has significant implications for planning green and sustainable future development. By analyzing the coupling factors and coordination level between new infrastructure investment intensity and green technology innovation, relevant departments can gain a better understanding of the government's attention to infrastructure and green development from the dynamic changes in coupling. It is widely recognized that infrastructure construction has become a future-oriented next-generation endeavor, and therefore, environmental protection and sustainable factors must be given more attention by relevant government and business departments. Comprehensive consideration of new infrastructure investment intensity and green technology innovation can help regions achieve a more sustainable and green development model for new infrastructure investment.

Conclusions

Taking China's 30 main provinces and cities as an example, we developed a CCDM to quantitatively evaluate the degree of coupling between NTI and GTI. In the context of the rapid development of new infrastructure, correlation analysis is applied to study the dynamic changes of the coupling coordination degree of NTI investment intensity and both macro and micro GTI. The study shows that the coupling coordination degree of NTI and GTI in China shows a U-shaped curve change from 2010 to 2020. Although the coupling system degree of both has increased behind, the coupling level of NTI and GTI in China is still at the stage of near dissonance level. In terms of micro and macro distinction, the overall NTI and micro GTI coupling coordination degree in China is significantly higher than that of NTI and macro GTI coupling coordination degree. In other words, the degree of coupling coordination between the intensity of new infrastructure investment and the level of corporate green technology innovation in China is significantly higher than its coupling coordination with the level of green technology innovation in society. This paper also makes classification results based on different NTI and GTI weights. The values of α and β generated for the three cases were generally consistent, which indicated that the parameters had little effect on the CCDM.

In response to the research findings, this paper makes the following policy recommendations:

(1) The government needs to pay attention to the level of coordination between the intensity of new infrastructure investment and green technology innovation. For new infrastructure investment to become a sustainable link in green development, the government must pay attention to its important relationship with green innovation. Let the intensity of new infrastructure investment and green innovation be coupled and developed, which can make the whole social development system enter a sustainable green development mode.

(2) Government departments need to strengthen the level of green innovation in society. We found that green innovation in enterprises is higher than social innovation, and in fact, green innovation needs to be promoted in all industries and all kinds of sectors. By increasing the level of social green innovation, we can more effectively promote the intensity of new infrastructure investment into the green development model.

(3) The intensity of new infrastructure investment is unbalanced across regions in China, with developed cities lagging average cities. In our study, we found that the investment intensity of new infrastructure construction in each region of China does not correlate with the regional economic level, and many remote regions have high new infrastructure investment intensity. This is certainly related to local GDP, but considering the marginal benefits, developed cities should also increase the intensity of new infrastructure investment.

(4) Relevant departments must promote the need for new infrastructure investment to be a part of green investment. While traditional infrastructure investment tends to focus on economic benefits, the green development opportunities brought by new infrastructure investment allow for more possibilities in infrastructure construction. The intensity of new infrastructure investment needs to be highly coupled with green innovation in order to enter reaching a green new infrastructure development model.

Appendix A

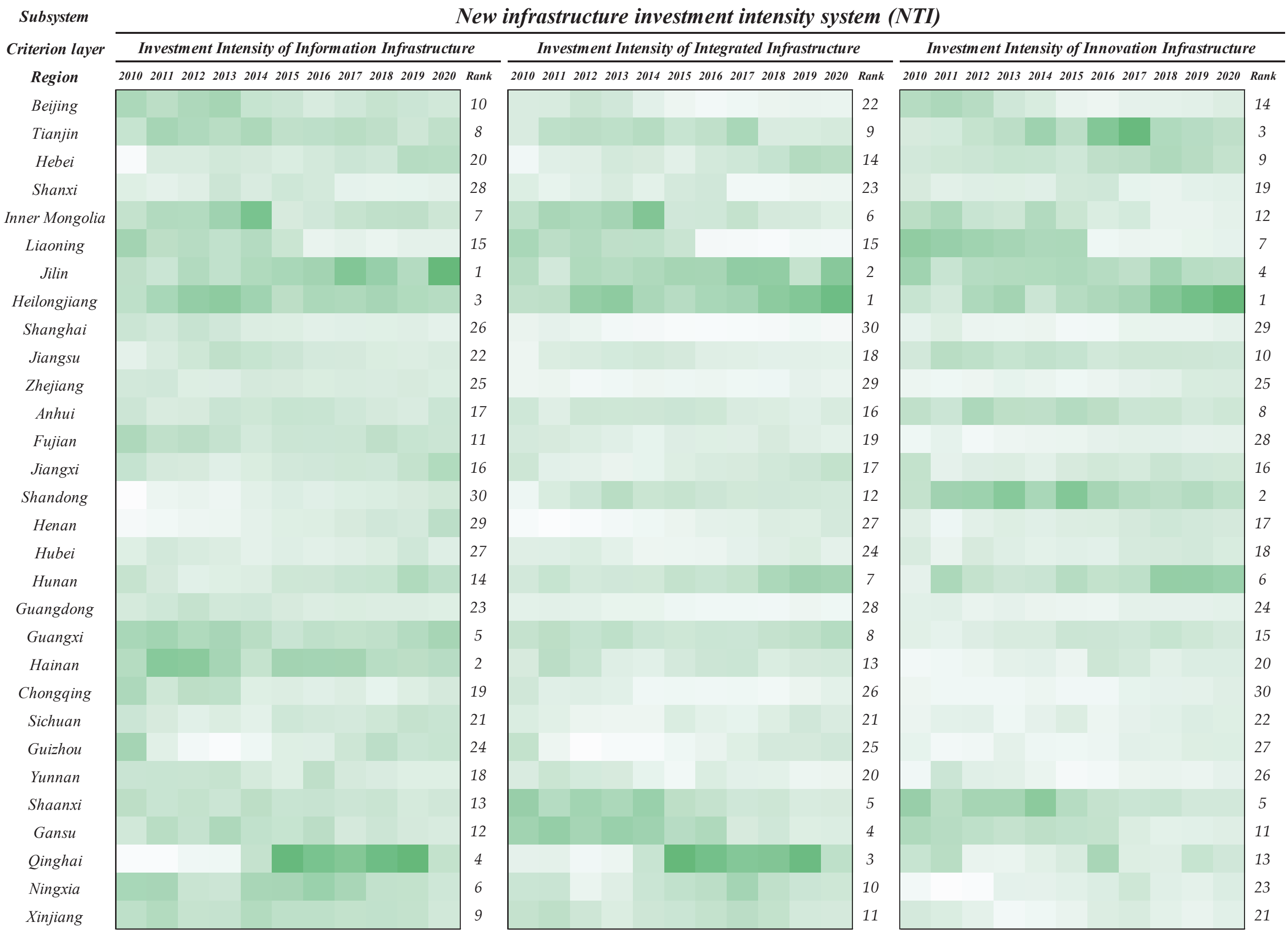

Fig. A1. Trends of criterion layer levels in NTI sub-system

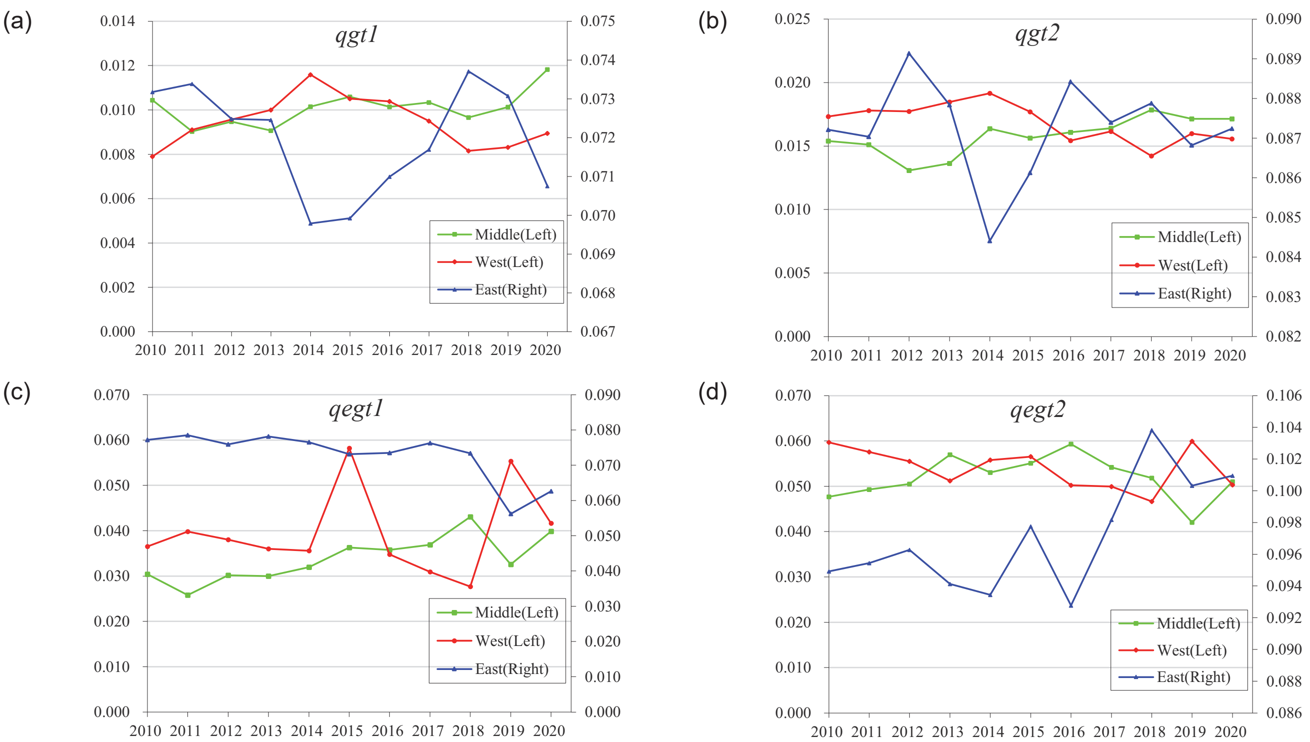

Fig. A2. NTI kernel density estimate

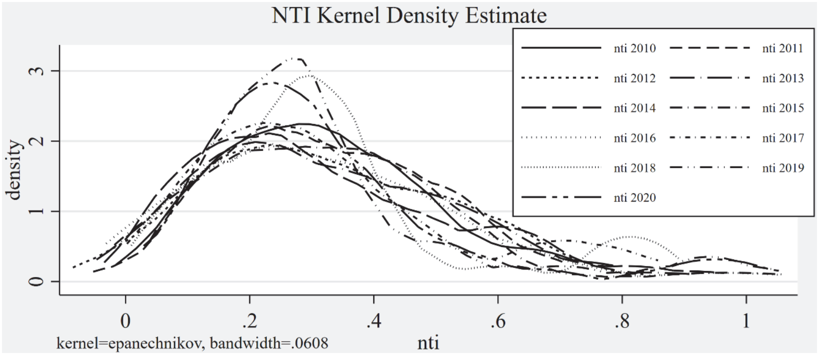

Fig. A3. Trends of criterion layer levels in GTI sub-system by region

Green technology innovation system(GTI)

qgt1

	region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Avg.	Rank
Macro	Beijing	0.95	0.95	0.97	0.98	1	1	0.99	0.99	0.98	0.98	0.99	0.980	1
	Tianjin	0.23	0.21	0.2	0.18	0.17	0.14	0.15	0.18	0.18	0.16	0.11	0.174	4
	Hebei	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.019	23
	Shanxi	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.02	0.01	0.01	0.02	0.023	19
	Inner Mongolia	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0.01	0.007	30
	Liaoning	0.09	0.08	0.07	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.05	0.066	8
	Jilin	0.05	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.033	17
	Heilongjiang	0.07	0.06	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.03	0.03	0.045	15
	Shanghai	0.4	0.41	0.35	0.32	0.29	0.3	0.31	0.3	0.3	0.3	0.26	0.322	2
	Jiangsu	0.13	0.14	0.17	0.18	0.17	0.18	0.18	0.19	0.21	0.2	0.17	0.175	3
	Zhejiang	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.15	0.18	0.18	0.22	0.158	5
	Anhui	0.03	0.03	0.03	0.04	0.05	0.05	0.07	0.06	0.08	0.07	0.09	0.055	13
	Fujian	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.07	0.08	0.07	0.07	0.062	10
	Jiangxi	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.011	27
	Shandong	0.06	0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.064	9
	Henan	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.019	23
	Hubei	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.08	0.08	0.062	11
	Hunan	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.048	14
	Guangdong	0.11	0.11	0.12	0.11	0.1	0.1	0.1	0.11	0.12	0.13	0.13	0.113	6
	Guangxi	0.01	0.01	0.01	0.02	0.03	0.03	0.04	0.03	0.02	0.01	0.01	0.020	21
	Hainan	0.01	0.02	0.02	0.06	0.04	0.02	0.03	0.02	0.02	0.02	0.02	0.025	18
	Chongqing	0.05	0.07	0.07	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.058	12
	Sichuan	0.03	0.03	0.03	0.03	0.04	0.04	0.05	0.05	0.04	0.05	0.05	0.040	16
	Guizhou	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0	0	0.01	0.009	28
	Yunnan	0.02	0.02	0.02	0.02	0.03	0.01	0.02	0.02	0.02	0.02	0.02	0.020	22
	Shaanxi	0.07	0.08	0.08	0.1	0.09	0.08	0.07	0.07	0.07	0.07	0.08	0.078	7
	Gansu	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.01	0	0.01	0.01	0.016	25
	Qinghai	0	0.01	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.02	0.008	29
	Ningxia	0.01	0.01	0.02	0.02	0.04	0.03	0.03	0.02	0.02	0.01	0.02	0.021	20
	Xinjiang	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0	0.01	0.01	0.013	26

qgt2

	region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Avg.	Rank
Macro	Beijing	0.96	0.96	0.95	0.97	1	0.97	0.94	0.94	0.96	0.98	0.97	0.964	1
	Tianjin	0.24	0.26	0.3	0.32	0.28	0.34	0.39	0.28	0.25	0.23	0.2	0.281	4
	Hebei	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.01	0.02	0.04	0.03	0.029	25
	Shanxi	0.05	0.04	0.04	0.04	0.04	0.03	0.02	0.01	0.02	0.03	0.03	0.032	22
	Inner Mongolia	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0	0.01	0.03	0.02	0.019	30
	Liaoning	0.1	0.11	0.13	0.12	0.09	0.08	0.08	0.06	0.07	0.07	0.05	0.087	10
	Jilin	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.05	0.05	0.042	19
	Heilongjiang	0.07	0.06	0.05	0.07	0.08	0.07	0.04	0.03	0.03	0.04	0.04	0.053	17
	Shanghai	0.5	0.46	0.44	0.37	0.34	0.36	0.36	0.38	0.37	0.42	0.44	0.404	2
	Jiangsu	0.25	0.29	0.32	0.31	0.3	0.29	0.29	0.32	0.29	0.26	0.27	0.290	3
	Zhejiang	0.15	0.14	0.16	0.15	0.15	0.17	0.2	0.22	0.25	0.21	0.25	0.186	5
	Anhui	0.06	0.06	0.07	0.07	0.11	0.14	0.19	0.2	0.2	0.12	0.13	0.123	7
	Fujian	0.08	0.07	0.06	0.06	0.06	0.08	0.08	0.09	0.1	0.08	0.09	0.077	13
	Jiangxi	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.03	0.04	0.026	27
	Shandong	0.08	0.08	0.1	0.12	0.11	0.11	0.1	0.09	0.08	0.08	0.09	0.095	9
	Henan	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.034	20
	Hubei	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.1	0.09	0.1	0.09	0.083	12
	Hunan	0.06	0.06	0.05	0.05	0.06	0.05	0.07	0.07	0.06	0.08	0.07	0.062	15
	Guangdong	0.17	0.14	0.14	0.14	0.13	0.14	0.17	0.21	0.22	0.2	0.19	0.168	6
	Guangxi	0.04	0.03	0.05	0.06	0.08	0.09	0.11	0.09	0.04	0.03	0.03	0.059	16
	Hainan	0.04	0.05	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.03	0.04	0.033	21
	Chongqing	0.08	0.09	0.09	0.07	0.09	0.14	0.08	0.06	0.07	0.09	0.09	0.086	11
	Sichuan	0.06	0.05	0.06	0.06	0.07	0.08	0.09	0.1	0.08	0.06	0.06	0.070	14
	Guizhou	0.03	0.03	0.03	0.03	0.04	0.03	0.02	0.02	0.03	0.03	0.03	0.029	24
	Yunnan	0.04	0.04	0.03	0.03	0.03	0.01	0.02	0.02	0.02	0.03	0.03	0.027	26
	Shaanxi	0.12	0.14	0.16	0.14	0.11	0.07	0.07	0.13	0.09	0.11	0.1	0.113	8
	Gansu	0.05	0.04	0.04	0.03	0.04	0.03	0.02	0.01	0.02	0.03	0.02	0.030	23
	Qinghai	0.03	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.04	0.026	27
	Ningxia	0.04	0.04	0.04	0.08	0.05	0.04	0.03	0.03	0.05	0.05	0.06	0.046	18
	Xinjiang	0.03	0.04	0.02	0.03	0.03	0.02	0.01	0	0.01	0.02	0.01	0.020	29

qegt1

	region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Avg.	Rank
Micro	Beijing	1	0.94	0.95	0.95	1	0.97	0.95	0.94	0.85	0.48	0.56	0.872	1
	Tianjin	0.18	0.15	0.11	0.07	0.11	0.06	0.05	0.12	0.15	0.14	0.09	0.112	17
	Hebei	0.08	0.11	0.13	0.17	0.12	0.15	0.16	0.19	0.16	0.08	0.11	0.133	13
	Shanxi	0.09	0.08	0.06	0.08	0.07	0.06	0.06	0.04	0.04	0.04	0.04	0.060	23
	Inner Mongolia	0.07	0.04	0.08	0.06	0.06	0.09	0.04	0.08	0.08	0.06	0.07	0.066	21
	Liaoning	0.11	0.1	0.11	0.13	0.1	0.08	0.04	0.04	0.04	0.09	0.14	0.089	19
	Jilin	0.05	0.03	0.06	0.07	0.04	0.04	0.03	0.02	0.01	0.05	0.06	0.042	28
	Heilongjiang	0.08	0.03	0.1	0.09	0.08	0.04	0.07	0.05	0.01	0.05	0.05	0.059	25
	Shanghai	0.2	0.27	0.2	0.15	0.17	0.21	0.18	0.16	0.15	0.13	0.1	0.175	8
	Jiangsu	0.14	0.15	0.17	0.23	0.19	0.19	0.2	0.23	0.23	0.13	0.12	0.180	7
	Zhejiang	0.11	0.11	0.11	0.11	0.09	0.09	0.08	0.08	0.06	0.07	0.09	0.091	18
	Anhui	0.07	0.09	0.1	0.15	0.11	0.11	0.19	0.22	0.22	0.11	0.14	0.137	12
	Fujian	0.09	0.12	0.11	0.1	0.09	0.07	0.1	0.1	0.13	0.15	0.2	0.115	16
	Jiangxi	0.1	0.05	0.08	0.04	0.08	0.07	0.05	0.05	0.11	0.07	0.05	0.068	20
	Shandong	0.13	0.1	0.08	0.12	0.12	0.11	0.13	0.16	0.15	0.15	0.17	0.129	14
	Henan	0.17	0.14	0.13	0.11	0.15	0.26	0.27	0.3	0.47	0.22	0.33	0.232	4
	Hubei	0.15	0.17	0.14	0.12	0.14	0.16	0.2	0.22	0.24	0.29	0.32	0.195	6
	Hunan	0.12	0.14	0.14	0.18	0.21	0.26	0.16	0.12	0.11	0.09	0.13	0.151	10
	Guangdong	0.21	0.29	0.28	0.25	0.26	0.24	0.29	0.26	0.27	0.2	0.22	0.252	3
	Guangxi	0.07	0.04	0.06	0.05	0.07	0.04	0.04	0.04	0	0.07	0.05	0.048	27
	Hainan	0.05	0.02	0.04	0.06	0.04	0.03	0.03	0.02	0.01	0.06	0.06	0.038	30
	Chongqing	0.14	0.33	0.41	0.4	0.18	0.22	0.21	0.2	0.13	0.16	0.08	0.224	5
	Sichuan	0.27	0.18	0.17	0.12	0.15	0.13	0.13	0.14	0.12	0.13	0.1	0.149	11
	Guizhou	0.07	0.14	0.08	0.04	0.07	0.08	0.04	0.06	0.05	0.06	0.03	0.065	22
	Yunnan	0.12	0.11	0.08	0.11	0.09	0.81	0.1	0.1	0.08	0.07	0.06	0.157	9
	Shaanxi	0.17	0.21	0.14	0.13	0.15	0.08	0.09	0.08	0.13	0.09	0.06	0.121	15
	Gansu	0.07	0.04	0.04	0.06	0.13	0.07	0.03	0.01	0.03	0.04	0.02	0.049	26
	Qinghai	0.05	0.09	0.04	0.03	0.04	0.07	0.18	0.05	0	0.1	0.01	0.060	24
	Ningxia	0.09	0.02	0.05	0.05	0.04	0.06	0.04	0.03	0	0.03	0.02	0.039	29
	Xinjiang	0.06	0.04	0.08	0.08	0.16	0.19	0.18	0.21	0.29	0.91	0.81	0.274	2

qegt20

	region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Avg.	Rank
Micro	Beijing	0.97	1	1	0.97	0.95	0.89	0.8	0.85	0.83	0.82	0.88	0.905	1
	Tianjin	0.2	0.17	0.18	0.15	0.13	0.14	0.13	0.12	0.22	0.17	0.13	0.158	16
	Hebei	0.14	0.17	0.25	0.19	0.17	0.16	0.15	0.25	0.29	0.21	0.21	0.199	13
	Shanxi	0.14	0.16	0.17	0.15	0.14	0.1	0.09	0.08	0.07	0.06	0.04	0.109	26
	Inner Mongolia	0.15	0.12	0.11	0.18	0.12	0.14	0.11	0.1	0.15	0.14	0.14	0.133	20
	Liaoning	0.17	0.18	0.17	0.16	0.13	0.15	0.13	0.15	0.14	0.15	0.16	0.154	17
	Jilin	0.12	0.14	0.11	0.1	0.1	0.08	0.08	0.09	0.05	0.09	0.21	0.106	27
	Heilongjiang	0.16	0.14	0.15	0.18	0.12	0.13	0.1	0.11	0.09	0.12	0.08	0.125	22
	Shanghai	0.25	0.21	0.21	0.21	0.21	0.22	0.22	0.21	0.2	0.27	0.28	0.226	10
	Jiangsu	0.21	0.2	0.24	0.29	0.26	0.3	0.33	0.26	0.27	0.24	0.23	0.257	5
	Zhejiang	0.17	0.16	0.16	0.14	0.15	0.14	0.13	0.12	0.13	0.15	0.16	0.146	19
	Anhui	0.18	0.18	0.19	0.22	0.25	0.3	0.27	0.28	0.32	0.22	0.27	0.244	7
	Fujian	0.15	0.16	0.14	0.14	0.16	0.16	0.17	0.16	0.21	0.24	0.28	0.179	14
	Jiangxi	0.15	0.14	0.13	0.12	0.11	0.11	0.23	0.2	0.13	0.08	0.05	0.132	21
	Shandong	0.19	0.18	0.19	0.19	0.23	0.3	0.28	0.33	0.3	0.31	0.28	0.253	6
	Henan	0.17	0.19	0.18	0.31	0.32	0.39	0.54	0.42	0.37	0.22	0.27	0.307	3
	Hubei	0.2	0.19	0.24	0.2	0.22	0.23	0.23	0.21	0.25	0.21	0.32	0.227	9
	Hunan	0.16	0.21	0.23	0.25	0.21	0.17	0.14	0.14	0.13	0.13	0.13	0.173	15
	Guangdong	0.28	0.31	0.27	0.29	0.33	0.39	0.37	0.42	0.46	0.35	0.33	0.345	2
	Guangxi	0.13	0.12	0.12	0.12	0.11	0.08	0.08	0.09	0.12	0.15	0.2	0.120	23
	Hainan	0.11	0.11	0.09	0.09	0.09	0.08	0.08	0.06	0.06	0.09	0.09	0.086	29
	Chongqing	0.41	0.27	0.27	0.28	0.24	0.21	0.16	0.22	0.17	0.17	0.16	0.233	8
	Sichuan	0.26	0.25	0.19	0.2	0.16	0.23	0.18	0.17	0.18	0.25	0.24	0.210	11
	Guizhou	0.14	0.14	0.15	0.13	0.13	0.12	0.11	0.1	0.08	0.08	0.09	0.115	25
	Yunnan	0.15	0.16	0.16	0.17	0.15	0.34	0.14	0.11	0.11	0.1	0.08	0.152	18
	Shaanxi	0.19	0.17	0.19	0.16	0.35	0.16	0.21	0.23	0.18	0.19	0.18	0.201	12
	Gansu	0.11	0.16	0.15	0.11	0.1	0.08	0.1	0.08	0.07	0.09	0.1	0.105	28
	Qinghai	0.12	0.11	0.15	0.08	0.13	0.14	0.08	0.1	0.13	0.13	0.13	0.118	24
	Ningxia	0.12	0.12	0.13	0.11	0.1	0.07	0.06	0.05	0.04	0.05	0	0.077	30
	Xinjiang	0.16	0.23	0.16	0.19	0.21	0.28	0.38	0.33	0.32	0.58	0.34	0.289	4

Fig. A4. Trends of criterion layer levels in GTI sub-system

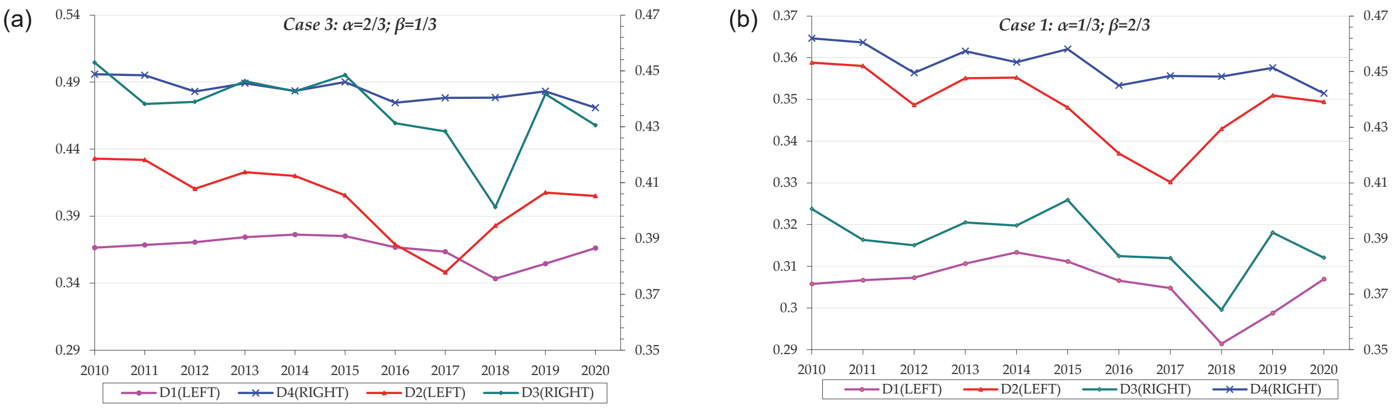

Fig. A5. Degree of coordinated coupling of NTI and GTI in China (Case1,3)

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Conflict of Interest

The authors declare no conflict of interest.

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