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Analysis the status and spatio-temporal characteristics of the synergistic development of China's multi-level medical insurance system

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Examined the synergistic development and spatio-temporal evolution of China's multi-level medical insurance system (MMIS) on a macroscopic level. We assess the comprehensive development of the MMIS across China's 31 provinces from 2011 to 2020 by constructing a comprehensive indicators evaluation model. Subsequently, a coupling coordination index (CCI) model is employed to provide precise insights into the coupling coordination effects among various medical insurance schemes comprising MMIS. Lastly, spatial autocorrelation analysis is conducted to evaluate both the global and local spatio-temporal evolutionary characteristics of MMIS. The CCI of MMIS at the national average level exhibited a fluctuating upward trend, progressing from the moderate disorder recession degree (0.287) in 2011 to the well-coordinated degree (0.887) in 2020. However, the majority of provinces (83.87%) still lingered within the realm of barely coordinated degree ([0.500–0.600]). Specifically, the CCI within the eastern coastal region surpassed that of the western and central regions, with the central region showing the most pronounced increase in CCI. Over the past decade, MMIS demonstrated significant spatial agglomeration, as evidenced by the global Moran's *I* ranging from [0.1668–0.3037]. Furthermore, findings from local spatial autocorrelation analysis suggest a gradual attenuation in the spatial clustering disparity of CCI across various provinces. Government ought to focus on the spatio-temporal evolution patterns of MMIS, and strengthen cooperation between the government and market in health governance, while utilizing information technology and data sharing to improve the overall quality of medical insurance benefits.

Keywords Multi-level medical insurance system, Health financing, Universal health coverage, Coupling coordination index, Spatio-temporal evolution characteristics, Health governance

Abbreviations

MMIS	Multi-level medical insurance system
CCI	Coupling coordination index
UHC	Universal Health Coverage
SMI	Social medical insurance
MA	Medical assistance
CMI	Complementary medical insurance
CHI	Commercial health insurance
NGOs	Non-governmental organizations
UEBMI	Urban employees basic medical insurance
URRBMI	Urban and Rural Residents Basic medical insurance
CII	Critical illness insurance
OOP	Out-of-pocket

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NCMS	New Rural Cooperative Medical Scheme
URBMI	Urban Resident Basic medical insurance
AHP	Analytic hierarchy process
NRDL	National reimbursement drug list

Since the World Health Organization introduced the goal of "Universal Health Coverage (UHC)", it has garnered significant global attention[1]. Nations worldwide are endeavoring to ensure equitable access to affordable healthcare for their populations[2]. Empirical evidence has demonstrated that medical insurance is a crucial instrument in achieving UHC, and even though the design and implementation of medical insurance schemes differ across countries and contexts, all schemes aim to enhance the sustainability and equity of health systems[3].

China has made significant strides toward achieving UHC and has established an MMIS[4,5] (Fig. 1). This system encompasses social medical insurance (SMI) and medical assistance (MA) funded by the government, complementary medical insurance (CMI) provided by the government and employers, commercial health insurance (CHI) offered by companies, as well as charitable donations and other financing methods facilitated by non-governmental organizations (NGOs)[6]. The core component of this system is SMI, which consists of the Urban Employees Basic Medical Insurance (UEBMI) and the Urban and Rural Residents Basic Medical Insurance (URRBMI). UEBMI covers urban employees and retirees, while URRBMI covers residents without formal employment, including children, students, the elderly, the disabled, and others[7,8]. SMI is the largest social insurance scheme in China, covering over 95% of the population[9]. Within SMI, critical illness insurance (CII) functions as a secondary reimbursement scheme for patients facing high out-of-pocket (OOP) costs, which is funded by allocating a specific percentage from the fund pool of SMI and offers the same coverage as SMI, effectively making it an integral part of SMI[10,11]. MA serves as a safety net for poor and vulnerable groups within the MMIS, ensuring they can meet their basic health needs[12]. CMI includes various forms of additional medical insurance, such as employee medical subsidies for significant medical expenses and public servant medical subsidies[13]. CHI is available to all residents and can cover pharmaceuticals and other items not included in SMI[14]. Additionally, charitable donations, typically organized by NGOs, raise funds through charitable aid programs to assist patients with specific diseases or residents facing financial distress due to illness in meeting urgent needs.

The development of MMIS in China has been a lengthy process. UEBMI was introduced in 1998, followed by the New Rural Cooperative Medical Scheme (NCMS) for rural residents in 2003. In 2007, the Urban Resident Basic Medical Insurance (URBMI) was launched to cover urban unemployed individuals, children, students, and the disabled[15]. This established the framework for China's SMI. Despite the government's extensive efforts to achieve universal medical insurance coverage within limited financial resources, the lack of market-oriented insurance and social contributions remains evident[16]. Years of reform have shown that the medical insurance system cannot rely solely on government efforts; private sector investment and market-driven mechanisms are also necessary to provide multi-level and diverse healthcare services to residents[17]. Consequently, since the 2009 national health system reform, China has increasingly promoted the development of CHI to complement the existing system[18]. While CHI has demonstrated significant positive externalities in improving public health, its growth has been slow and its share within the overall medical insurance system remains small[19–21]. In 2020, CHI compensation expenditures in China accounted for less than 4.05% of total health expenditure, compared to approximately 10% in developed countries[22].

The fragmentation of the medical insurance fund pool has resulted in varied benefit schemes, which significantly contributed to the development of the MMIS in China[4]. Establishing a multi-pillar MMIS encompassing government, market, and societal contributions can enhance the resilience of the medical insurance fund and alleviate the unprecedented financial pressure on SMI as a single-payer[23]. Particularly in China, the SMI fund is vulnerable to overdraft risks due to complex social factors such as escalating healthcare costs and rapid population aging[12,24,25]. Research indicates that separate pools of funds may lead to inefficiencies within the healthcare system[4]. However, multi-fund systems in countries like the Netherlands, Germany, Japan, and Colombia, as well as several OECD nations, have demonstrated that universal health insurance coverage and benefit equity are achievable, suggesting that multi-fund systems do not inherently result in fragmentation and inequality[26,27]. Moreover, nearly every resident in China participates in the SMI, and their participation does not conflict with other insurance schemes. Residents can voluntarily join other medical insurance schemes based on factors such as employment, economic conditions, and residence, thus reducing OOP expenses through cross-subsidization[15]. This approach aligns with China's original intent in establishing the MMIS and its ongoing commitment to the social development goal of common prosperity, ensuring equitable, accessible, and affordable healthcare services for the entire population[26].

While the MMIS has been established in China, it remains in its nascent stages. First, the Chinese government issued the "14th Five-Year Plan for Universal Medical Security," which serves as the highest-level blueprint for the period 2021–2025. This document explicitly indicates that China's MMIS framework has only recently been established. Second, the system's limited coverage is evidenced by an actual reimbursement rate of 42.3%, leaving patients to bear 47% of direct costs, substantially higher than the 15–20% threshold recommended by the WHO for poverty control expenditure[7,28,29]. Third, the relatively short history of the MMIS further underscores its immaturity: the CII was established in 2015, the URRBMI was introduced in 2016, and the National Healthcare Security Administration, the primary agency responsible for managing medical insurance was founded in 2018. In light of these factors, it is imperative to assess the developmental status and characteristics of the MMIS and to determine whether the relationships among its various insurance schemes are cooperative or adversarial. Given China's vast expanse, it is essential to investigate whether the development of multiple insurance schemes exhibits internal disparities. A comprehensive understanding of these dynamics is crucial for elucidating the underlying principles of the MMIS and for formulating more detailed developmental strategies. Regrettably,

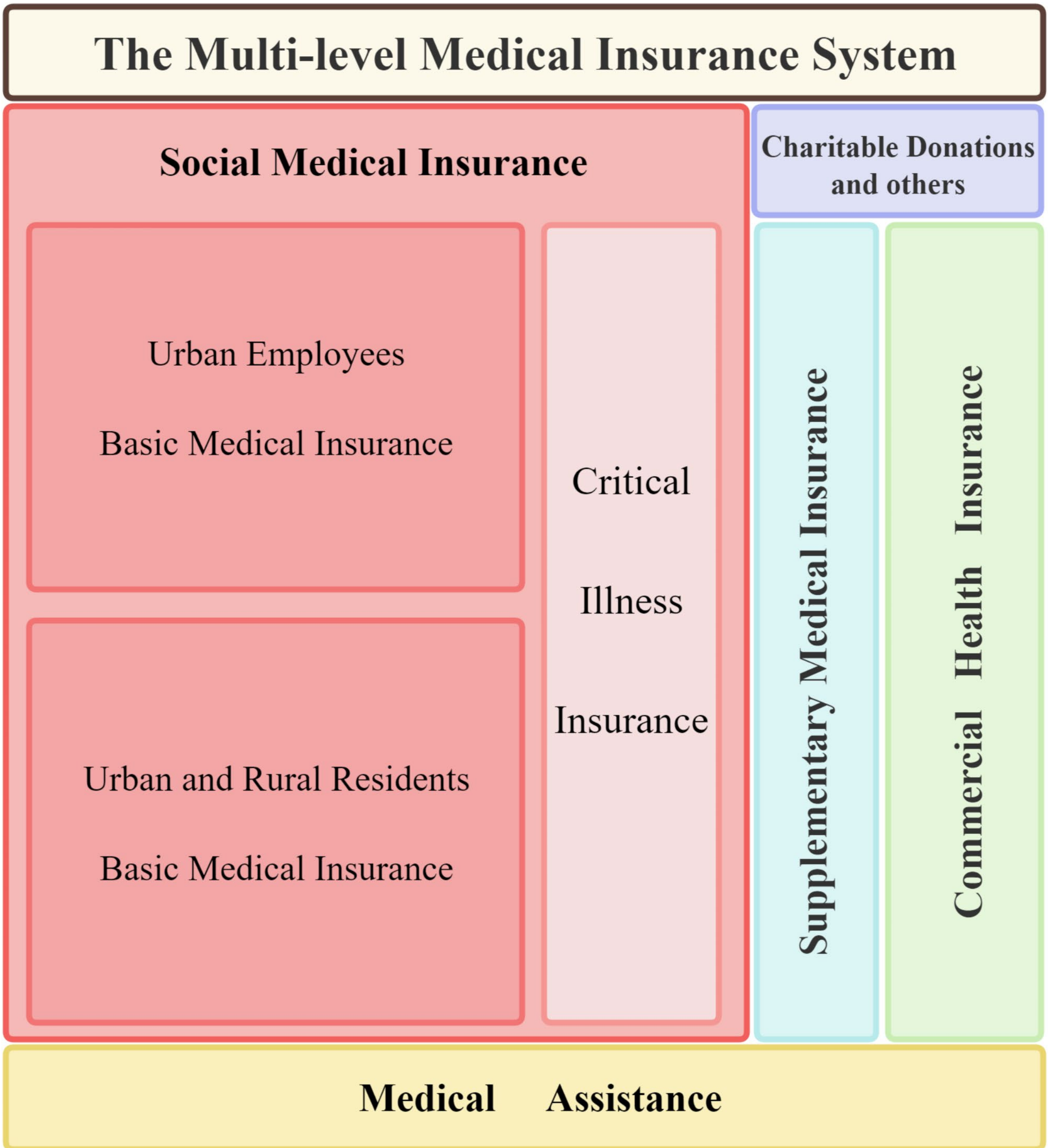

Fig. 1. Components and structure of multi-level medical insurance system in China.

no studies have yet addressed these inquiries. Hence, our research is of significant importance, as it provides an exploratory contribution to the systematic analysis of the interrelations among multiple welfare systems. This investigation not only offers empirical evidence to inform policymakers in planning the next phase of the medical insurance system but also provides valuable insights for other developing nations undertaking medical financing system reforms.

Methods

Research object

China's MMIS encompasses several medical insurance schemes, and the interplay among these schemes prompts a dynamic interaction within the system's internal structure, constituting a coupling coordination mechanism[30]. Consequently, drawing on principles from system theory and coupling theory, our study conceptualizes MMIS as a composite system of medical insurance, comprising SMI, CHI, MA, and other medical insurance subsystems[31]. Each subsystem operates as a functional unit, interlinked by elements or behavioral forces within its domain[31]. This composite system underscores a holistic perspective, forming a structurally integrated functional entity characterized by hierarchical complexity, structural correlation, and co-evolution[31]. Hence, we adopt the CCI model to examine the interaction dynamics among MMIS subsystems. This choice stems from the model's ability to comprehensively consider multiple aspects and indicators across various systems, thereby yielding comprehensive evaluation outcomes[32]. In contrast to alternative models, the CCI model places greater emphasis on internal relations and dynamic fluctuations within systems, offering a more precise depiction of coordination development levels[33]. Moreover, the model's operational simplicity and intuitive results facilitate further analysis.

China's MMIS encompasses schemes such as SMI, CHI, MA, CMI, and charitable donations. However, both CMI and charitable donations primarily serve specific groups or patients with particular diseases, resulting in a limited coverage population and the absence of nationwide standardized statistical data[34]. Furthermore, as the CII scheme essentially stems from the fund pool of SMI, it is inherently a component of SMI. Consequently, our study integrates CII into SMI and no longer treats it as a separate research object. Thus, we focus on SMI as the main body, CHI as an effective supplement, and MA as the safety net, representing the three subsystems of MMIS in this investigation.

Models and methodology

(1) Comprehensive evaluation indicators model.

Comprehensive evaluation indicators constitute a technical process aimed at scientifically quantifying the evaluation outcomes of research objects[35]. This process primarily centers on the research object, crafting an indicator framework capable of delineating its characteristics across multiple dimensions. Subsequently, this framework is synthesized with specific weights to generate comprehensive indicators. These indicators serve to gauge the overall development status of MMIS composite systems and subsystems. Notably, establishing a scientifically sound evaluation indicator system forms the cornerstone of the entire study[35].

Based on the characteristics of the three subsystems, our study engaged 24 experts from government agencies, medical institutions, research facilities, universities, and major insurance firms in three rounds of meetings and discussions. We adhered to principles of dynamism, scientific rigor, objectivity, representativeness, and accessibility[35–37]. Subsequently, we established a comprehensive evaluation indicator system comprising 3 subsystems, 6 layers of dimensions, and 21 indicators, as detailed in Table 1.

A total of 9920 records of directly relevant indicators were sourced from public databases for this study. Following appropriate calculations and processing, we obtained 6510 records representing 21 evaluation indicators across 31 Chinese provinces over 10 years. Raw data exhibits disorder and discreteness[31], necessitating

Subsystems	Weight (AHP)	Dimensional layers	Evaluation indicators	Unit	Attribute	Weight (entropy method)
SMI	0.6474	Financing level	Per capita financing level	CNY	+	0.2247
		Benefit level	Per capita expenditure level	CNY	+	0.1951
		Expenditure level	Proportion of total fund expenditure to total health expenditure	%	+	0.0519
			Proportion of total fund expenditure to total social insurance fund expenditure	%	+	0.1163
			Proportion of total fund expenditure to GDP	%	+	0.1506
			Proportion of total fund expenditure to government budget expenditure	%	+	0.1272
		Sustainability	Current fund balance rate	%	+	0.0651
			Growth rate of accumulated fund balance	%	+	0.0691
CHI	0.2055	Financing level	Proportion of total premium income to total personal insurance premium income	%	+	0.1218
		Benefit level	Proportion of total compensation expenditure to total health expenditure	%	+	0.1490
			Proportion of total compensation expenditure to total personal health expenditure	%	+	0.1898
		Development level	Insurance density	CNY/person	+	0.3020
			Insurance penetration	%	+	0.2307
		Sustainability	Current fund balance rate	%	+	0.0067
MA	0.1471	Benefit level	Per capita level of funding for SMI coverage	CNY/person	+	0.1858
			Per capita level of direct MA	CNY/person-time	+	0.1468
		Expenditure level	Proportion of total MA expenditure to civil affairs expenditure	%	+	0.0673
			Proportion of total MA expenditure in the government budget expenditure	%	+	0.0736
		Service level	Per capita expenditure on civil affairs	CNY/person	+	0.0989
			Civil service institutions and facilities per 10,000 people	Per 10,000 people	+	0.1004
			Certified social workers per 10,000 people	Per 10,000 people	+	0.3271

Table 1. Comprehensive evaluation indicators of MMIS composite system.

standardization to mitigate discrepancies stemming from variations in data dimensions. The processing method is as follows:

For positive indicators:

$$X_{ij}\prime = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \tag{1}$$

For negative indicators:

$$X_{ij}\prime = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \tag{2}$$

where $X_{ij}\prime$ is the standardized value of the original data, X_{ij} is the original value of the *j*th indicator in year *i*, $max(X_{ij})$ and $min(X_{ij})$ indicate the maximum and minimum values of the indicator, respectively. If $X_{ij}\prime$ has a zero value, it is translated by 0.01 to ensure that $X_{ij}\prime \neq 0$.

In this study, the entropy method is employed for weighting based on the established evaluation indicators system. The entropy method, grounded in the principle of information entropy, provides an objective approach to determining the weight of each indicator. This approach calculates the information entropy of each indicator, thereby mitigating potential biases associated with subjective valuation methods[32,35]. Consequently, the entropy method offers the benefits of producing objective results, ensuring high reliability, and facilitating straightforward implementation[31]. The calculation steps are as follows:

$$P_{ij} = \frac{X_{ij}\prime}{\sum_{i=1}^{m} X_{ij}\prime} \tag{3}$$

where *m* represents the number of years to be counted, and P_{ij} is the proportion of the *j* indicator in the total number of years in the year *i*.

$$H_j = -\frac{1}{\ln_m} \sum_{i=1}^{m} (P_{ij} \ln P_{ij}) \tag{4}$$

where H_j is the information entropy of the indicators.

$$G_j = 1 - H_j \tag{5}$$

where $0 \leq G_j \leq 1$, the greater the entropy value, the smaller the index difference coefficient, when P_{ij}=0, G_j=0, the greater the G_j value the more important the indicator.

$$W_j = \frac{G_j}{\sum_{j=1}^{n} G_j} \tag{6}$$

where W_j is the weight of indicators in each subsystem, and *n* is the number of indicators in each subsystem.

$$U_k = \sum_{j=1}^{n} W_j X_{ij}\prime \tag{7}$$

where U_k represents the comprehensive development index of *k* different medical insurance subsystems.

(2) CCI model

CCI is a model that assesses the coupling coordination degree among the subsystems of SMI, CHI, and MA based on a comprehensive evaluation indicators modal. The concept of coupling originates from physics, denoting the interaction between multiple systems not linearly related to each other[35]. The extent and impact of coupling determine the system's tendency from disorder to order. The crux of the system's transition lies in the synergy among internal order parameters[35]. This synergistic effect influences the characteristics and laws of the system's phase transition, with the degree of coupling serving as a gauge of this synergy. Hence, the model incorporates the concepts of the coupling index and coordination index. The coupling index denotes the strength of interaction between parties, irrespective of pros and cons, while the coordination index signifies the quality of harmonious interaction, reflecting the state of coordination[38,39]. Relying solely on the coupling index or coordination index is insufficient, as the coupling index may falsely suggest high coupling when the comprehensive evaluation indicators of the system are low[36]. Thus, the CCI model becomes imperative to depict the developmental status of SMI, CHI, and MA subsystems and their interrelationships.

Widely utilized for assessing coordination among various systems[30–32,35,36,40–42], the CCI model lacks studies investigating the coupling and coordination of diverse insurance systems within China's MMIS. Hence, in line with our research objectives, we construct the CCI model for these three subsystems based on Jiang's[43] modified three-system CCI formula:

$$D = \sqrt{C * T} \tag{8}$$

$$T = \alpha U_1 + \beta U_2 + \gamma U_3 \tag{9}$$

$$C = \left[\frac{U_1 * U_2 * U_3}{\left(\frac{U_1+U_2+U_3}{3} \right)^3} \right]^{\frac{1}{3}} \tag{10}$$

where U_1, U_2 and U_3 represent the comprehensive development index of SMI subsystem, CHI subsystem and MA subsystem respectively. *C* represents the coupling index of the three subsystems and *T* represents the coordination index, and *D* represents the CCI of MMIS. Additionally, α, β and γ represent the weight coefficients of the SMI, CHI, and MA subsystems in MMIS, respectively, indicating their relative importance. Previous studies have assigned equal weight coefficients to α, β and γ, implying an equal significance of each subsystem within the composite system[32,35,36,41,42]. However, our study deviates from this approach due to significant disparities among SMI, CHI, and MA, particularly in terms of population coverage within China. Notably, SMI covers over 95% of the Chinese population, while MA caters to a small fraction, with only 3.13% receiving minimum living allowances in 2020 (*China Statistical Yearbook 2021*). Moreover, each subsystem serves a distinct role in MMIS, SMI functions as the primary component, CHI as a complementary element, and MA as a safety net. Hence, assigning equal weight coefficients to them would be inappropriate. Instead, we propose resetting these coefficients based on their functional roles and significance. In our study, we employ the analytic hierarchy process (AHP) to determine the weight coefficients of these three subsystems in MMIS. AHP is a widely recognized multi-criteria decision-making tool, that facilitates complex decision-making by breaking it down into hierarchical levels and employing pairwise comparisons to assess the importance of alternatives[44,45]. Despite the potential impact of sample size on AHP, it is generally agreed that AHP does not necessitate an excessively large sample[45]. Accordingly, we engaged 15 experts from the pool of 24 mentioned earlier to conduct AHP. Subsequently, we established that the weight coefficients α, β and γ are 0.647, 0.206 and 0.147, respectively, with the results passing consistency tests (CI 0.002, RI 0.52, CR 0.003).

CCI was divided into 10 degrees using the "0.1 cut-off point method"[46] (Table 2).

(3) Spatial autocorrelation model.

Spatial autocorrelation analysis examines the correlation of a variable across different spatial positions, serving as a metric for the degree of aggregation of attribute values within spatial units. This analysis technique elucidates the spatial interactions of geographical phenomena among neighboring regions[47]. In the context of China, a nation characterized by vast territory, dense population, and significant socio-economic disparities, employing spatial statistical analysis techniques to quantify the spatio-temporal evolution pattern of the CCI results of MMIS holds considerable importance. Such a study enables the effective identification of areas with low CCI in MMIS, facilitating the optimization of health financing spatial allocation and the formulation of precise policy measures aimed at reducing disparities in residents' medical insurance benefits distribution. This is our study's unique contribution lies in its ability to innovate in this area.

The cornerstone of spatial autocorrelation analysis is the spatial autocorrelation coefficient (Moran's *I* index), typically categorized into global and local spatial autocorrelation analyses. The formula for global Moran's *I* is provided in (11). Consequently, we used the CCI values for each province from 2011 to 2020 as the variable x and substituted them into (11) to compute the global autocorrelation analysis to ascertain any clustering relationships within CCI result spaces. Subsequently, we employ local spatial autocorrelation analysis to assess the local aggregation of CCI results.

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} \omega_{i,j} \left(x_i - \overline{x} \right) \left(x_j - \overline{x} \right)}{\sum_{i=1}^{n} \sum_{j=1}^{n} \omega_{i,j} \sum_{i=1}^{n} \left(x_j - \overline{x} \right)^2} \tag{11}$$

where *n* is the number of observations of variable *x*, x_i and x_j are the observations of variable *x* at positions *i* and *j*, respectively, $\overline{x}$ is the mean of all observations, $\omega_{i,j}$ is the spatial weight matrix value.

The value range of the global Moran's *I* is [− 1, 1]. The closer Moran's *I* is to 1, the stronger the degree of agglomeration, and the closer it is to − 1, the stronger the degree of dispersion. When Moran's *I* is 0, it means that there is no spatial clustering, that is, the data is randomly distributed. A Moran's *I* below 0 indicates a negative correlation, while a value above 0 denotes a positive correlation. Local spatial autocorrelation results are depicted through Moran's *I* index scatter diagrams, with the four quadrants representing four spatial clustering types of "high-high", "low–high", "low-low", and "high-low", respectively.

D-value	Coordination type	*D*-value	Coordination type
[0.0–0.1]	Extremely maladjusted recession	(0.5–0.6]	Barely coordinated
(0.1–0.2]	Severe dysregulation	(0.6–0.7]	Primary coordinated
(0.2–0.3]	Moderate disorder recession	(0.7–0.8]	Intermediate coordinated
(0.3–0.4]	Mild dysregulation	(0.8–0.9]	Well-coordinated
(0.4–0.5]	On the verge of coordinated	(0.9–1.0]	High-quality coordinated

Table 2. Classification standards of CCI (*D*-value).

The standardized Z-statistic serves to assess whether global or local spatial correlations are statistically significant. The formula for calculating the Z-value is:

$$Z(I) = \frac{1 - E(I)}{\sqrt{V(I)}} \tag{12}$$

where E (*I*) and V (*I*) can be calculated according to the formula (13) and (14) below.

$$E(I) = \frac{-1}{n-1} \tag{13}$$

$$V(I) = E\left[I^2\right] - E\left[I\right]^2 \tag{14}$$

Data source
The advancements in China's health system can be attributed to the reforms initiated in 2009[29]. Hence, the period from 2011 to 2020, marking a decade post-reform, was chosen as the timeframe for this study. Another pivotal factor is the delay in the release of Chinese statistical data. As a core metric in our analysis, China has only made available its total health expenditure for 2020 (up to April 2024), representing the latest accessible data. Thus, to ensure consistency in evaluating indicators, we opted for the 2011–2020 timeframe. Furthermore, our study encompasses 31 provinces of China (excluding Hong Kong, Macau, and Taiwan). The original data sources utilized include the *China Statistical Yearbook*, *China Health Statistical Yearbook*, *China Medical Security Statistical Yearbook*, *China Civil Affairs Statistical Yearbook*, and data published by provincial government departments overseeing the insurance sector. All raw data are secondary and sourced from existing databases, with some figures derived through relevant formulas and basic data calculations.

Statistical software
For this study, Excel was employed for data collection and cleaning, while SPSS 25 was utilized for data processing and CCI calculations. Additionally, GeoDa 1.22 facilitated spatial autocorrelation analysis, and ArcGIS 10.8 was employed for mapping and visualizing the CCI outcomes. The level of statistical significance was set at $\alpha = 0.05$.

Results
Trends of CCI in the national average level
Through our constructed comprehensive evaluation indicators model (Table 1), we initially computed the coupling degree index *C*, coordination degree index *T*, and the CCI *D* for the MMIS performance at Chinese average level spanning from 2011 to 2020. The mean values of these three indexes over the decade were 0.772, 0.465, and 0.590, respectively. Consequently, the CCI *D*-value for MMIS at the national average level over the past decade is barely coordinated. Figure 2 illustrates the trend in indexes *C*, *T*, and *D*. Generally, these indexes demonstrate an upward trajectory, yet indexes *C* and *D* exhibit significant fluctuations, notably during the period from 2011 to 2015. In 2016, both indexes experienced a sudden decline, followed by a gradual recovery post-2016. Notably, index *D* surged from 0.287 in 2011 to 0.887 in 2020, indicating a well-coordinated status, signifying a strong correlation among the three main subsystems of MMIS.

Distribution characteristics of regional CCI
Table 3 presents the regional CCI results for 31 provinces in China spanning from 2011 to 2020. It is evident that the CCI across these provinces demonstrates an upward trajectory. Notably, Beijing and Shanghai exhibit the highest CCI at 0.925 and 0.805, respectively, indicative of a high-quality and well-coordinated status. The majority of provinces (26, 83.87%) fall within the range [0.500, 0.600], indicating a state of barely coordination. Nei Mongol and Xizang remain within the [0.400, 0.500] range, thus still reflecting a degree of dysregulation. Over the past decade, Jiangxi, Henan, and Hunan have experienced the most significant growth in CCI, with growth rates of 0.428, 0.386, and 0.372, respectively. Conversely, Xizang, Yunnan, and Xinjiang exhibit the lowest growth rates, with Xizang even demonstrating a negative growth rate (-0.013). To visually illustrate the spatial distribution evolution of CCI of MMIS at the provincial level over the past decade, we selected 2011 (a), 2014 (b), 2017 (c), and 2020 (d) as cross-sectional years at fixed intervals (every 2 years) for visualization, as depicted in Fig. 3. Observable disparities in CCI distribution at the provincial level in China are apparent. Most provinces have transitioned from the yellow category in 2011 (CCI < 0.05) to the green category in 2020 (CCI > 0.05). Darker shades in the figure correspond to higher CCI, indicating that in the past 10 years, the CCI of MMIS across most provinces in China has progressed from a state of dysregulation to coordination. Generally, the eastern region exhibits higher CCI compared to the western region, with significant increases noted in the central region. Moreover, most western and northeast regions demonstrate a gradual upward trend in CCI.

Spatial autocorrelation analysis results
The results of the global Moran's *I* and significance test are presented in Table 4. The CCI of MMIS exhibits a positive Moran's *I* across all years, ranging from 0.1668 to 0.3037, with each year's values being statistically significant. This indicates that the CCI of MMIS in China demonstrates a positive spatial correlation nationwide, with significant spatial clustering rather than random distribution. However, the global Moran's *I* for CCI shows a notable downward trend from 2011 to 2020. Over the past decade, Moran's *I* experienced two significant declines, specifically between 2011–2012 and 2016–2018, with the most substantial drop of 0.1062 occurring in 2016–2018. This suggests a weakening spatial aggregation of the CCI of MMIS in China. Additionally, a

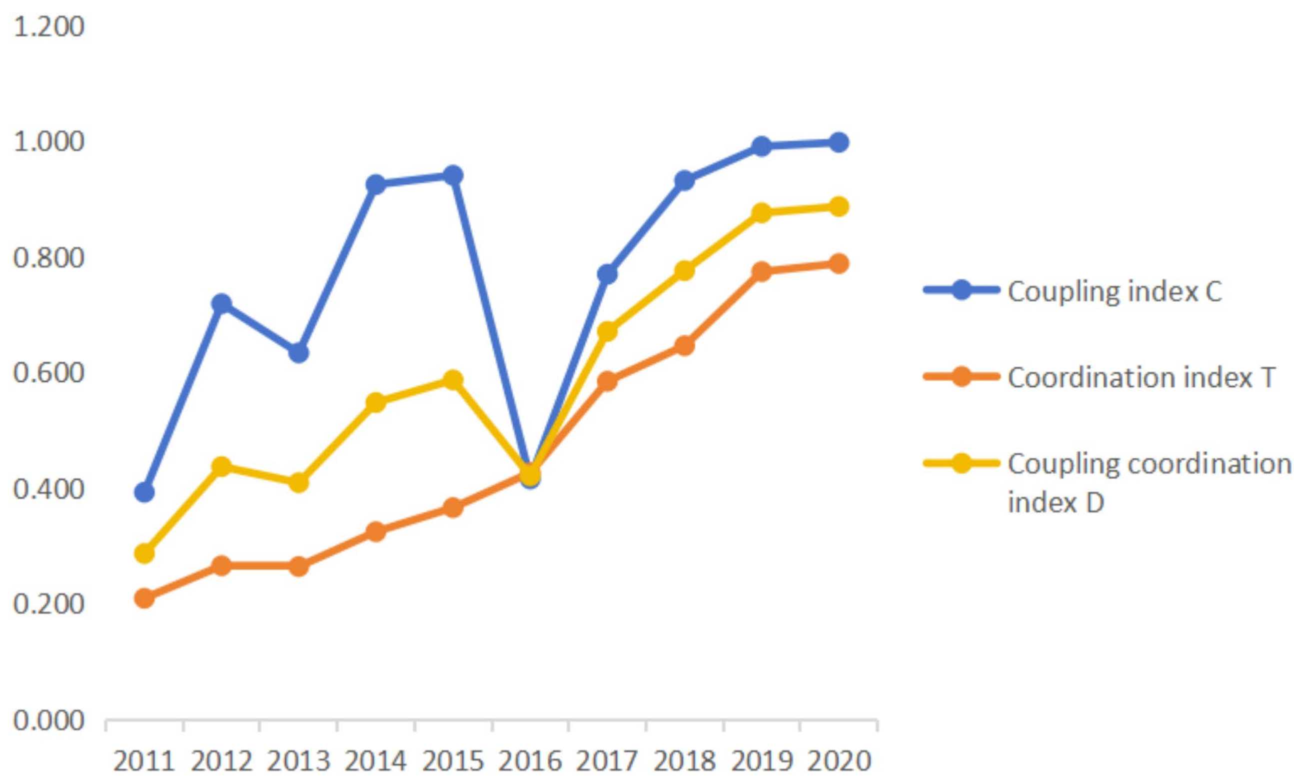

Fig. 2. The change of three indexes in the average level of China.

scatter diagram of local Moran's *I* (Fig. 4) was created to assess the local aggregation of the CCI of MMIS in each province. Figure 4 reveals that, over the past decade, most provinces in China are situated in the first and third quadrants, corresponding to "high-high" and "low-low" clusters, respectively. This indicates that regions with high (low) CCI are surrounded by regions with similarly high (low) CCI. Furthermore, the scatter diagram shows a progression from a more dispersed state (a) to a more clustered state (d). This implies that the spatial clustering differences of CCI among different provinces in China are gradually diminishing.

Discussion

China's MMIS represents a significant outcome of health system reform and plays a crucial role in achieving UHC goals. Therefore, studying the coordination among the multiple insurance schemes comprising the MMIS is essential. In our study, we employed the CCI model and spatial autocorrelation model to analyze the interactions between SMI, CHI, and MA across 31 provinces in China. Our findings are as follows. First, from 2011 to 2020, the national average level CCI of the MMIS exhibited a fluctuating upward trend, improving from the moderate disorder recession degree (0.287) to the well-coordinated degree (0.887). Second, most provinces progressed slowly from a state of dysregulation in 2011 to a barely coordinated state by 2020. The eastern provinces consistently showed higher CCI values than the western regions, while the central regions demonstrated significant improvements. Third, the CCI of the MMIS in China displayed a positive spatial correlation nationwide, with notable spatial clustering, although the intensity of this clustering has been diminishing over time. Constructing the MMIS indicators system through a comprehensive evaluation model and conducting related quantitative research is a valuable endeavor. This approach enables a comparable assessment of MMIS development levels across different regions, which is particularly important given China's vast geographic area and numerous provinces. Additionally, our results highlight the impacts of the health reforms initiated in China since 2009.

Over the past decade, China's average development has progressed through six stages: moderate disorder recession, mild dysregulation, barely coordinated, primarily coordinated, intermediate coordinated, and well-coordinated. However, in 2016, the CCI experienced a sudden decline from barely coordinated to mild dysregulation. We attribute this decline primarily to the Chinese government's 2016 decision to merge the URBMI and NCMS into the URRBMI. This merger introduced numerous changes, including those to cover participants, benefit packages, and reimbursement rates, and it likely impacted the statistical consistency of the original data[15]. Consequently, a noticeable decline occurred, but after just one year of adjustment, the CCI rebounded in 2017 to a primarily coordinated level (0.671), surpassing the pre-adjustment 2015 level (0.587). In 2018, China established the National Medical Security Administration, centralizing the management of medical insurance and unifying the oversight of multiple insurance systems at the national level[5]. Following this, the MMIS advanced from an intermediate coordinated stage to a well-coordinated degree. These developments demonstrate that policy changes, system reforms, and structural adjustments within government departments

Region	Provinces	Year									
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Eastern	Beijing	0.589	0.627	0.709	0.750	0.804	0.841	0.856	0.868	0.930	0.925
	Tianjin	0.368	0.377	0.439	0.488	0.539	0.559	0.590	0.600	0.617	0.622
	Hebei	0.250	0.279	0.311	0.350	0.386	0.480	0.495	0.453	0.524	0.542
	Shanghai	0.599	0.594	0.585	0.581	0.644	0.669	0.757	0.731	0.803	0.805
	Jiangsu	0.344	0.356	0.384	0.417	0.447	0.502	0.511	0.540	0.590	0.593
	Zhejiang	0.379	0.413	0.431	0.479	0.496	0.539	0.567	0.618	0.651	0.663
	Fujian	0.323	0.341	0.279	0.355	0.373	0.447	0.440	0.485	0.546	0.560
	Shandong	0.318	0.332	0.351	0.468	0.448	0.472	0.483	0.536	0.552	0.581
	Guangdong	0.325	0.355	0.420	0.452	0.473	0.526	0.527	0.548	0.581	0.594
	Hainan	0.250	0.261	0.284	0.308	0.349	0.404	0.426	0.429	0.528	0.504
Northeast	Liaoning	0.308	0.346	0.355	0.372	0.422	0.446	0.485	0.480	0.532	0.583
	Jilin	0.197	0.228	0.250	0.276	0.315	0.365	0.376	0.457	0.527	0.512
	Heilongjiang	0.280	0.300	0.326	0.365	0.408	0.493	0.525	0.540	0.577	0.562
Central	Shanxi	0.249	0.305	0.335	0.362	0.384	0.416	0.468	0.502	0.521	0.539
	Anhui	0.198	0.212	0.270	0.291	0.314	0.367	0.393	0.470	0.530	0.544
	Jiangxi	0.125	0.167	0.217	0.247	0.277	0.321	0.460	0.425	0.515	0.553
	Henan	0.143	0.175	0.204	0.231	0.256	0.288	0.424	0.420	0.504	0.529
	Hubei	0.251	0.220	0.261	0.287	0.348	0.381	0.469	0.499	0.534	0.552
	Hunan	0.171	0.202	0.232	0.284	0.317	0.355	0.451	0.462	0.523	0.543
Western	Nei Mengol	0.248	0.291	0.335	0.369	0.374	0.415	0.471	0.461	0.494	0.499
	Guangxi	0.235	0.239	0.258	0.304	0.327	0.339	0.404	0.481	0.515	0.557
	Chongqing	0.196	0.331	0.361	0.387	0.442	0.477	0.473	0.559	0.562	0.557
	Sichuan	0.337	0.334	0.359	0.414	0.464	0.432	0.497	0.481	0.532	0.552
	Guizhou	0.221	0.212	0.269	0.303	0.367	0.400	0.395	0.502	0.570	0.557
	Yunnan	0.375	0.376	0.363	0.393	0.420	0.422	0.464	0.493	0.509	0.562
	Xizang	0.464	0.480	0.477	0.538	0.521	0.553	0.598	0.554	0.580	0.451
	Shanxi	0.173	0.222	0.279	0.318	0.374	0.383	0.443	0.508	0.514	0.507
	Gansu	0.266	0.270	0.329	0.344	0.386	0.415	0.534	0.546	0.574	0.592
	Qinghai	0.377	0.398	0.461	0.490	0.503	0.504	0.440	0.575	0.577	0.577
	Ningxia	0.313	0.395	0.404	0.438	0.449	0.508	0.515	0.526	0.556	0.563
	Xinjiang	0.393	0.423	0.458	0.468	0.494	0.519	0.527	0.568	0.601	0.591

Table 3. CCI results for 31 provinces in China from 2011 to 2020.

significantly impact the integrated development of the MMIS. Therefore, policymakers should closely monitor the MMIS development trends, thoroughly analyze the characteristics and challenges of each stage, and formulate and implement targeted policies and measures. By leveraging precise policy guidance and market mechanisms, it is possible to promote the coordinated development of the MMIS from its current stage to higher levels of integration.

The provinces with high CCI of the MMIS are concentrated in China's eastern coastal areas, including Beijing, Shanghai, Tianjin, and Zhejiang. Beijing, as the capital, stands out due to its superior socio-economic conditions and social benefits compared to other regions[36]. The other provinces benefit from their coastal locations, which provide a more open social environment and robust socio-economic foundations conducive to their coupled and coordinated development. In contrast, regions with low CCI, such as Xizang, Nei Mongol, Shaanxi, and Hainan, are primarily located in the western part of China. This spatial disparity is closely linked to geographical and socio-economic conditions[36]. From a policy and economic perspective, China's eastern coastal regions benefit from substantial geographic advantages that have spurred higher economic development than in the central and western areas. Consequently, eastern local governments possess stronger fiscal capacities, enabling them to develop a more comprehensive MMIS. In contrast, limited fiscal resources and constrained industrial structures in the central and western regions result in insufficient matching funds, an overreliance on central transfer payments, and inadequate supplementary insurance coverage, thereby overburdening the SMI and hindering systemic synergy. Moreover, the spatial misallocation of medical resources further deepens these regional disparities. The concentration of tertiary (Grade III) hospitals in the east has fostered a high-quality service network that synergizes well with the MMIS, whereas the relatively weak capacity of primary healthcare institutions in the central and western regions undermines the effective implementation of medical security policies. Finally, eastern cities, characterized by high openness and advanced technological integration, have successfully incorporated AI innovations into their MMIS, enhancing management practices and service delivery efficiency. In contrast, geographic constraints, limited governance capacity, and underdeveloped AI infrastructure in parts of the central and western regions have resulted in an informatization coverage rate of

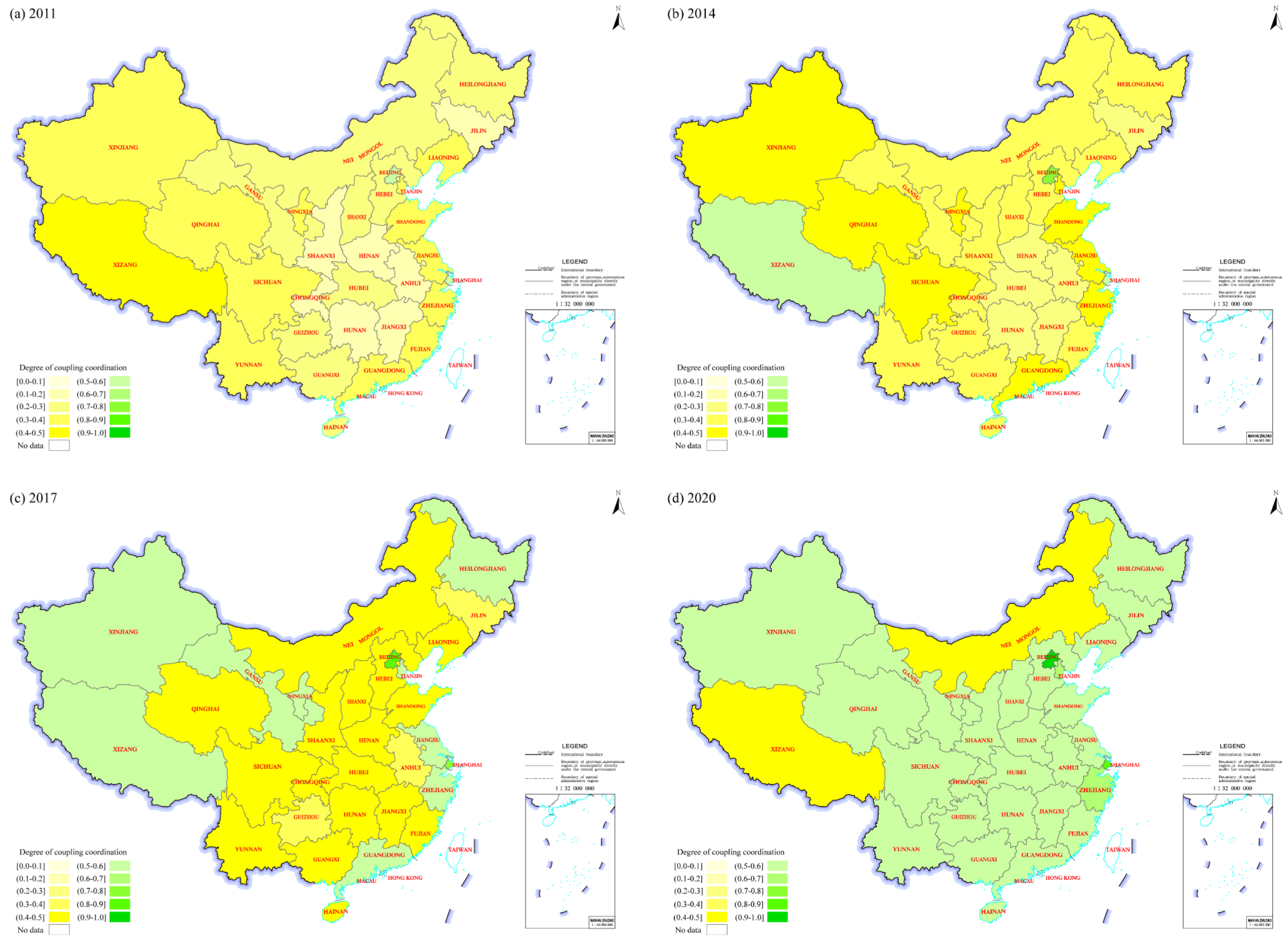

Fig. 3. Spatial distribution evolution of CCI of MMIS in China. *Note*: Figures (**a**), (**b**), (**c**), and (**d**) depict the spatial distribution evolution of CCI of MMIS in China for the years 2011, 2014, 2017, and 2020 respectively.

Year	Moran's *I*	Z-value	Year	Moran's *I*	Z-value
2011	0.3037	2.8834***	2016	0.2730	2.8368***
2012	0.2505	2.4259**	2017	0.2036	2.3015**
2013	0.2549	2.5308**	2018	0.1668	1.8937*
2014	0.2525	2.5713***	2019	0.1842	2.1863**
2015	0.2626	2.7207***	2020	0.1701	2.0151**

Table 4. China's average level of CCI of global Moran's *I* 2011–2020. ***, **, and * indicate significant correlations at the 1%, 5%, and 10% levels, respectively.

less than 30% for primary healthcare institutions compared to over 80% in the east, thus further exacerbating the regional gap. Although the western region's CCI is lower, the gap between the CCI of most western and central regions and the eastern region has been rapidly decreasing over the past decade. Currently, 83.87% of China's provinces have reached the barely coordinated degree. Spatial autocorrelation analysis confirms this trend. These improvements demonstrate the success of the Chinese government's strategy of "promoting the development of the west, the rise of the central region, and the pioneering development of the east"[36]. However, it is important to recognize that disparities between provinces persist. Consequently, we propose an integrated "Institutional-Service-Information" reform framework. At the institutional level, a flexible mechanism linking central fiscal transfer payments to local performance should be established to dynamically compensate for funding shortfalls in central and western provinces. To rectify healthcare resource misallocation, the incentive structure for tiered diagnosis and treatment must be reformed by leveraging national medical centers to disseminate high-quality resources from the east to central and western regions. Regarding information infrastructure, we recommend incorporating the Hospital Information System integration rate of county-level healthcare institutions in central and western regions into the mandatory standards of the national medical insurance information platform,

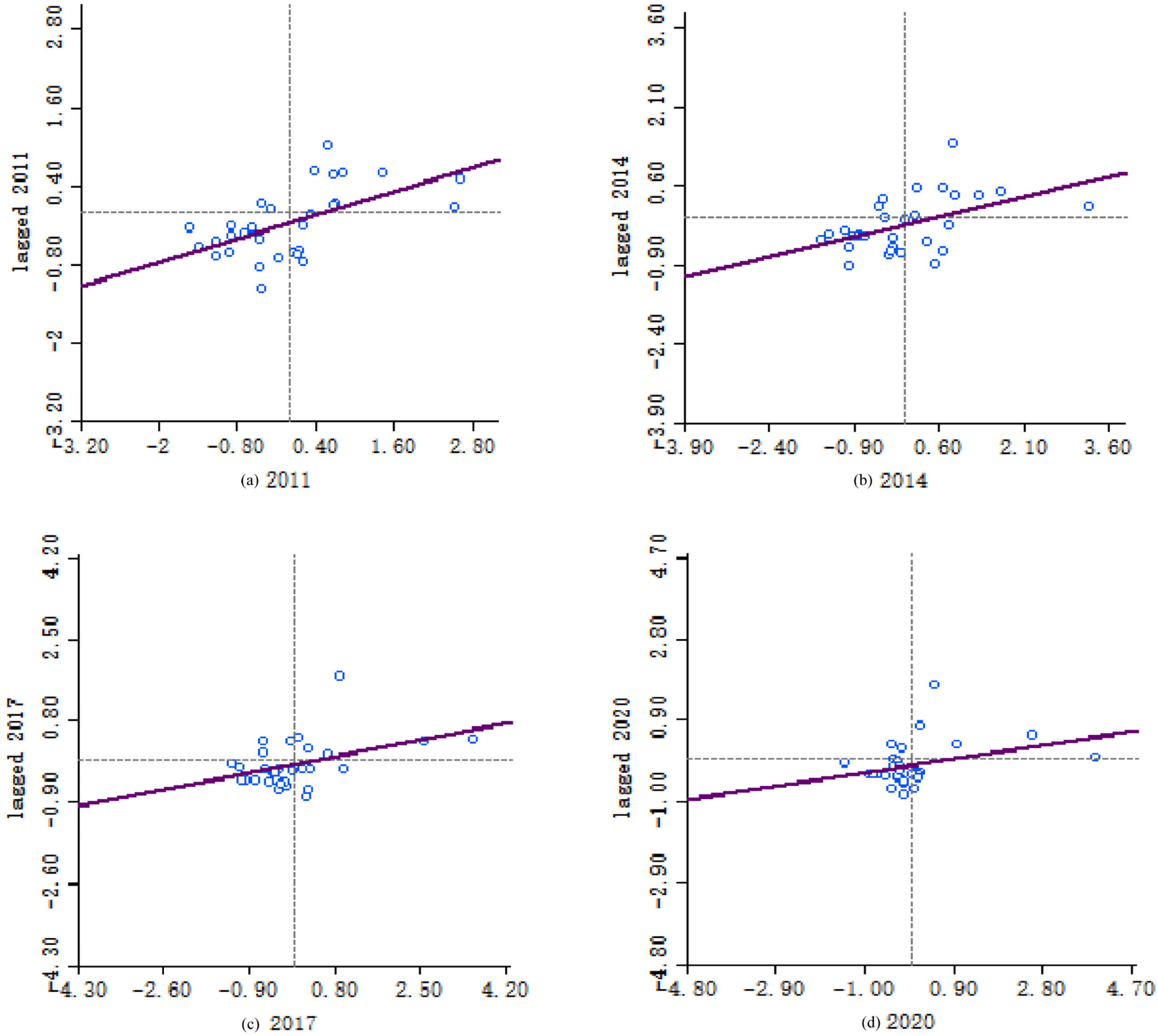

Fig. 4. Moran's *I* scatter diagram of CCI of MMIS in China. *Note*: Figures (**a**), (**b**), (**c**), and (**d**) depict the scatter diagrams illustrating China's Moran *I* for the years 2011, 2014, 2017, and 2020 respectively.

alongside launching a "Digital Health West" initiative that utilizes national platforms and targeted eastern support to upgrade regional information systems.

Our results indicate that although China's overall MMIS has reached a well-coordinated degree, significant disparities remain among provinces, with over 80% of provinces only achieving a barely coordinated degree. This suggests that China still faces considerable challenges in advancing the integrated development of the MMIS. Moreover, it highlights that the integration of SMI, CHI, and MA is a dynamic, continuous process involving the government, the market, and residents as key stakeholders. To further promote the development of MMIS, concerted efforts and attention from all stakeholders are essential. Consequently, from a stakeholder perspective, we propose policy recommendations to enhance the integrated development of MMIS.

Firstly, government departments and policymakers must adjust and innovate policies based on the relationship between the current multiple insurance systems and actual needs. Given that the subsystems of the MMIS are interconnected and mutually dependent, the advancement or delay of any subsystem impacts the overall level of collaborative development. Hence, an incremental and carefully sequenced approach is essential to promote deeper integration of the MMIS[48]. One priority is to clearly delineate the development scope and guarantee boundaries between the government and the market to avoid resource wastage from overlapping coverage. Drawing from Mexico's health reform experience, establishing a health system with clear, standardized rules and effective mechanisms for integrating public and private sectors is key to expanding comprehensive healthcare access[49]. Additionally, the trend in developed countries towards hybrid public–private insurance systems underscores the limitations of compulsory social insurance in covering all health needs, countries with public healthcare systems, such as Singapore and Germany, have introduced CHI to cover additional services on a co-payment basis[16,50]. In light of this, government-provided social health insurance should primarily secure residents' basic outpatient and inpatient services, with its coverage defined through the National Reimbursement Drug List (NRDL). In contrast, market-based commercial health insurance should adopt a differentiated strategy that targets healthcare services and projects beyond the NRDL, thereby addressing residents' diverse needs. This clear division of responsibilities lays a solid foundation for coordinated development, creating a complementary framework that prevents resource competition and enhances the overall effectiveness of the MMIS. And continue expanding insurance coverage, as the percentage of the population covered is a key determinant in achieving UHC goals[2]. URRBMI, a voluntary insurance scheme, is particularly challenging due to its principle of voluntary participation, which affects overall population coverage. In 2020, the participation rate decreased by 0.8% compared to the previous year, indicating that some people remain uninsured, so there is a case for transitioning from a voluntary to a compulsory insurance model through legislative measures[16]. Simultaneously, the government should take steps to reduce the personal financial burden and offer subsidies to ensure the poor can afford medical insurance. Studies have shown that nearly half of the uninsured population in China remains uninsured due to financial constraints[5,51]. Therefore, expanding the pool of centrally funded MA to provide tiered support for the poor and those near the poverty line is crucial for protecting these populations from financial risks[1]. Additionally, the existing financing criteria should be adjusted. Currently, SMI premiums are raised according to a unified standard that does not differentiate between rich and poor, which undermines social equity. Instead, premiums should be linked to residents' household income, with different proportions paid according to varying income levels. This approach would more effectively promote social equity. Currently, China's medical insurance information technology is in its nascent stage, with barriers preventing information sharing between medical insurance systems and other relevant departments[5]. Therefore, China should actively promote the integration of medical insurance information systems with those of other departments, leveraging technologies such as blockchain, Internet of Things, and big data to enable cross-regional and cross-departmental sharing of medical insurance information, it can improve the precision of CHI design and boost the claims efficiency of the MMIS.

Secondly, CHI companies should proactively strengthen cooperation with SMI, which can mitigate the financial risks faced by policyholders under public policies through reinsurance, while also expanding the consumer base for insurance companies[52]. Then effective insurance products should consider consumers' risk preferences and local disease burdens[53]. Simultaneously, integrating health management and disease prevention services with insurance products is recommended to enhance consumers' experience with these products[20]. Moreover, it is advisable to develop more tailored products catering to different age groups, income levels, or disease characteristics[22,29]. At last, insurance practitioners should convey essential information to consumers concisely and aid them in discerning similar products, enabling them to select the most suitable options based on their needs. Given that the intricate product designs and claims processes in CHI can be overwhelming for individuals lacking the cognitive capacity to grasp such intricacies, these represent significant consumer segments that insurance companies should target[18,54].

Finally, it is imperative for residents to enhance their awareness of risk management. Given that insurance is perceived as a preventive protection tool, the level of acceptance and awareness of insurance among Chinese residents remains relatively low[54]. Consequently, there is a need to enhance residents' awareness of health risks through health education initiatives. Subsequently, efforts should be made to encourage residents to bolster their management of health risks, thereby enabling them to actively engage in SMI and purchase CHI to mitigate potential economic risks associated with illnesses[14].

There are several limitations to our study. Firstly, our study is conducted at the provincial level in China. Initiating our analysis at a more granular level, such as the city and county level, and comparing the results of empirical analysis on a finer spatial scale would enhance our comprehension. Secondly, our study relies predominantly on data sourced from existing statistical yearbooks, which may not be promptly updated. Consequently, our conclusions may lag behind current developments, introducing a degree of obsolescence. Thirdly, our investigation currently excludes considerations of CMI, charitable donations, and other insurance schemes. Despite their limited coverage within MMIS, these insurance schemes can still mitigate the financial burdens faced by specific demographics through cross-subsidization. Thus, future research endeavors could encompass these insurance schemes as focal points, delve into the systematic and hierarchical traits of MMIS, and foster more intricate exploration in this domain.

Conclusion

This study represents the first attempt to comprehensively analyze the intricate dynamics and spatio-temporal evolution of MMIS in China. Utilizing panel data analysis encompassing 31 provinces from 2011 to 2020, our findings reveal that China's CCI of MMIS exhibits a pattern of fluctuation and gradual increase, attaining a well-coordinated degree by 2020. However, the majority of regions still demonstrate a barely coordinated. This underscores a positive correlation in the spatial distribution among provinces, albeit with a diminishing disparity between the eastern coastal and western regions. Looking ahead, it is imperative to closely monitor the spatio-temporal evolution of MMIS, enhance institutional linkages and inter-departmental collaboration, and devise more precise development strategies involving key stakeholders such as government, insurance companies, and residents.

Data availability

The data that support the findings of this study are openly available in China Statistical Yearbook, China Health Statistical Yearbook, China Medical Security Statistical Yearbook, China Civil Affairs Statistical Yearbook and https://www.cbirc.gov.cn/cn/view/pages/tongjishuju/tongjishuju.html.

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Author contributions

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Declarations

Competing interests

The authors declare no competing interests.

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