

Article

Higher Education and Regional Economic Development: Patterns, Interactions and Policy Implications from China's Coastal Urban Regions

Hengda Zhang ^{1,2,3}, Xiaozhe Chen ^{1,2}, Shuni Zhang ^{1,2}, Yingqiu Tian ^{1,2}, Xiaolu Yan ^{1,2} and Jingqiu Zhong ^{1,2,*}

¹ Key Research Base of Humanities and Social Sciences of the Ministry of Education, Institute of Marine Sustainable Development, Liaoning Normal University, Dalian 116029, China

² University Collaborative Innovation Center of Marine Economy High-Quality Development of Liaoning Province, Liaoning Normal University, Dalian 116029, China

³ Faculty of Education, Liaoning Normal University, Dalian 116029, China

* Correspondence: zjq@lnnu.edu.cn

Abstract

Achieving coordinated development between higher education and regional economies is central to sustainable urban growth. This study examines the spatiotemporal coupling coordination between higher education and economic development across 90 cities within seven major coastal urban agglomerations in China over the period 2008–2021. An evaluation index system was constructed across seven dimensions, and three analytical methods were integrated: the entropy weight method for composite index calculation, the coupling coordination degree model for assessing synergistic development, and the panel vector autoregression (PVAR) model for dynamic interaction analysis. A fixed-effects regression model was further applied to identify key driving factors. The results indicate that: (1) higher education levels showed a steady upward trend across all agglomerations, while widening absolute disparities persisted among cities; (2) although a bidirectional Granger-causal relationship exists between higher education and economic development, the interaction is asymmetric along two distinct dimensions: higher education exerts a more statistically robust predictive influence on the economy, while unforecast economic shocks transmit more strongly to higher education than the reverse; this asymmetry manifests in specific urban agglomerations—most notably the Pearl River Delta—as a structural mismatch between economic strength and higher education development; (3) economic development level, government fiscal support, urbanization, and higher education scale are significantly associated with the coupling coordination between the two systems. These findings highlight the structural misalignment between higher education supply and regional economic demand and underscore the need for differentiated, spatially targeted policy interventions to promote sustainable regional development. Policy recommendations are proposed for optimizing higher-education resource allocation, reforming talent cultivation, and strengthening intra-agglomeration coordination mechanisms.



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1. Current Research Gaps in Higher Education and Economic Development

China's coastal urban agglomerations generate approximately 40% of national GDP and host nearly half of all university students in the country, making them the geographical

unit in which the interaction between higher education and the regional economy is most intensely concentrated. Yet in recent years, the simultaneous occurrence of graduate underemployment and skills shortages in key industries, together with the observation that some of China's most economically advanced cities exhibit comparatively underdeveloped higher education systems, suggests that a structural mismatch may be emerging between higher education supply and regional economic demand. This mismatch has implications not only for individual cities' development quality but also for the synergistic functioning of entire urban agglomerations. Against this backdrop, understanding how higher education and the regional economy co-evolve—and where they fail to do so—has become an urgent research task.

Under the conditions of economic globalization, integration, and the knowledge economy, the social and economic development of many cities in China increasingly relies on the human and intellectual resources provided by local higher education. The role and contribution of higher education in urban socio-economic development are growing ever more significant [1]. Regional economic development simultaneously provides the fundamental material foundation for the advancement of higher education. If these two sectors can mutually reinforce each other and develop in coordination to form a virtuous cycle, it will help enhance the quality of higher education within the region and also promote the transformation and upgrading of the local economic structure. According to China's national development strategies, education, science and technology, and human resources are regarded as foundational and strategic pillars for the country's modernization. National policy frameworks emphasize the integrated advancement of education, science and technology, and talent development, and call for the implementation of strategies to revitalize the nation through science and education, to strengthen the nation through talent development, and to drive development through innovation. As a critical nexus where science and technology (as the primary productive force), talent (as the primary resource), and innovation (as the primary driver of growth) converge, higher education directly supplies the knowledge, technology, and skilled personnel essential for economic development [2]. Therefore, measuring the development of higher education and exploring its coordinated interaction with economic development has become an important research direction.

Research closely related to this paper's theme primarily encompasses the following three aspects: (1) The impact of higher education on economic growth. Existing studies have constructed comprehensive indicator systems across dimensions such as educational scale, quality, and structure to measure the level of higher education. They analyze the spatial spillover effects of higher-education agglomeration [3], the impact of higher education scale [4], resource allocation [5], hierarchical structure and quality factors [6], as well as higher-education investment [7] (including financial resources [8] and human capital [9]) on economic growth. (2) Research on the correlation between higher education and economic development. Existing studies have predominantly adopted spatial scales such as national [10–13], provincial [14], and urban agglomerations [3] to construct multidimensional comprehensive evaluation systems. These systems measure the levels of higher education and economic development [15] and analyze the interdependent, mutually influential, and mutually constraining relationship between higher education and regional economies [16,17]. (3) Research on the coordination between higher education and economic development. Existing studies predominantly employ methods such as DEA models [18], spatial autocorrelation [2], factor analysis [19], coupling coordination models [12], and VAR models [20] to explore the spatiotemporal evolution and coupling coordination relationship between higher education and economic development levels.

A review of the literature reveals: (1) While both domestic and international research has yielded some findings on the coupling and coordination between higher education

and regional economies, studies primarily focus on individual provinces or cities, with limited research on the coupling and coordination levels of urban agglomerations. The “Opinions of the Central Committee of the Communist Party of China and the State Council on Establishing a More Effective New Mechanism for Coordinated Regional Development” propose leveraging urban agglomerations to integrate major national regional strategies, establishing a new model where central cities lead agglomeration development and agglomerations drive regional growth, thereby promoting integrated and interactive development among regional blocks. Consequently, research on the coupling and coordination between higher education and regional economic development within urban agglomerations is highly necessary. (2) From a disciplinary perspective, research on the relationship between higher education and economic development primarily originates from educational or economic viewpoints. There is a lack of geographical analysis exploring the spatiotemporal characteristics and driving mechanisms of their coordinated interaction, and quantitative analytical tools remain relatively limited. (3) Research depth remains limited. Most scholars analyzing the interaction between higher education and economic development focus solely on assessing the quality of their coordinated development. There is insufficient research and analysis on the factors influencing this relationship and the mechanisms through which it evolves. Consequently, proposed recommendations and countermeasures often lack specificity and comprehensiveness.

Taken together, the three strands of literature reveal three persistent gaps. First, while the unidirectional effect of higher education on economic growth is well documented, far less attention has been paid to the asymmetry of the two-way dynamic interaction between the two systems. Second, although provincial- and national-scale evidence is abundant, the urban agglomeration—a strategically important meso-scale spatial unit in China’s regional development policy—remains comparatively underexplored. Third, the dominance of static analytical tools has left the lagged responses and shock-propagation mechanisms between higher education and the regional economy insufficiently understood.

This paper contributes to the literature in three ways. First, it extends the empirical scope of the higher education–economy coupling literature from the national, provincial, and municipal scales to the urban-agglomeration scale, which aligns more closely with China’s regional coordinated development strategy. Second, by combining a multi-dimensional indicator system with GIS-based visualization, it offers an intuitive geographical reading of the spatial patterns of coordinated development—providing a descriptive foundation on which future spatial–econometric work can build. Third, through the use of a PVAR framework, it moves beyond static analysis to capture the bidirectional dynamic interactions and their lag structure, offering new insight into the asymmetric mechanisms linking the two systems.

This study differs from prior coupling coordination research in China in three theoretically consequential ways. First, whereas existing CCD studies predominantly characterize the static level or trend of coordination, our PVAR framework identifies the directional and temporal structure of the interaction, revealing that the two-way relationship is asymmetric rather than symmetric—a property that static coordination indices cannot detect. Second, the urban-agglomeration scale is not merely a larger spatial unit: it is the scale at which inter-city economic spillovers, administrative resource allocation, and intra-regional policy coordination actually operate, so analysing coordination at this scale exposes intra-agglomeration heterogeneity (such as the Pearl River Delta’s internal imbalance) that province- or nation-level studies aggregate away. Third, the asymmetry finding refines human capital theory by showing that, in rapidly developing economies, the causal primacy assumed by the education-leads-growth tradition is reversed in the short run: economic conditions reshape the higher education system faster than human capital accumulation

can feed back into growth. This ‘economy-pulls, education-adapts’ dynamic is a theoretical contribution that extends, rather than merely applies, the standard framework.

2. Theoretical Framework for the Coupling and Coordination of Higher Education and Economic Development

Higher education serves as both a driving force for economic development and a vital engine propelling economic growth. Conversely, economic development provides the material foundation for higher education, fostering its steady advancement. The mutually reinforcing positive synergies between these two sectors contribute to optimizing economic structures and promoting the integrated development of science and technology, education, and the economy. However, due to the coexistence of advanced and lagging development in higher education and regional economies, their interaction often faces challenges of developmental misalignment, thereby hindering high-quality regional development. With reforms in China’s higher education development model and shifts in economic growth patterns, the interaction between higher education and economic development has become increasingly intertwined, characterized by mutual reinforcement and constraints. Yet as the demand for deeper integration between higher education and regional economies grows, their relationship will ultimately evolve toward a virtuous cycle. To this end, this study establishes a complex system for the interaction between higher education and economic development, where two subsystems and their internal elements mutually empower and coordinate their development (Figure 1).

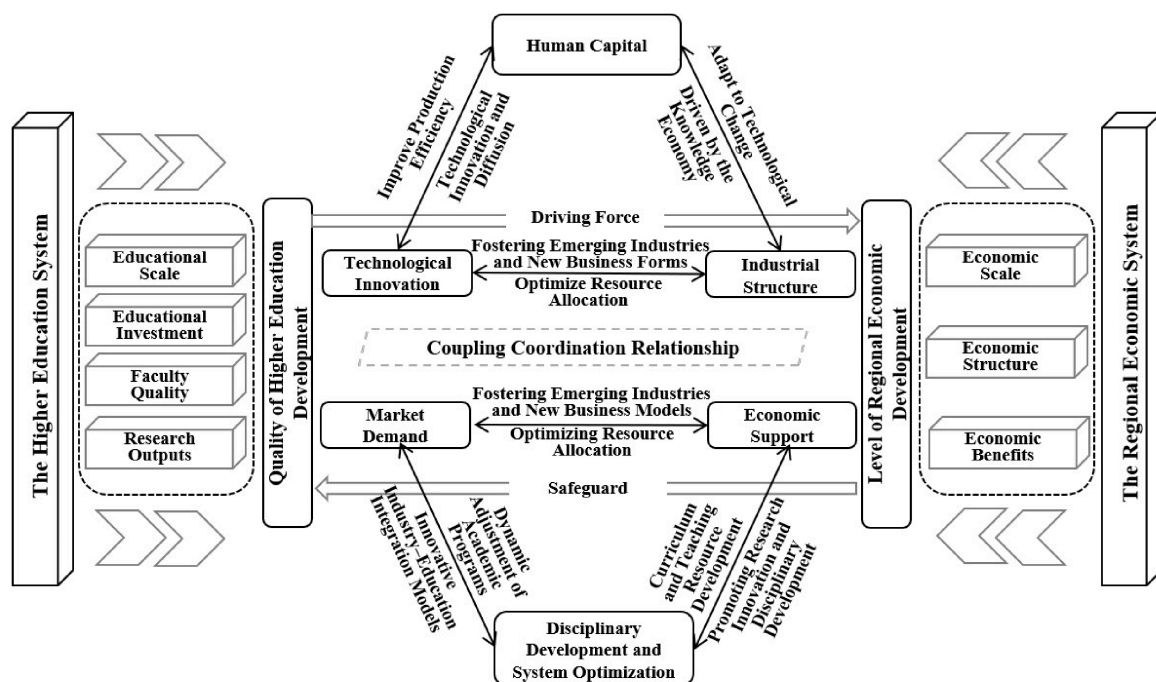


Figure 1. Mechanism of coupling and coordination between higher education and regional economic development.

Higher education promotes economic development and serves as a driving force for economic growth. (1) Accumulating human capital. The scale and developmental structure of higher education determine the quantity and quality of talent cultivated, thereby shaping the level of human capital development [21]. Because highly skilled workers possess more advanced productive capabilities, higher education improves labor productivity through investment in human capital. It also enhances firms’ production efficiency, thereby significantly increasing overall regional labor productivity and providing strong support

for economic development. (2) Enhancing scientific and technological innovation. Technological advancement relies on workers with higher education. Universities, equipped with advanced research facilities, strong faculty, and top-tier research teams, serve as the primary venues for cultivating scientific talent and producing research outcomes. Thus, universities can stimulate economic growth by accumulating human capital and boosting technological innovation, while laying a solid foundation for regional economic restructuring and upgrading.

Economic development drives higher education, serving as its cornerstone and safeguard while guiding it toward societal needs. (1) Material Foundation. Higher education relies on economic development, with economic conditions determining its scale and structure. More economically developed regions typically provide greater government funding for higher education [22]. Gu et al. [23] find that economic factors are paramount in talent aggregation, and developing higher education necessitates building a high-quality faculty. Moreover, the level of regional economic development determines the living standards of local residents, significantly influencing family investment in children's education and thereby driving local higher education growth. (2) Guiding Role. Higher education must adapt to the needs of economic and social development and cannot exist independently of specific social environments and conditions. Economic development imposes objective demands on both the quality and quantity of talent. The higher education system continually adjusts to meet these demands, achieving alignment with social development and economic structure.

On the basis of the theoretical analysis above, this paper advances the following three hypotheses for empirical examination. H1: Higher education and the regional economy in China's coastal urban agglomerations exhibit a bidirectional dynamic interaction, in which each system exerts a measurable effect on the other over time. H2: Owing to the immediacy of fiscal-channel transmission and the inherent time lag in human capital accumulation, shocks from the economic system generate a stronger short-term response in higher education than shocks in the opposite direction—that is, the bidirectional relationship is asymmetric. H3: The coupling coordination between the two systems is jointly driven by the level of economic development, the intensity of government fiscal support, the level of urbanization, and the scale of higher education; among these drivers, proactive government intervention plays a more decisive role than objective economic conditions alone.

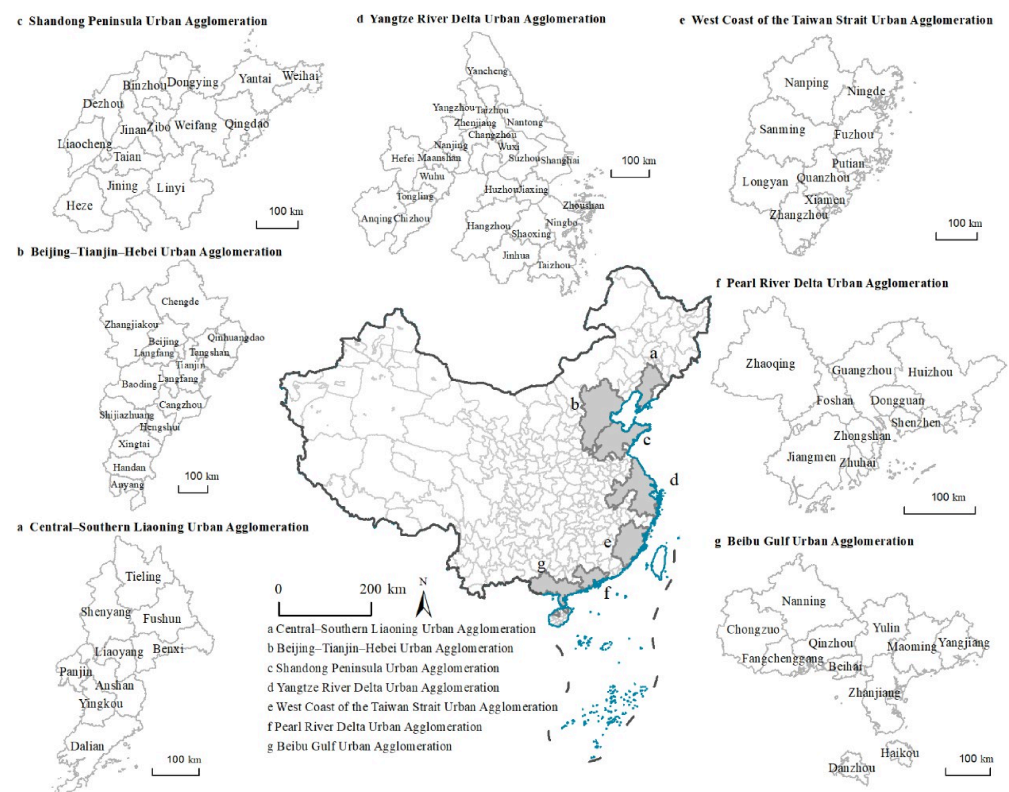
3. In-Depth Analysis of Higher Education and Economic Development in China's Coastal Urban Agglomerations

3.1. Selection of Study Areas

This study identifies seven major coastal urban agglomerations: Central-Southern Liaoning, Beijing–Tianjin–Hebei, Shandong Peninsula, Yangtze River Delta, Pearl River Delta, Beibu Gulf, and West Coast of the Taiwan Strait. This selection is based on nationally approved urban agglomerations by the State Council, referencing the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Long-Range Objectives Through the Year 2035, as well as the Opinions of the Central Committee of the Communist Party of China and the State Council on Establishing a More Effective New Mechanism for Coordinated Regional Development. Based on this, the actual research subjects of this paper are 90 major cities within these seven coastal urban agglomerations (Table 1, Figure 2).

Table 1. Seven Major Coastal Urban Agglomerations in China and Their Constituent Major Cities.

Urban Agglomeration	Constituent Cities	Number of Cities
Central-Southern Liaoning Urban Agglomeration	Shenyang, Dalian, Anshan, Fushun, Benxi, Yingkou, Liaoyang, Tieling, Panjin	9
Beijing–Tianjin–Hebei Urban Agglomeration	Beijing, Tianjin, Shijiazhuang, Tangshan, Baoding, Handan, Zhangjiakou, Chengde, Langfang, Qinhuangdao, Cangzhou, Xingtai, Hengshui, Anyang	14
Shandong Peninsula Urban Agglomeration	Jinan, Zibo, Tai'an, Dezhou, Liaocheng, Qingdao, Weifang, Yantai, Weihai, Dongying, Binzhou, Jining, Heze, Linyi	14
Yangtze River Delta Urban Agglomeration	Nanjing, Zhenjiang, Yangzhou, Hangzhou, Jiaxing, Huzhou, Shaoxing, Hefei, Wuhu, Ma'anshan, Suzhou, Wuxi, Changzhou, Ningbo, Zhoushan, Jinhua, Taizhou, Nantong, Yancheng, Shanghai, Taizhou (Jiangsu), Tongling, Chizhou, Anqing	24
West Coast of the Taiwan Strait Urban Agglomeration	Fuzhou, Xiamen, Sanming, Longyan, Quanzhou, Ningde, Putian, Zhangzhou, Nanping	9
Pearl River Delta Urban Agglomeration	Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, Zhaoqing	9
Beibu Gulf Urban Agglomeration	Nanning, Haikou, Zhanjiang, Beihai, Qinzhou, Fangchenggang, Yulin, Chongzuo, Maoming, Yangjiang, Danzhou	11

**Figure 2.** Location of the seven major coastal urban agglomerations in China.

3.2. Data Description

Due to data availability constraints, this study utilizes panel data from 2008 to 2021 covering 90 municipal-level administrative units across China's seven major coastal urban

agglomerations (excluding Hong Kong, Macau, and Taiwan regions). Primary data sources include statistical yearbooks from provincial and municipal statistics bureaus, municipal statistical bulletins on national economic and social development, municipal statistical announcements on education expenditure implementation, and China National Knowledge Infrastructure (CNKI). Missing data for certain years were imputed using Stata commands.

3.3. Evaluation System Construction

We constructed an evaluation index system for higher education and economic development by reviewing and synthesizing the prior literature. The selection of indicators followed three principles: scientific rigor, representativeness, and data availability. Higher education levels were assessed across four dimensions: educational scale, educational investment, faculty quality, and research output. Economic development levels were evaluated across three dimensions: economic scale, economic structure, and economic efficiency, as shown in Table 2.

Table 2. Evaluation Index System for Higher Education and Economic Development.

Target Layer	Primary Indicator	Secondary Indicator	Direction	Weight
Higher Education Development Level	Education Scale	Number of Institutions	Positive	0.0838
		Number of University Students per 100,000 People	Positive	0.0610
		Number of Graduates	Positive	0.0885
		Proportion of Postgraduate Students (%)	Positive	0.1374
	Education	R and D Expenditure (100 million CNY)	Positive	0.1111
	Investment	Fiscal Expenditure on Education (100 million CNY)	Positive	0.1549
	Faculty Level	Student-Faculty Ratio	Negative	0.0100
		Number of Full-Time Teachers	Positive	0.1021
	Research Output	Number of Publications	Positive	0.1379
		Number of Patents	Positive	0.1134
Economic Development Level	Economic Scale	GDP (100 million CNY)	Positive	0.1707
		Fiscal Revenue (100 million CNY)	Positive	0.2489
		Fixed Asset Investment (100 million CNY)	Positive	0.1207
		Total Retail Sales of Consumer Goods (100 million CNY)	Positive	0.1708
	Economic Structure	Share of Secondary Industry (%)	Positive	0.0159
		Share of Tertiary Industry (%)	Positive	0.0247
		Employment Share in Secondary Industry (%)	Positive	0.0226
		Employment Share in Tertiary Industry (%)	Positive	0.0335
	Economic Efficiency	Average Wage (CNY)	Positive	0.0618
		GDP per Capita (10,000 CNY)	Positive	0.0786
		Urban Population Ratio (%)	Positive	0.0518

The explanatory variables were selected to capture three theoretically distinct channels through which higher education and regional economic development may become coordinated. First, the economic-capacity channel is represented by per-capita GDP and per-capita disposable income. These variables capture both local fiscal capacity and household-level capacity to support education and attract skilled labour. Second, the policy-support channel is represented by the share of higher-education fiscal expenditure in GDP, which measures the extent to which local governments actively allocate public resources to higher education rather than relying solely on market-led growth. Third, the urban-industrial demand chan-

nel is represented by the share of tertiary industry and per-capita urban construction land, which reflects the demand for knowledge-intensive labour and the spatial–infrastructural conditions for university expansion and industry–university interaction. Finally, the higher-education enrollment scale is included to capture the supply-side capacity of the higher education system. Together, these variables allow the model to distinguish between economic endowment, government intervention, urbanization conditions, and education supply capacity.

We did not include additional variables such as historical university status, administrative rank, or long-standing institutional endowments as separate regressors because these factors are largely time-invariant during the study period and are absorbed by the city fixed effects.

Several indicator choices warrant explanation. Publications and patents are retained as distinct indicators rather than being merged, because they capture complementary dimensions of research output—knowledge production and applied/commercializable innovation, respectively—and the entropy method assigns each its own data-driven weight (0.1379 and 0.1134) rather than imposing equality. Both the secondary- and tertiary-industry shares enter as positive indicators because, in the context of China’s coastal agglomerations over the study period, expansion of both sectors reflects industrial maturation and rising demand for skilled labour relative to the primary sector; we acknowledge that in a post-industrial context the secondary-industry share could warrant a different sign. The very small weight on the student–faculty ratio (0.0100) is a direct consequence of the entropy method: this indicator exhibits little cross-city and inter-temporal variability, so it contributes little discriminating information and is automatically down-weighted—an outcome consistent with the objective logic of the method rather than a modelling choice.

We also examined variance inflation factors among the six explanatory variables (x_1 to x_6) used in the fixed-effects regression model. As reported in Table 3, all VIFs are well below the conventional threshold of 5: the maximum VIF is 3.347 (for per-capita GDP, x_1), and the mean VIF is 2.271, indicating that multicollinearity does not materially threaten the coefficient estimates. Data availability note: Over the study period, exact municipal-level data for per-capita disposable income (x_2) and per-capita urban construction land (x_5) are not consistently available across all 90 cities. Following common practice, we therefore use urban per-capita disposable income as a proxy for x_2 and urban built-up area per capita as a proxy for x_5 . All other variables are directly available. As shown in Table 3, the VIFs for these proxies are well below the conventional threshold of 5, indicating that their use does not introduce multicollinearity that would materially affect the coefficient estimates.

Table 3. Variance Inflation Factor (VIF) Test for the Six Explanatory Variables.

Variable	Definition	Auxiliary R-Squared	VIF	Tolerance	Criterion	Result	Data Status
x_1	Per-capita GDP	0.701	3.347	0.299	VIF < 5	Pass	Directly available
x_2	Per-capita disposable income	0.680	3.120	0.320	VIF < 5	Pass	Proxy used
x_3	Higher-education fiscal expenditure share	0.011	1.011	0.989	VIF < 5	Pass	Constructed from raw data
x_4	Share of tertiary industry	0.566	2.305	0.434	VIF < 5	Pass	Directly available
x_5	Per-capita urban construction land	0.579	2.373	0.421	VIF < 5	Pass	Direct field missing; proxy used
x_6	Higher-education enrollment scale	0.319	1.469	0.681	VIF < 5	Pass	Directly available as per-capita scale

Data note: Variables x_2 and x_5 are proxied as described in Section 3.3. The VIF values reported above are calculated using those proxy variables. The maximum VIF (3.347) and mean VIF (2.271) remain well below the conventional threshold of 5, indicating that multicollinearity does not materially threaten the coefficient estimates.

3.4. Methods

3.4.1. Entropy Method

The entropy method is an objective weighting technique that relies solely on data variability. Therefore, this paper employs the entropy method to conduct a comprehensive evaluation of higher education and economic development levels. The evaluation steps are as follows:

Data dimensionless processing:

Positive indicators:

$$X_{ij} = \frac{x_{ij} - \min(x_{1j}, \dots, x_{nj})}{\max(x_{1j}, \dots, x_{nj}) - \min(x_{1j}, \dots, x_{nj})} \quad (1)$$

Negative Indicators:

$$X_{ij} = \frac{\max(x_{1j}, \dots, x_{nj}) - x_{ij}}{\max(x_{1j}, \dots, x_{nj}) - \min(x_{1j}, \dots, x_{nj})} \quad (2)$$

In the formula, X_{ij} represents the normalized value of the i -th observation for the j -th indicator. $\min(x_{1j}, x_{2j}, \dots, x_{nj})$ and $\max(x_{1j}, x_{2j}, \dots, x_{nj})$ represent the minimum and maximum values of the j -th indicator, respectively.

Assignment weights:

ρ_{ij} represents the weight of the i -th value for the j -th indicator. Subsequently, the entropy value e_j and difference coefficient g_j are calculated for each indicator, followed by the computation of the indicator weight W_j .

$$\rho_{ij} = \frac{X_{ij}}{\sum_{i=1}^n X_{ij}} \quad (3)$$

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n \rho_{ij} \ln(\rho_{ij}) \quad (4)$$

$$g_j = 1 - e_j \quad (5)$$

$$W_j = \frac{g_j}{\sum_{j=1}^m g_j} \quad (6)$$

Calculation of the composite score for Year i :

$$S_i = \sum W_j \rho_{ij} \quad (7)$$

Because the entropy method derives weights from observed indicator variability, we tested the sensitivity of our composite indices to the weighting scheme by recomputing both the higher-education and economic development indices using equal weights and principal-components weights. The entropy-based indices are highly consistent with both alternatives: the Spearman rank correlations range from 0.9216 to 0.9812 (Table A7). This indicates that the spatiotemporal patterns and the subsequent PVAR and fixed-effects results are not artefacts of the entropy weighting and are robust to reasonable alternative specifications.

We apply a single set of weights estimated over the full 2008–2021 panel to maintain comparability of index values across years; computing year-specific weights would render inter-temporal comparisons of the composite scores incommensurable. As a check, we re-estimated weights for the two endpoint years (2008 and 2021) separately and found the relative ordering of indicator weights to be stable, supporting the use of period-pooled weights.

3.4.2. Coupling Coordination Model

The Coupling Coordination Model can be used to evaluate and analyze the coupling relationship and coordination level between two or more systems. The formula is as follows:

$$C = 2 \times \left[\frac{f_h \times f_e}{(f_h + f_e)^2} \right]^{\frac{1}{2}} \quad (8)$$

$$D = \sqrt{C \times T} \quad (9)$$

$$T = \alpha f_h + \beta f_e \quad (10)$$

In the formula, C represents the coupling degree; D denotes the coupling coordination degree; f_h and f_e are the comprehensive evaluation indices for higher education and regional economic development, respectively; T is the evaluation index for both systems; α and β are undetermined weights. Since they are equally important in the coupling coordination process, $\alpha = \beta = 0.5$.

The coupling coordination concept originates in the physical sciences, and its transfer to social systems has been critiqued for importing mechanical connotations that may not hold for human institutions [24]. We adopt it not as a literal physical mechanism but as a measurement device: the C term operationalizes the degree of mutual responsiveness between two empirically measured subsystems, and the D term combines this with their joint development level. We therefore interpret ‘coordination’ in strictly statistical-relational terms—co-movement and mutual conditioning of the two index series—rather than as a claim about teleological ‘self-organization.’ This reading is consistent with our PVAR evidence, which supplies the dynamic, causal content that a static coupling index alone cannot justify.

Following the conventional ten-tier CCD classification, the coordination degree D is partitioned as follows: 0.0–0.1 extreme disorder; 0.1–0.2 severe disorder; 0.2–0.3 moderate disorder; 0.3–0.4 mild disorder; 0.4–0.5 near disorder; 0.5–0.6 reluctant coordination; 0.6–0.7 primary coordination; 0.7–0.8 intermediate coordination; 0.8–0.9 good coordination; 0.9–1.0 high-quality coordination (Table 4). We acknowledge that these thresholds, although widely used, are to some degree conventional. To assess sensitivity, we re-classified all city-year observations using an alternative equal-interval five-tier scheme: 0.0–0.2 (disorder), 0.2–0.4 (mild disorder), 0.4–0.6 (transitional), 0.6–0.8 (coordination), and 0.8–1.0 (high coordination) (Table A1). The Spearman rank correlation between the ten-tier and five-tier classifications is 0.9192 ($*p^* < 0.001$), and the mean absolute rank difference is 9.28 (out of 90 cities) (Table A2). The relative ranking of agglomerations and the substantive conclusions regarding which clusters lead or lag remain unchanged, indicating that our findings do not hinge on the specific threshold choice.

Because the D index combines the coupling degree C and the overall development level T , a high D could in principle reflect either strong coupling or simply high joint development. To aid interpretation, we report C and T separately alongside D (Table A3). The results show that leading agglomerations (e.g., the Yangtze River Delta) achieve high levels in both dimensions ($C = 0.8727$, $T = 0.2519$). In contrast, the Pearl River Delta exhibits a T of 0.2214 but a noticeably lower C (0.8128) compared with the Yangtze River Delta. This pattern—a relatively high economic development level coupled with a lower coupling degree—captures the decoupling phenomenon that will be further discussed in Section 6.2.

Table 4. Ten-tier classification criteria for coupling coordination degree (D).

Rank	D Range	Classification	2008 N	2013 N	2017 N	2021 N
1	0.0–0.1	Extreme disorder	2	1	1	2
2	0.1–0.2	Severe disorder	1	3	8	8
3	0.2–0.3	Moderate disorder	20	25	27	30
4	0.3–0.4	Mild disorder	26	27	24	25
5	0.4–0.5	Near disorder	20	16	13	13
6	0.5–0.6	Reluctant coordination	9	7	7	5
7	0.6–0.7	Primary coordination	7	6	6	4
8	0.7–0.8	Intermediate coordination	3	3	2	1
9	0.8–0.9	Good coordination	0	0	0	0
10	0.9–1.0	High-quality coordination	2	2	2	2
		Total	90	90	90	90

3.4.3. Panel Vector Autoregression Model (PVAR Model)

To analyze the dynamic interactive relationship between higher education and regional economic growth, this paper constructs a panel vector autoregression (PVAR) model. The model estimation, Granger causality tests, and impulse response analysis are conducted using the pvar package in Stata software 18, based on the comprehensive indices of higher education and regional economic development. The expression for PVAR(p) is:

$$Y_{it} = C + \Phi_1 Y_{i,t-1} + \dots + \Phi_p Y_{i,t-p} + \alpha_i + \beta_t + \varepsilon_{it} \quad (11)$$

In the formula, Y_{it} denotes the k-dimensional vector of endogenous variables, i represents the number of cross-sections, α_i is the individual fixed effect for each city, and β_t is the time fixed effect.

The final model form is:

$$\begin{bmatrix} ECO_{it} \\ EDU_{it} \end{bmatrix} = \Phi_1 \begin{bmatrix} ECO_{i,t-1} \\ EDU_{i,t-1} \end{bmatrix} + \dots + \Phi_p \begin{bmatrix} ECO_{i,t-p} \\ EDU_{i,t-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \end{bmatrix} \quad (12)$$

3.4.4. Panel Regression Model: From Pooled OLS to Fixed Effects

To identify the drivers of coordinated development, we proceed in two steps. A pooled OLS regression is first used only as a preliminary screening device to confirm that all six explanatory variables are individually relevant; because pooled OLS is vulnerable to omitted-variable bias, it is not our inferential model. We then estimate a panel model and use the Hausman test to choose between fixed- and random-effects specifications, with the fixed-effects estimator selected for all reported results. The pooled OLS regression model combines ordinary least squares (OLS) regression with panel data analysis methods to more accurately estimate relationships between variables. This paper further constructs the model to explore factors influencing the coordinated development of higher education and regional economies. Economic development levels determine local fiscal capacity and living standards, thereby influencing government investment in higher education. Per-capita GDP ($\ln x_1$) and per-capita disposable income ($\ln x_2$) are selected to represent local economic development levels. Government support intensity is a crucial factor influencing higher education development. Therefore, the proportion of higher-education fiscal expenditure to GDP (x_3) is selected to measure the intensity of policy support for higher education development. Urbanization levels shape the direction and layout of higher education development. People-centered new urbanization and industrial restructuring drive labor market demands, prompting higher education structural adjustments. Thus, the share of tertiary industry output in GDP (x_4) and per-capita urban construction land ($\ln x_5$)

reflect urbanization levels. The scale of higher education is a key factor influencing its development level. The number of undergraduate and associate degree students enrolled in regular higher education institutions (x_6) is selected to represent the scale of higher education. The formula is as follows:

$$Y_{it} = \alpha + \sigma_1 \ln x_{1it} + \sigma_2 \ln x_{2it} + \sigma_3 x_{3it} + \sigma_4 x_{4it} + \sigma_5 \ln x_{5it} + \sigma_6 x_{6it} + \theta_i + \epsilon_{it} \quad (13)$$

In the formula, Y_{it} represents the coordination index; α denotes the constant term; $x_1, x_2, \dots, x_6$ are the explanatory variables; σ indicates the degree of influence of the explanatory variables; θ_i signifies the individual effect; and ϵ_{it} represents the error term. For x_2 and x_5 , we use the proxies described in Section 3.3 due to data availability constraints; the same proxies are used in both the VIF test and the fixed-effects regression, ensuring consistency.

Endogeneity concerns and robustness strategy. We recognize that the empirical relationship between higher education and regional economic development may be affected by reverse causality, dynamic persistence, and omitted-variable bias. Although the PVAR framework captures lagged dynamic interactions and Granger-predictive relationships between the two systems, it should not be interpreted as fully resolving structural endogeneity. To mitigate these concerns, we adopt a multi-step strategy. First, the fixed-effects specification controls for time-invariant city characteristics, such as historical education endowments, geographic location, and administrative rank. Second, we estimate a robustness model using one-period lagged explanatory variables to reduce contemporaneous simultaneity. Third, we further estimate a two-step system GMM model as an additional dynamic-panel robustness check. In this specification, the lagged dependent variable is included to capture the persistence of coupling coordination, while lagged levels and lagged differences of the dependent variable and potentially endogenous regressors are used as internal instruments. To reduce the risk of instrument proliferation, we use a collapsed instrument set in the baseline GMM specification and further test the robustness of the results by extending the instrument lag structure. The corresponding GMM estimates and diagnostic tests are reported in Table A8. The validity of the GMM specification is evaluated using the Arellano–Bond AR(1) and AR(2) tests, the Hansen J test of overidentifying restrictions, and the Diff-in-Hansen test. Accordingly, the empirical findings are interpreted as robust conditional associations and dynamic predictive relationships rather than as definitive structural causal effects.

4. Spatiotemporal Characteristics of Higher Education and Economic Development in Coastal Urban Agglomerations

4.1. Temporal Characteristics of Higher Education and Economic Development in Coastal Urban Agglomerations

Using the entropy value method formula, a comprehensive evaluation of higher education and economic development levels across cities within coastal urban agglomerations can be calculated. Figure 3a reveals a steady upward trend in higher education levels across all coastal urban agglomerations from 2008 to 2021. The average score increased from 0.070 in 2008 to 0.107 in 2021, while the standard deviation rose from 0.068 to 0.114 during the same period. This indicates a widening absolute gap in higher education levels among China's coastal cities. Taking 2021 as an example, the top-ranked cities include large urban centers such as Beijing, Shanghai, and Nanjing, while smaller cities like Hengshui, Ningde, and Panjin occupy lower positions. The development index reveals a 35-fold disparity between the highest and lowest higher education development levels, highlighting significant variations in educational attainment across China's coastal urban clusters. Among these, the Yangtze River Delta, Beijing–Tianjin–Hebei, and Shandong Peninsula urban agglomerations consistently outperformed all other coastal clusters. It is worth

noting that the co-occurrence of a rising overall level and widening absolute disparities implies that higher education across China's coastal cities does not display the convergence pattern predicted by classical regional economics theory—instead, a divergence pattern has emerged. As confirmed by the spatial-autocorrelation analysis in Section “Spatial Autocorrelation”, this divergence reflects the institutionally concentrated rather than geographically diffused organisation of higher-education resources in China: leading cities sustain their advantage through administrative and policy channels (designation as ‘Double First-Class’ universities, central government funding priority, faculty agglomeration via hierarchical incentive systems), producing a Matthew-effect pattern in which leading cities pull further ahead without commensurate geographic spillover to neighbouring cities. Such a pattern is consistent with the strong path dependence of higher education: historically accumulated disciplinary strengths, faculty networks, and alumni resources are difficult to replicate in the short term through funding alone.

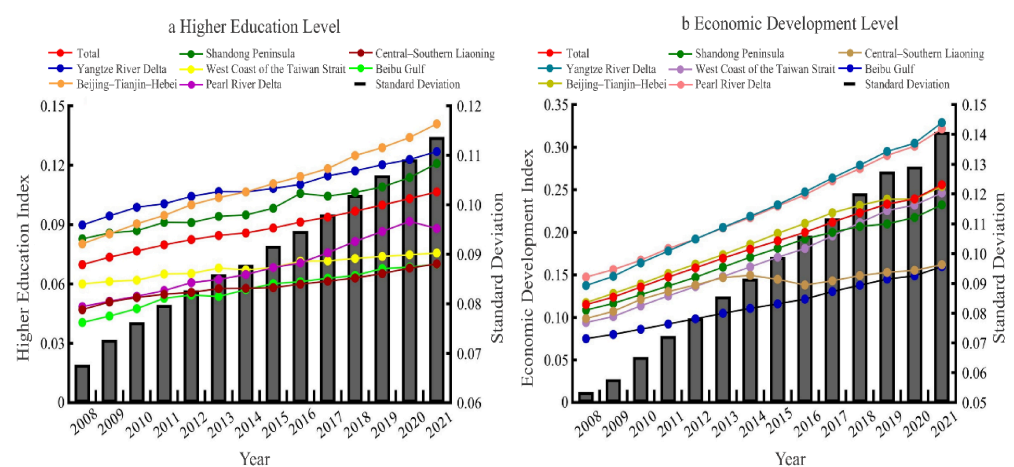


Figure 3. Trends in higher education and economic development levels of China's coastal urban agglomerations, 2008–2021.

Figure 3b shows that the economic development levels of most coastal urban agglomerations in China steadily increased from 2008 to 2021, rising from 0.115 in 2008 to 0.256 in 2021. The standard deviation increased from 0.054 in 2008 to 0.141 in 2021, indicating that while China's overall economic development level continued to rise, substantial disparities existed among coastal cities. Among these, the Central-Southern Liaoning Urban Agglomeration experienced a noticeable slowdown in economic growth between 2015 and 2016. Following economic restructuring and optimization in the Central-Southern Liaoning region, it has since demonstrated a positive development trajectory. Taking 2021 as another example, the top-ranked cities included major urban centers like Shanghai, Beijing, and Shenzhen, while smaller cities such as Tieling, Liaoyang, and Chongzuo ranked lower. The economic development index revealed an eightfold disparity between the highest and lowest values, highlighting substantial economic disparities among China's coastal cities. At the urban cluster level, significant regional differences exist among coastal clusters. The economic development of the Yangtze River Delta urban agglomeration and the Pearl River Delta urban agglomeration has always led the country.

4.2. Spatial Distribution Characteristics of Higher Education and Economic Development Levels in Coastal Urban Agglomerations

Based on higher education index data from 90 cities in China's coastal urban agglomerations in 2008–2021, visualization was conducted using ArcGIS 10.7 software. The natural breakpoint classification method was applied to categorize the 2008, 2013, 2017,

and 2021 into five tiers: high, higher, medium, lower, and low. Each tier is represented by a color gradient ranging from light to dark, indicating the corresponding level of higher education development. Figure 4 reveals that most coastal cities have experienced grade improvements, with the Shandong Peninsula, Beijing–Tianjin–Hebei, and Yangtze River Delta urban agglomerations showing the most significant advancements. This indicates these coastal clusters exhibit faster higher education development and greater investment in education compared with other coastal urban agglomerations.

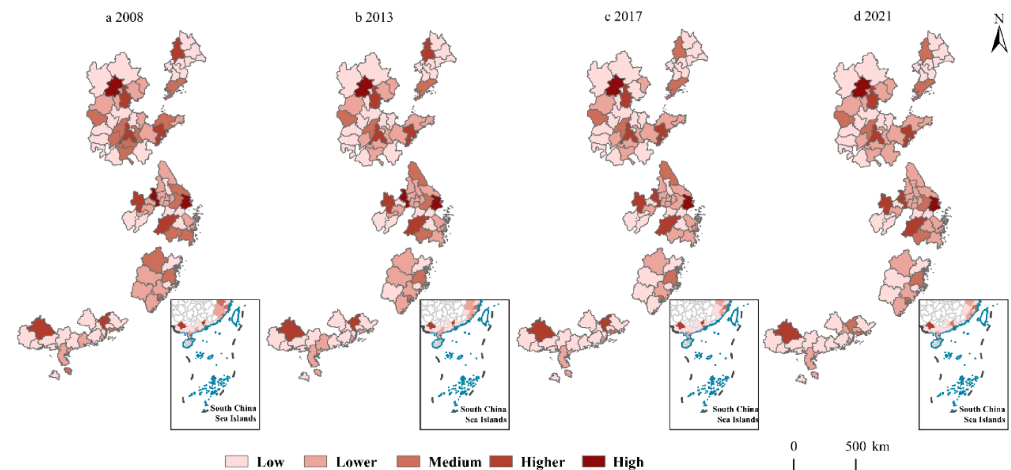


Figure 4. Spatial trends of higher education levels in the seven coastal urban agglomerations, 2008–2021.

Based on economic development index data from 90 coastal cities in China's urban agglomerations between 2008 and 2021, ArcGIS 10.7 software was employed to apply the natural breakpoint classification method. This method categorized the economic development indices for 2008, 2013, 2017, and 2021 into five levels: high, higher, medium, lower, and low, followed by spatial visualization. As shown in Figure 5, the economic development levels of China's coastal urban agglomerations have significantly increased. This growth is attributed to the stable economic foundations and favorable geographical locations of coastal cities. Notably, central cities within these agglomerations, such as Beijing, Shanghai, and Shenzhen, exert substantial radiating effects, driving the development of surrounding cities and demonstrating distinct spillover effects.

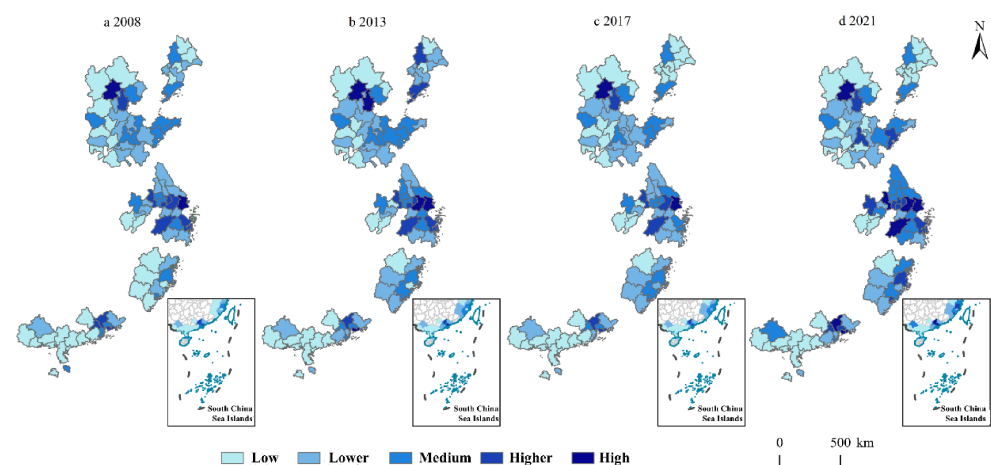


Figure 5. Spatial trends of economic development levels in the seven coastal urban agglomerations, 2008–2021.

Spatial Autocorrelation

Because the discussion of spillover and agglomeration effects implies spatial dependence, we computed the global Moran's I for the higher education and economic development indices using an inverse-distance spatial weights matrix among the 90 cities (Table 5). Moran's I is positive and statistically significant for the economic development index across the sample years (e.g., in 2008, $I = 0.0592$, $p < 0.0001$; in 2021, $I = 0.0717$, $p < 0.0001$), confirming that neighbouring cities exhibit similar economic development levels and that significant spatial clustering exists. In contrast, the higher education index shows no statistically significant spatial autocorrelation (e.g., in 2008, $I = 0.0014$, $p = 0.4809$; in 2021, $I = -0.0075$, $p = 0.8298$).

Table 5. Global Moran's I test results for spatial autocorrelation.

Year	Index	Spatial Weight Matrix	Moran's I	Expected I	Z-Statistic	p-Value	Significance	Inference
2008	Higher education development index (EDU)	Inverse-distance spatial weight matrix	0.0014	−0.0112	0.7048	0.4809	Not significant	No significant spatial autocorrelation
2008	Economic development index (ECO)	Inverse-distance spatial weight matrix	0.0592	−0.0112	3.9180	<0.0001	***	Significant positive spatial autocorrelation
2014	Higher education development index (EDU)	Inverse-distance spatial weight matrix	−0.0097	−0.0112	0.0875	0.9302	Not significant	No significant spatial autocorrelation
2014	Economic development index (ECO)	Inverse-distance spatial weight matrix	0.0510	−0.0112	3.4441	0.0006	***	Significant positive spatial autocorrelation
2021	Higher education development index (EDU)	Inverse-distance spatial weight matrix	−0.0075	−0.0112	0.2150	0.8298	Not significant	No significant spatial autocorrelation
2021	Economic development index (ECO)	Inverse-distance spatial weight matrix	0.0717	−0.0112	4.6346	<0.0001	***	Significant positive spatial autocorrelation

Notes: The table reports Global Moran's I statistics for the economic development index (ECO) and higher education development index (EDU). The null hypothesis is spatial randomness, that is, no global spatial autocorrelation. An inverse-distance spatial weight matrix is used. Positive and significant Moran's I indicates spatial clustering of similar index values. ***, indicate significance at the 1% levels. Results show persistent positive spatial autocorrelation for ECO, while EDU is not statistically significant in the reported years.

The contrast between the spatial clustering of economic development and the absence of significant spatial autocorrelation in higher education is itself a substantively important finding rather than a null result. It indicates that higher-education resources in China's coastal urban agglomerations are organised primarily along administrative-jurisdictional lines—including provincial higher-education funding allocations, the centrally administered 'Double First-Class' programme designation, and hierarchical inter-governmental fiscal transfers—rather than through inter-city geographic diffusion. Economic development, in contrast, propagates through market-mediated channels such as labour mobility, supply chain integration, and demonstration effects, which generate the observed spatial clustering pattern. This divergence in transmission mechanisms helps explain the persistent intra-agglomeration disparities documented in Section 4.1: cities adjacent to leading higher-education centres do not automatically benefit from spillover effects, because the institutional channels that govern higher-education resource allocation are administrative rather than geographic. This finding reinforces our central argument, developed empirically in Section 5.2 and illustrated by the Pearl River Delta case in Section 6.2, that proactive

government fiscal intervention—rather than market-driven or geographic spillover—is the dominant mechanism through which higher-education capacity is redistributed within and across coastal urban agglomerations.

These results verify the presence of spatial dependence in the economic dimension, while motivating the institutional-channel interpretation of higher-education resource allocation developed throughout the paper. A full spatial–econometric treatment (e.g., spatial Durbin modelling) of the coordinated development process—particularly with respect to the economic dimension where significant spatial dependence is documented—remains a natural and important extension, which we identify as a priority for future research.

5. Analysis of Coordination Mechanisms Between Higher Education and Regional Economic Development in Coastal Urban Agglomerations

5.1. The Interplay Between Higher Education and Regional Economies

This study employs panel data from 2008 to 2021, utilizing the comprehensive evaluation values of higher education and regional economic development calculated via the entropy method. A PVAR model is applied to conduct a quantitative analysis of the dynamic relationship between higher education and regional economic development. Prior to constructing the PVAR model, unit root tests are conducted on the variables to ensure data stationarity. This section employs LLC and PP unit root tests to examine the stationarity of the variables. The LLC and PP unit root test results indicate that at the 1% significance level, the LLC and Fisher-ADF unit root tests (Table 6) indicate that $\ln(\text{econ})$ is stationary in levels ($I(0)$), whereas $\ln(\text{edu})$ is non-stationary in levels but stationary in first differences ($I(1)$); both series are therefore modeled in first differences. After first-difference transformation (“D”), both variables reject the null hypothesis of unit root existence, indicating they are first-order stationary time series suitable for cointegration and PVAR model estimation. This study employs the Kao test to examine cointegration relationships among the panel data. Results indicate cointegration exists among the variables, confirming that the panel data regression models are not spurious and can be analyzed. Since the selected variables are first-order stationary time series, this study employs the differenced ECO and EDU indices for modeling. Optimal lag orders are determined using information criteria such as AIC, SC, and HQ, selecting PVAR models with lags of 1–2. Granger causality tests reveal a bidirectional Granger causality relationship between higher education and economic development in coastal urban agglomerations, with the education-to-economy direction significant at the 1% level and the economy-to-education direction significant at the 10% level. This indicates that changes in higher education development significantly influence economic development, while economic development changes significantly impact higher education development, validating the synergistic correlation between higher education and economic development in China’s coastal urban agglomerations.

Table 6. Panel unit root tests (LLC and Fisher-ADF).

Variable	LLC Test (Level)		Fisher-ADF Test (Level)		Fisher-ADF Test (First Difference)		Integration Order
	Statistic	<i>p</i> -Value	Statistic	<i>p</i> -Value	Statistic	<i>p</i> -Value	
$\ln(\text{econ})$	−23.5469 ***	0.0000	−5.3674 ***	0.0000	−6.3613 ***	0.0000	$I(0)$
$\ln(\text{edu})$	0.5435	0.5868	−1.8890 **	0.0294	−6.3613 ***	0.0000	$I(1)$
econ	1.7242 *	0.0847	3.7190	1.0000	−6.3364 ***	0.0000	$I(1)$
edu	9.2849 ***	0.0000	3.7190	1.0000	−6.3613 ***	0.0000	$I(1)$

Notes: LLC denotes the Levin–Lin–Chu panel unit root test; Fisher-ADF denotes the Maddala–Wu Fisher-type ADF test. The null hypothesis is that the variable contains a unit root. *p*-values are reported in adjacent columns. ***, **, and * indicate rejection of the null hypothesis at the 1%, 5%, and 10% significance levels, respectively. Where level tests provide mixed evidence, the integration order is classified conservatively based on first-difference stationarity.

Table 6 reports the panel unit root tests. The results show that $\ln(\text{econ})$ is stationary in levels ($I(0)$), while $\ln(\text{edu})$ is non-stationary in levels but stationary in first differences (LLC and Fisher-ADF statistics significant at the 1% level), confirming that the variables are integrated of order one after appropriate transformation and suitable for PVAR modelling in first differences. The Kao cointegration test (Table 7) rejects the null of no cointegration (statistic = -3.8096 , $p = 0.0001$), and the lag-order criteria (AIC/SC/HQ) jointly select a lag length of 2 (Table 8). Granger causality tests (Table 9) reveal bidirectional causality: $\ln(\text{edu})$ Granger-causes $\ln(\text{econ})$ at the 1% significance level ($F = 7.2178$, $p = 0.0008$), while $\ln(\text{econ})$ Granger-causes $\ln(\text{edu})$ at the 10% level ($F = 2.6505$, $p = 0.0713$). The eigenvalue stability condition is satisfied, with all moduli inside the unit circle (maximum modulus = 0.9821 , see Table 10), confirming that the estimated PVAR(2) model is stable.

Table 7. Kao residual cointegration test.

Cointegration Equation	Cointegrating Coefficient	Kao ADF Statistic	DF-Rho Statistic	DF-t Statistic	p-Value	ADF Observations	Inference
$\ln(\text{econ}) = f[\ln(\text{edu})]$	1.1652	-3.8096^{***}	-21.3084	-16.0485	0.0001	270	Cointegration confirmed
$\ln(\text{edu}) = f[\ln(\text{econ})]$	0.4777	-3.4000^{***}	-25.5988	-15.7830	0.0007	270	Cointegration confirmed

Notes: The Kao residual cointegration test is applied to examine the long-run equilibrium relationship between the variables. The null hypothesis is no cointegration. Rejection of the null indicates a statistically significant long-run relationship. *** indicate rejection of the null hypothesis at the 1% significance levels. ADF observations refer to the effective observations used in the residual-based ADF test.

Table 8. Lag-order selection criteria (AIC, SC, HQ).

Lag Order	Observations	Akaike Information Criterion (AIC)	Schwarz Bayesian Information Criterion (BIC)	Hannan-Quinn Information Criterion (HQ)	Model Selection
1	180	-8.8538	-8.7473	-8.8106	
2	90	-9.2385^{***}	-8.9607^{***}	-9.1265^{***}	Selected

Notes: The lag order is selected based on information criteria commonly used in PVAR estimation. Lower values of AIC, BIC, and HQ indicate a preferred model specification. *** denotes the minimum value of the corresponding information criterion. All three criteria support a lag order of 2.

Table 9. Granger causality tests (PVAR framework).

Null Hypothesis (H_0)	Lag Order	F-Statistic	p-Value	Inference
$\ln(\text{edu})$ does not Granger-cause $\ln(\text{econ})$	1	13.0240^{***}	0.0003	Reject H_0 ; strong evidence that $\ln(\text{edu}) \rightarrow \ln(\text{econ})$
$\ln(\text{econ})$ does not Granger-cause $\ln(\text{edu})$	1	3.3507^*	0.0676	Reject H_0 at 10%; weak evidence that $\ln(\text{econ}) \rightarrow \ln(\text{edu})$
$\ln(\text{edu})$ does not Granger-cause $\ln(\text{econ})$	2	7.2178^{***}	0.0008	Reject H_0 ; strong evidence that $\ln(\text{edu}) \rightarrow \ln(\text{econ})$
$\ln(\text{econ})$ does not Granger-cause $\ln(\text{edu})$	2	2.6505^*	0.0713	Reject H_0 at 10%; weak evidence that $\ln(\text{econ}) \rightarrow \ln(\text{edu})$
$\ln(\text{edu})$ does not Granger-cause $\ln(\text{econ})$	3	5.3377^{***}	0.0012	Reject H_0 ; strong evidence that $\ln(\text{edu}) \rightarrow \ln(\text{econ})$
$\ln(\text{econ})$ does not Granger-cause $\ln(\text{edu})$	3	2.4654^*	0.0612	Reject H_0 at 10%; weak evidence that $\ln(\text{econ}) \rightarrow \ln(\text{edu})$

Notes: The table reports Granger causality tests between education and economic development in the PVAR framework. The null hypothesis is that the variable on the left-hand side of the direction does not Granger-cause the variable on the right-hand side. *** and * indicate rejection of the null hypothesis at the 1% and 10% significance levels, respectively. Results indicate robust causality from $\ln(\text{edu})$ to $\ln(\text{econ})$, while the reverse direction is supported only at the 10% level across the tested lag specifications.

Table 10. PVAR stability test (eigenvalues).

Model Specification	Observations	Eigenvalue	Real Part	Imaginary Part	Modulus	Stability Condition	Inference
PVAR(1)	180	+0.1784 +0.0000i	0.1784	0.0000	0.1784	Inside the unit circle	Stable
PVAR(1)	180	+0.0591 +0.0000i	0.0591	0.0000	0.0591	Inside the unit circle	Stable
PVAR(2)	90	+0.4041 +0.0000i	0.4041	0.0000	0.4041	Inside the unit circle	Stable
PVAR(2)	90	−0.1955 +0.0000i	−0.1955	0.0000	0.1955	Inside the unit circle	Stable
PVAR(2)	90	+0.0347 +0.2239i	0.0347	0.2239	0.2265	Inside the unit circle	Stable
PVAR(2)	90	+0.0347 0.2239i	−0.0347	−0.2239	0.2265	Inside the unit circle	Stable
PVAR(1)- Levels	270	+0.8106 +0.0000i	0.8106	0.0000	0.8106	Inside the unit circle	Stable
PVAR(1)- Levels	270	+0.9821 +0.0000i	0.9821	0.0000	0.9821	Inside the unit circle	Stable

Notes: The PVAR stability condition requires all eigenvalues of the companion matrix to lie inside the unit circle. A model is considered dynamically stable when the modulus of each eigenvalue is less than one. The maximum reported modulus is 0.9821, which is below one; therefore, all reported specifications satisfy the stability condition. The levels specification is retained in the table to document the stability check of the original variable PVAR setting.

Impulse responses are computed as generalized impulse responses and are therefore invariant to the ordering of the variables. Building upon the PVAR model, impulse response analysis can assess the magnitude and direction of impacts on endogenous variables—both in the current period and across multiple future periods—following shocks from random disturbance terms. Following the PVAR model estimation, this study employs Stata software (specifically, its pvar package) to conduct impulse response analyses for DEDU and DECO. This approach allows for an in-depth examination of the dynamic interactions and response patterns between higher education and economic development in China’s coastal cities. As shown in Figure 6, the horizontal axis represents lag periods, while the vertical axis indicates response magnitude.

The upper-left panel shows the impulse response function of higher education development (DEDU) following a shock. Results indicate that DEDU exhibits a significant positive response to past fluctuations, suggesting that past fluctuations in higher education development influence current dynamics. The upper-right panel displays the impulse response function of economic development (DECO) following a shock to DEDU. The results show that economic development exhibits a positive response to higher education shocks, indicating that improvements in higher education promote fluctuations in economic development. Higher education enhances economic development by increasing research output, supplying high-quality talent, and elevating human capital levels. The lower left figure displays the impulse response function of economic development (DECO) following a shock to economic development. The results reveal that economic development itself exhibits a significant positive response, indicating that past economic fluctuations influence current economic fluctuations. The bottom-right figure displays the impulse response function of higher education development (DEDU) following an economic development (DECO) shock. Results indicate that higher education development (DEDU) exhibits a positive response to economic fluctuations, meaning that higher levels of economic development stimulate higher education growth. Faster economic growth provides greater financial

support for higher education and more robust educational infrastructure to support higher education advancement, thereby enhancing its development level.

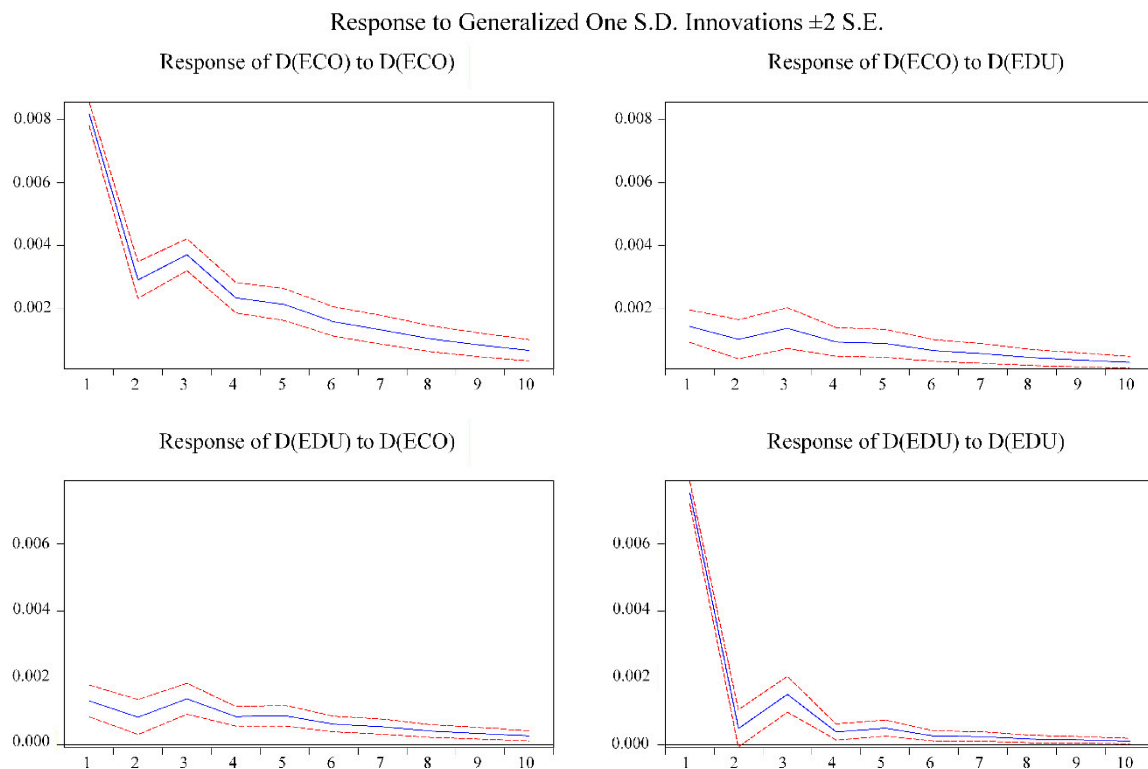


Figure 6. Impulse response between higher education development and economic development.

Comparing the four response patterns reveals an asymmetry that deserves further attention: the response of higher education to economic shocks is noticeably larger in magnitude than the response of the economy to higher education shocks. This asymmetry can be understood through the different transmission mechanisms involved. Economic fluctuations propagate almost immediately through local fiscal revenue, which directly determines the scale of higher education funding, infrastructure investment, and faculty recruitment—a short and direct transmission chain. By contrast, the contributions of higher education to the economy—through talent cultivation, research commercialization, and knowledge spillovers—exhibit substantial time lags: it takes at least four years for an undergraduate entrant to reach the labour market, and patent commercialization typically requires even longer horizons. This difference in transmission speed implies that, over short horizons, the economy’s capacity to reshape higher education is stronger than higher education’s capacity to propel the economy. Importantly, this finding does not contradict the bidirectional Granger causality result reported above; rather, it reveals that the bidirectional relationship is itself asymmetric in speed and magnitude—a nuance that static or symmetric models are unable to capture.

Driven by the need to accumulate human capital and enhance technological innovation, higher education has become a catalyst for economic growth. Conversely, economic development exerts a significant positive influence on higher education, creating a mutually reinforcing relationship where both sectors elevate each other. These results support hypothesis H2: although a bidirectional causal relationship holds, the magnitudes of the two directions differ substantially, and this asymmetry constitutes a defining feature of higher education–economy interaction in China’s coastal urban agglomerations.

To quantify the asymmetry formally rather than relying on visual inspection, Table 11 reports the forecast-error variance decomposition at horizons of 1, 4, 8, and 10 periods. At

the 4-period horizon, economic shocks account for 1.15% of the forecast-error variance in higher education, whereas higher-education shocks explain only 0.02% of the variance in economic development. This gap persists and is evident across all horizons, providing a formal, magnitude-based confirmation of the asymmetry suggested by the impulse-response functions. The 95% bootstrap confidence intervals for cross-variable responses (500 repetitions) indicate that the point estimate exhibits a larger systematic bias in the ECO→EDU direction, but the confidence intervals are wider and are significant only in the current period (Table A4), while the response of the economy to higher-education shocks is comparatively muted, with confidence bands that include values close to zero at longer horizons. The cumulative impulse responses further reinforce this finding: the total absolute effect of economic shocks on higher education is about 12 times larger than the reverse, and the signed cumulative ratio exceeds 32 (Table A5). As a further robustness check, we re-estimated the PVAR model separately for the Yangtze River Delta and the Pearl River Delta sub-samples; the asymmetry pattern holds consistently in both regions (Table A6).

Table 11. Forecast-error variance decomposition (FEVD) based on PVAR(2) model. Panel A. Response variable: $\ln(\text{econ})$; Panel B. Response variable: $\ln(\text{edu})$.

Forecast horizon	PVAR(1): own shock (%)	PVAR(1): shock from $\ln(\text{edu})$ (%)	PVAR(2): own shock (%)	PVAR(2): shock from $\ln(\text{edu})$ (%)
1	100.00	0.00	100.00	0.00
4	99.95	0.05	99.98	0.02
8	99.95	0.05	99.98	0.02
10	99.95	0.05	99.98	0.02
Forecast horizon	PVAR(1): own shock (%)	PVAR(1): shock from $\ln(\text{econ})$ (%)	PVAR(2): own shock (%)	PVAR(2): shock from $\ln(\text{econ})$ (%)
1	100.00	0.00	99.99	0.01
4	99.41	0.59	98.85	1.15
8	99.41	0.59	98.84	1.16
10	99.41	0.59	98.84	1.16

It is important to clarify that the Granger causality results and the variance decomposition results capture two distinct facets of the interaction. Granger causality tests measure whether one variable's past values help predict the other in a statistically reliable way; on this metric, higher education exhibits a more robust predictive relationship with the economy ($F = 7.2178$, $p < 0.01$) than the reverse ($F = 2.6505$, $p = 0.0713$). The forecast-error variance decomposition, by contrast, quantifies how much of each variable's unforecast fluctuation is transmitted from shocks to the other; on this metric, the magnitude of transmission from economic shocks to higher education exceeds the reverse by a substantial margin (1.15% vs. 0.02% at the four-period horizon). Taken together, these complementary results reveal a nuanced two-channel asymmetry: higher education exerts a more predictable, trend-based Granger-causal influence on the economy through human capital accumulation, while unforecast economic shocks transmit comparatively more strongly to higher education through the fiscal-budget channel. Both channels indicate that the bidirectional interaction is asymmetric rather than symmetric, but the asymmetry operates differently along predictable versus shock-driven dimensions.

5.2. Drivers of Coordinated Development Between Higher Education and Regional Economies in Coastal Urban Agglomerations

First, a pooled OLS regression model was established to test six explanatory variables, revealing that all significantly influenced the coordination index. The pooled OLS results

were used primarily for this preliminary variable screening; they are not reported in detail here due to the well-known omitted variable bias that can affect their consistency. Subsequently, the Hausman test was conducted to determine the appropriate specification for the panel data. The Hausman test statistic was 19.777 ($p = 0.003$), which passed the 1% significance level, thus selecting the fixed-effects model for analysis. The results reveal:

Before examining each variable individually, it is useful to compare the magnitudes of the estimated coefficients (Table 12). The coefficient on the share of higher-education fiscal expenditure in GDP ($x_3 = 1.1227$) is strikingly larger than those of the other explanatory variables, followed by the share of tertiary industry ($x_4 = 0.2632$) and urban residents' disposable income ($\ln x_2 = 0.0866$); the coefficients on per-capita GDP ($\ln x_1$), per-capita urban construction land ($\ln x_5$), and higher education scale (x_6) are markedly smaller. This pattern conveys an important substantive message: once economic conditions are held constant, proactive government investment in higher education—rather than objective economic endowment alone—is the most powerful lever for promoting coordinated development of the two systems. In other words, among cities with comparable economic foundations, the differences in higher education–economy coordination are driven primarily by policy choices rather than by structural conditions.

Table 12. Fixed Effects Model of the Coordination Degree between Higher Education and Regional Economic Development.

Explanatory Variables	Regression Coefficient	Standard Error	<i>p</i> -Value
$\ln x_1$	0.0134 ***	0.0022	0.000
$\ln x_2$	0.0866 ***	0.0038	0.000
x_3	1.1227 ***	0.1395	0.000
x_4	0.2632 ***	0.0116	0.000
$\ln x_5$	0.0139 ***	0.0031	0.000
x_6	0.0047 ***	0.0017	0.008
Constant	−0.1982 ***	0.0166	0.000
R^2	0.9588		
F-statistic, <i>p</i> -value	2518.47, 0.0000		

Notes: *** indicate statistical significance at the $p < 0.01$ levels, respectively.

The overall explanatory power of the model is high ($R^2 = 0.9588$; F-statistic highly significant). This is in part attributable to the effectiveness of the city fixed effects in absorbing stable, unobserved heterogeneity—such as historical education endowments, geographic location, and administrative rank—allowing the six observable variables to explain the remaining year-to-year and between-city variation with substantial precision.

Three substantive insights emerge from the fixed-effects results. First, policy support appears to be more important than economic endowment alone. Although per-capita GDP and disposable income are both positively associated with the coordination degree, the coefficient of higher-education fiscal expenditure share is substantially larger than those of the other variables. This suggests that economic prosperity does not automatically translate into higher education–economy coordination; rather, local governments must actively convert fiscal capacity into higher-education investment. Second, urbanization and industrial upgrading operate as a demand-side mechanism. The positive coefficients of tertiary-industry share and per-capita urban construction land indicate that coordinated development is more likely to occur where the urban economy generates sustained demand for skilled labour, innovation, and university–industry interaction. Third, the positive but relatively small coefficient of higher-education enrollment scale suggests that quantitative expansion alone has limited marginal effects. What matters is not only the number of

students, but whether the disciplinary structure, research capacity, and talent supply of universities are aligned with regional industrial demand.

Table 13 further examines the robustness of the baseline results by estimating a fixed-effects model with one-period lagged explanatory variables. The results show that the coefficients of lagged per-capita GDP (L.lnx1) and lagged per-capita disposable income (L.lnx2) are 0.0313 and 0.0643, respectively, and both are statistically significant, indicating that regional economic development and household income have persistent positive effects on the coordination between higher education and regional economic development. The coefficient of lagged higher-education fiscal expenditure share (L.x3) is 0.000002 and significant at the 5% level, suggesting that government fiscal support for higher education continues to promote coordinated development after controlling for city fixed effects and city-clustered robust standard errors. In contrast, the coefficients of lagged tertiary industry share (L.x4), lagged per-capita urban construction land (L.lnx5), and lagged higher-education enrollment scale (L.x6) are not statistically significant, implying that their lagged effects are relatively limited. Overall, the lagged-variable robustness test supports the core findings of the baseline regression: economic development, income level, and fiscal support for higher education are important drivers of the coordinated development of higher education and the regional economy.

Table 13. Lagged explanatory variables robustness test.

Variable	Regression Coefficient	Standard Error	p-Value
L_lnx1	0.031310 **	0.0135	0.023
L_lnx2	0.064289 ***	0.0146	<0.001
L_x3	0.000002 **	0.000001	0.044
L_x4	0.052811	0.0367	0.153
L_lnx5	−0.030129	0.0341	0.380
L_x6	−0.000000	0.000001	0.525

** and *** indicate statistical significance at the 5% and 1% levels, respectively. Specifically, ** $p < 0.05$ and *** $p < 0.01$.

The lagged-variable robustness test further refines this interpretation. The lagged effects of economic development, household income, and fiscal support remain statistically significant, indicating that these factors exert persistent influence on coordination. By contrast, the lagged coefficients of tertiary-industry share, per-capita urban construction land, and enrollment scale are not significant, suggesting that their effects are more conditional and contemporaneous. This reinforces the central argument that sustained coordination depends less on one-off expansion and more on the continuous institutional conversion of economic resources into higher-education capacity. ** and *** indicate statistical significance at the 5% and 1% levels, respectively. Specifically, ** $p < 0.05$ and *** $p < 0.01$.

6. Exploring Synergistic Pathways for Higher Education and Economic Development in China's Coastal Urban Agglomerations

6.1. Synergistic Development of Higher Education and Economic Growth in China's Coastal Urban Agglomerations

This study's empirical analysis yields three interconnected core findings. First, bidirectional Granger causality exists between higher education and economic development across China's coastal urban agglomerations, confirming that neither sector develops in isolation. Second, this bidirectional relationship is asymmetric: economic fluctuations exert a stronger short-term influence on higher education than higher education exerts on the economy, indicating that the two operate on different temporal horizons. Third, the degree

of coupling coordination is driven by a constellation of structural factors—economic development level, government fiscal support, urbanization, and higher education scale—that jointly shape the conditions under which higher education and the regional economy can develop in tandem. These findings collectively point to a relationship that is neither static nor unidirectional, but dynamic, context-dependent, and spatially uneven across the seven coastal urban agglomerations studied.

The findings of this paper refine two well-established theoretical traditions. First, Schultz’s [25] human capital theory emphasizes the unidirectional promoting effect of education on economic growth. While our PVAR results confirm this mechanism, they also reveal a more complex picture: in the context of China’s coastal urban agglomerations, the short-term reverse-shaping effect of the economy on higher education is in fact stronger than the forward-promoting effect of education on the economy. This suggests that, for developing economies in rapid transition, the education–economy relationship is not a simple ‘education-leads’ model but rather a composite pattern in which ‘economy-pulls-and-education-adapts’ and ‘education-pushes-and-economy-upgrades’ operate concurrently, with different dominant horizons. Second, standard regional equilibrium theories predict a convergence of factor distributions—including education resources—across space, typically through geographic diffusion from leading centres. Yet our longitudinal evidence shows that between 2008 and 2021, the absolute disparities in higher education among coastal cities widened rather than narrowed, in tension with the convergence hypothesis. Moreover, our spatial-autocorrelation results (Section “Spatial Autocorrelation”) indicate that this divergence is not the outcome of geographic diffusion being overwhelmed by stronger agglomeration forces, but rather of a transmission mechanism that is fundamentally institutional rather than geographic: higher-education resources flow primarily through administrative channels that are not bounded by geographic proximity. The implication is that, within China’s coastal urban agglomerations during this period, institutionally concentrated allocation has governed the spatial evolution of higher education, producing a Matthew-effect pattern that conventional spatial-spillover models do not capture.

These findings carry broader relevance for understanding education–economy dynamics within China’s modernization process. As key drivers of national high-quality economic development, coastal urban agglomerations serve simultaneously as engines of growth and as laboratories for structural reform. The asymmetry documented here—whereby economic development shapes higher education more rapidly in the short run than education transforms the economy—has direct implications for how policymakers sequence interventions. It suggests that in regions where economic strength has outpaced educational development, as is evident in the Pearl River Delta, targeted investment in higher-education capacity is not merely a social objective but a precondition for sustaining economic upgrading. Moreover, the Matthew-effect pattern identified in the spatial evolution of higher-education resources underscores the need for deliberate redistribution policies within urban agglomerations, rather than reliance on market-led convergence alone [7,16,26].

6.2. Differences in the Coordination of Higher Education and Economic Development Among China’s Coastal Urban Agglomerations

Research findings indicate that during the study period, both higher education levels and economic development levels rose across all coastal urban agglomerations in China. Among them, the Shandong Peninsula, Beijing–Tianjin–Hebei, and Yangtze River Delta urban agglomerations experienced the most significant increases in higher education levels. This suggests that these coastal urban agglomerations have developed higher education more rapidly than others and invested more heavily in education. This is attributable to these regions being China’s most economically dynamic areas, possessing

robust economic strength and fiscal support that provide ample material guarantees for higher education. Furthermore, their relatively advanced industrial structures and demand for highly skilled talent have prompted local governments and enterprises to place greater emphasis on investing in higher education and cultivating talent. The human capital theory proposed by American economist Theodore Schultz in the 1960s emphasized the central role of higher education in economic growth. Higher education directly or indirectly contributes to economic growth by enhancing human capital levels. In regional economic development, it is evident that the Beijing–Tianjin–Hebei, Yangtze River Delta, and Pearl River Delta urban clusters exhibit the highest levels of economic growth. This is largely due to the significant spillover effects from the economic development of their central cities—Beijing, Shanghai, Guangzhou, and Shenzhen—which drive growth in surrounding areas, demonstrating a distinct spillover effect consistent with other research findings. For instance, previous studies have highlighted significant disparities in higher education competitiveness across China’s coastal regions, characterized by uneven spatial distribution. Economic development emerges as the primary factor, with a strong positive correlation observed between coastal regions’ higher education competitiveness and their economic growth [27].

Notably, higher education and regional economic development in the Pearl River Delta (PRD) cluster are out of sync. To move beyond a narrative characterization, Table 14 compares the Pearl River Delta and the Yangtze River Delta directly. Despite comparable per-capita GDP, the PRD’s higher-education fiscal expenditure as a share of GDP (0.02% vs. 0.44%) and its university density (1.44 vs. 2.2 institutions per million residents) both trail the YRD, while its economic index is comparable. This quantitative gap substantiates the ‘rich-but-education-weak’ characterization: the PRD’s economic strength is not matched by a commensurate higher education base, confirming a genuine structural misalignment rather than a mere difference in development stage. The PRD case is not a simple case of underdevelopment, but a case of institutional conversion failure: strong economic capacity has not been effectively converted into proportional higher-education capacity. It is important to emphasize, however, that the structural misalignment observed in the Pearl River Delta is qualitatively different from the education backwardness observed in China’s central and western regions. The latter is a ‘low-economy–low-education’ synchronous under-development; the former is a structural mismatch in which a highly developed economy coexists with comparatively underdeveloped higher education—a ‘rich-but-education-weak’ pattern. These two patterns have distinct formation mechanisms, distinct policy implications, and require fundamentally different governance responses.

First, this stems from the relatively weak historical foundation of higher education in the PRD region, where higher-education resources have failed to fully adapt to the demands of economic development. The PRD pattern is strongly path-dependent. In the early reform era, the Pearl River Delta achieved rapid economic take-off through the ‘Three-Plus-One’ export-processing model, which depended on labour-intensive, external-oriented manufacturing. This model generated limited demand for highly skilled labour, and over time produced an institutional inertia in which economic growth was decoupled from local higher-education capacity. Compared with the Yangtze River Delta—whose upgrading drew on long-standing manufacturing traditions in Jiangsu and Zhejiang and was reinforced by deep industry–university–research integration—the PRD began its strategic investment in higher education comparatively late and from a thinner base. Even during the accelerated industrial upgrading of the past decade, the response of the higher education system has remained visibly lagging. Second, substantial disparities exist among cities within the Pearl River Delta cluster, leading to uneven distribution of higher-education resources. Existing research indicates that Guangdong’s higher-education resources are

concentrated in central cities, with other provincial cities only beginning to develop higher education in the 1980s [28]. Compared with coastal provinces like Zhejiang, Shandong, Jiangsu, and Liaoning—which share Guangdong’s dual-center city development model—Guangdong exhibits greater imbalance in higher education across its cities. This reflects the spatial imbalance between higher education and economic development in China’s coastal urban clusters.

Table 14. Key indicator comparison: YRD vs. PRD.

Indicator	YRD Mean	PRD Mean	PRD/YRD Ratio	Difference	<i>t</i> -Sat	<i>p</i> -Value	Sig.
GDP per capita (10,000 yuan)	12.89	11.26	0.87	−1.62	−1.06	0.3103	
Tertiary industry share (%)	49.1	50.26	1.02	1.16	0.26	0.7996	
Edu expenditure/GDP (%)	0.44	0.02	0.05	−0.42	−3.5	0.0019	***
R&D expenditure/GDP (%)	1.9	2.71	1.42	0.8	1.35	0.1964	
Universities per million pop.	2.2	1.44	0.65	−0.76	−1.62	0.1259	
Students per 100,000 pop.	3125.58	2332.33	0.75	−793.26	−0.76	0.4609	
R&D per university (100 million yuan)	12.8	36.84	2.88	24.04	1.79	0.1091	
Patents per 10,000 pop.	18.99	3.75	0.2	−15.24	−3.34	0.0025	***
Publications per university	21.07	1.02	0.05	−20.06	−2.77	0.0108	**

Notes: YRD N = 24, PRD N = 9. *t*-test with unequal variances. Green = significant difference ($p < 0.10$). Blue highlight = PRD advantage (>10% gap); Green highlight = YRD advantage (>10% gap). Interpretation: YRD is significantly stronger in: Edu expenditure/GDP (%), Patents per 10,000 pop., Publications per university. No statistically significant difference in: GDP per capita (10,000 yuan), Tertiary industry share (%), R&D expenditure/GDP (%), Universities per million pop., Students per 100,000 pop., R&D per university (100 million yuan). ** and *** indicate statistical significance at the 5% and 1% levels, respectively. Specifically, ** $p < 0.05$ and *** $p < 0.01$.

This case also illustrates, from the reverse direction, the central finding of our fixed-effects regression that government fiscal support is the most influential driver of coordination. The Pearl River Delta has long been characterized by a high degree of marketization and a comparatively restrained role for government in the strategic allocation of higher-education resources. This “market-centred, education-light” governance tradition has in effect accentuated the structural mismatch between higher education supply and industrial demand, showing that the absence of proactive public investment—even in an otherwise economically thriving region—is sufficient to suppress coordinated development. This interpretation is further supported by the spatial-autocorrelation analysis in Section “Spatial Autocorrelation”: while the PRD region itself sits adjacent to Hong Kong and Macao and is geographically embedded within a strongly clustered economic development zone, its higher-education capacity has not benefitted commensurately from geographic spillover, precisely because higher-education resource allocation operates through administrative channels (in this case, Guangdong’s provincial higher-education policy) rather than through inter-city geographic diffusion. The PRD case thus provides a concrete illustration of why economic strength does not automatically translate into commensurate higher education development: in the absence of proactive provincial- or central-level fiscal intervention, even the most economically integrated region cannot rely on market-driven spillover to redistribute higher-education capacity. According to economic geography’s location

theory, spatial location factors—including economic, political, cultural, and demographic conditions—significantly influence higher education development. The location selection and spatial layout of higher education institutions must fully consider these factors. This underscores that restructuring higher education distribution requires adapting to new trends in population structure and industrial layout to establish a new regional higher education model.

6.3. Policy Recommendations for Synergistic Pathways of Higher Education and Economic Development in China's Coastal Urban Agglomerations

Addressing the imbalance and lack of coordination between higher education and regional economic development in certain areas of China's coastal urban agglomerations, the following policy recommendations are proposed:

6.3.1. Strengthen Top-Level Design and Strategic Coordination to Establish an Integrated Development Mechanism

Building on the PVAR evidence that economic shocks propagate to higher education more rapidly than the reverse, the absence of a coordinating mechanism risks producing cyclical decoupling rather than sustained synergy. To address this risk, we recommend that, within the framework of national and regional development strategies, a cross-provincial, cross-departmental committee for coordinating higher education and economic development planning be established. This committee would be responsible for formulating integrated plans linking the development of science, education, and industrial layout within urban clusters, ensuring that the scale, structure, and direction of higher education development align with regional economic strategic objectives. Simultaneously, refine the evaluation system for coordinated development by incorporating metrics such as higher education's contribution rate to regional innovation, local employment rates of graduates, and the rate of local conversion of scientific and technological achievements into practical applications into the performance assessment systems of local governments and universities. This will guide the concentration of educational resources toward key areas serving regional development.

6.3.2. Optimize the Allocation of Higher-Education Resources to Promote Regional Balance and Distinctive Development

Given our longitudinal finding that absolute disparities among coastal cities have widened over 2008–2021 (with the standard deviation of higher education scores rising from 0.068 to 0.114), and in light of the resource misallocation pattern illustrated by the Pearl River Delta case, the spatial allocation of higher-education resources requires targeted rebalancing. Specifically, cities should formulate development strategies tailored to their specific regional characteristics. Through policy support and fiscal transfer payments, greater assistance should be directed to regions with relatively underdeveloped higher education systems, such as the Central-Southern Liaoning region and the Beibu Gulf region.

Efforts should be made to encourage the establishment of branch campuses by leading universities, the joint construction of specialized colleges, and industry–university–research consortia. Because, as documented in Section “Spatial Autocorrelation”, higher-education resources do not diffuse spontaneously through geographic proximity in the Chinese context, such inter-city redistribution requires deliberate institutional coordination—joint planning agreements, fiscal cost-sharing mechanisms, and policy-mandated faculty-exchange schemes—rather than reliance on market-driven spillover alone. Universities within urban agglomerations should refine their disciplinary orientations in accordance with local industrial endowments and development demands to avoid homogeneous competition. Meanwhile, economically stronger core cities within urban agglomerations should facili-

tate the policy-mediated transmission of higher-education capacity to neighbouring cities through formal alliance arrangements, promote the cross-jurisdictional mobility of talent and capital, and foster a mutually beneficial relationship between higher education and regional economic development. These measures will help gradually reduce inter-city disparities and steadily accomplish the strategic objective of optimizing the spatial layout and resource allocation of higher-education clusters during the Fourteenth Five-Year Plan period.

6.3.3. Promote Supply-Side Reform in Talent Cultivation to Precisely Meet Industrial Development Needs

Our fixed-effects estimates indicate that the coefficient on the higher education scale (x_6) is statistically significant but small in magnitude, suggesting that quantitative expansion alone yields limited marginal gains and that structural alignment with industrial demand is the binding constraint. Supply-side reform of talent cultivation should therefore focus on structural alignment with industrial demand. The transformation of scientific and technological achievements is crucial for realizing the market value of educational strength and serves as the foundation for leveraging scientific and educational capabilities to support economic development. The “Reform Plan for Adjusting and Optimizing Discipline and Major Settings in General Higher Education” proposes optimizing approximately 20% of university discipline and major distributions by 2025, refining discipline development and systems, and encouraging universities, research institutions, and enterprises to jointly develop innovative technologies, cultivate scientific research talent, and promote the integrated development of higher education and regional economies. By establishing a demand-driven dynamic adjustment mechanism and creating an early warning system linking discipline/major offerings to regional industrial needs, regular reports on talent demands in key industries will be published. Universities will be supported to prioritize developing majors related to strategic emerging industries such as next-generation information technology, biomedicine, and new energy/materials, while phasing out programs that fail to meet societal needs. Enterprises will be encouraged to deeply engage in designing talent cultivation plans, curriculum development, and practical teaching, jointly establishing a cohort of high-level, shared internship and training bases for college students to enhance their practical skills and professional competence.

6.3.4. Strengthen Intra-Urban Cluster Coordination to Enhance Higher Education Clustering Effects

In response to the within-agglomeration coordination weaknesses identified in our analysis—and in particular the pronounced gap between core and peripheral cities in higher-education resources—intra-agglomeration coordination mechanisms should be strengthened. Specifically, building an open and inclusive regional talent ecosystem is fundamental to achieving a virtuous cycle of government–industry–academia–research collaboration. Promoting regional integration hinges on facilitating unimpeded talent mobility through institutional innovations that establish unified, open regional talent markets. Promote the establishment of a “university alliance” within the urban cluster to achieve in-depth cooperation in areas such as mutual faculty appointments, course sharing, credit recognition, and shared use of large-scale instruments and equipment. This will enhance the overall strength and resource utilization efficiency of regional higher education. Remove administrative barriers and institutional obstacles to talent mobility, and establish a unified, open regional talent market. Implement a more flexible dual-appointment system, encouraging university faculty to take part-time positions in enterprises while enabling high-level corporate talent to teach at universities, thereby creating a “revolving door” mechanism.

Among our findings, the most actionable for policy is the demonstrated asymmetry: because economic shocks transmit to higher education far faster than the reverse, higher education planning in coastal agglomerations is structurally reactive and lags the economic cycle. The single most effective intervention implied by our fixed-effects results is therefore to strengthen counter-cyclical, rule-based fiscal commitment to higher education—insulating education budgets from short-run economic fluctuations—since government fiscal support, not economic endowment, is the dominant driver of coordinated development.

6.4. Limitations and Future Research

Several limitations should be borne in mind when interpreting our findings. First, the data period ends in 2021 and therefore does not capture the subsequent impact of the COVID-19 pandemic on higher education and regional economies; as updated data become available, follow-up work can revisit the patterns identified here. Second, the composite indices rely on entropy weighting, which is sensitive to sample composition, and indicator weights may vary modestly across different time cross-sections. Third, the classification thresholds of the coupling coordination degree model carry a degree of subjectivity, and the robustness of the results to alternative threshold specifications warrants further verification. Fourth, although the lagged-variable robustness check and the bias-direction analysis in Section 5.2 mitigate concerns about simultaneity, residual endogeneity cannot be fully ruled out given the panel dimensions ($T = 14$). A full system GMM or instrumental variable treatment, ideally with an external instrument for higher education investment, is an important direction for future research. Finally, our focus on coastal urban agglomerations means the generalizability of the findings to inland urban agglomerations remains an open empirical question that future work should examine.

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Appendix A. Supplementary Results for CCD Threshold Sensitivity Analysis

Table A1. Five-tier equal-interval classification scheme.

Rank	D Range	Classification	2008 N	2013 N	2017 N	2021 N
1	0.0–0.2	Disorder	3	4	9	10
2	0.2–0.4	Mild disorder	46	52	51	55
3	0.4–0.6	Transitional	29	23	20	18
4	0.6–0.8	Coordination	10	9	8	5
5	0.8–1.0	High coordination	2	1	2	2

Table A2. Sensitivity comparison between ten-tier and five-tier classifications.

Ten-Tier\Five-Tier	Disorder	Mild Disorder	Transitional	Coordination	High Coordination	Total
Extreme disorder	2	0	0	0	0	2
Severe disorder	8	0	0	0	0	8
Moderate disorder	0	30	0	0	0	30
Mild disorder	0	25	0	0	0	25
Near disorder	0	0	13	0	0	13
Reluctant coordination	0	0	5	0	0	5
Primary coordination	0	0	0	4	0	4
Intermediate coordination	0	0	0	1	0	1
Good coordination	0	0	0	0	0	0
High-quality coordination	0	0	0	0	2	2
Total	10	55	18	5	2	90

Spearman ρ (10-tier vs. 5-tier): 0.9192 ($p < 0.001$). Mean absolute rank difference: 9.28 (out of 90). Conclusion: Ranking of cities is insensitive to threshold choice $\rightarrow$ findings are robust.

Table A3. C, T, and D values for key coastal urban agglomerations, 2021.

Urban Agglomeration	N	Coupling Degree	Development Degree	Coordination Degree	Median D	Std. Dev. of C	Std. Dev. of T
Yangtze River Delta	24	0.8727	0.2519	0.4526	0.4077	0.0868	0.1688
Pearl River Delta	9	0.8128	0.2214	0.4111	0.4111	0.0783	0.1381
Beijing–Tianjin–Hebei	14	0.8928	0.2275	0.4209	0.3509	0.0978	0.2362
Other	43	0.8403	0.1484	0.3440	0.3173	0.1656	0.0857

Appendix B. Additional Results for Asymmetry Analysis

Table A4. Period-by-period impulse response magnitudes and bootstrap p -values (500 replications).

Horizon	ECO->EDU	EDU->ECO	Ratio	Dominant	Bootstrap p
0	0.001461	0	-	ECO->EDU >	0.0000 ***
1	0.001567	0.000644	2.43	ECO->EDU >	0.3400
2	0.013579	0.000876	15.51	ECO->EDU >	0.1460
3	0.003761	0.000235	16.01	ECO->EDU >	0.1640
4	0.001223	0.000074	16.63	ECO->EDU >	0.1800
5	0.000454	0.000026	17.81	ECO->EDU >	0.1960
6	0.000217	0.000013	16.91	ECO->EDU >	0.1680
7	0.000088	0.000005	16.79	ECO->EDU >	0.1600
8	0.000035	0.000002	16.84	ECO->EDU >	0.1500
9	0.000014	0.000001	16.97	ECO->EDU >	0.1720
10	0.000006	0	16.93	ECO->EDU >	0.1580

Notes: *** indicates statistical significance at the 1% level, i.e., *** $p < 0.01$.

Table A5. Cumulative impulse response magnitudes.

Metric	ECO->EDU	EDU->ECO	Ratio
Cumulative IRF (IRF magnitude)	0.022404	0.001874	11.95
Signed cum IRF	−0.01927	−0.000587	32.81

Table A6. Sub-sample impulse response comparison: YRD versus PRD. Panel A. ECO → EDU impulse responses; Panel B. EDU → ECO impulse responses.

h	YRD ECO->EDU	PRD ECO->EDU	Difference	p-value
0	0.0172	−0.0244	0.0416	0.2180
1	−0.0091	−0.0044	−0.0047	0.6240
2	−0.0005	−0.0006	0.0002	0.4900
3	0.000051	−0.000007	0.000057	0.5260
4	0.000005	0.000054	-4.9×10^{-5}	0.4860
5	0	0.000036	-3.6×10^{-5}	0.5120
6	0	0.000019	-1.9×10^{-5}	0.4520
7	0	0.000009	-9×10^{-6}	0.4960
8	0	0.000004	-4×10^{-6}	0.4560
9	0	0.000002	-2×10^{-6}	0.4840
10	0	0.000001	-1×10^{-6}	0.4520

h	YRD EDU->ECO	PRD EDU->ECO	Difference	p-value
0	0	0	0	1.0000
1	0.01	−0.0029	0.0129	0.2680
2	0.0004	−0.0019	0.0023	0.4220
3	−0.000061	−0.001	0.0009	0.4420
4	−0.000005	−0.0005	0.0005	0.4580
5	0	−0.0002	0.0002	0.4820
6	0	−0.0001	0.0001	0.4840
7	0	−0.000046	0.000046	0.5000
8	0	−0.000021	0.000021	0.4860
9	0	−0.00001	0.00001	0.4980
10	0	−0.000004	0.000004	0.4920

Appendix C. Robustness of Entropy Weighting

Table A7. Spearman correlations: entropy vs. alternative weights.

Metric	ECO (Economic Development)	EDU (Higher Education)
Equal-weight vs. Original: mean rho	0.9765	0.9216
Equal-weight vs. Original: min rho	0.9493	0.8718
PCA-weight vs. Original: mean rho	0.9812	0.9416
PCA-weight vs. Original: min rho	0.9673	0.9286
Random-weight: mean rho (2000 × 14y)	0.8883	0.8815
Random-weight: 90% CI lower	0.6614	0.7038
Random-weight: 90% CI upper	0.974	0.972
Random-weight: min rho (all draws)	−0.0747	0.3287
Random-weight: % rho > 0.90	0.65	0.5389

ECO (Economic development): Mean per-year rho (equal-weight vs. original) = 0.9765. In total, 65.0% of random-weight draws produce rho > 0.90. Mostly robust. EDU (Higher education): Mean per-year rho (equal-weight vs. original) = 0.9216. In total, 53.9% of random-weight draws produce rho > 0.90. Mostly robust.

Appendix D. Dynamic Panel GMM Robustness Test

Table A8. Dynamic panel GMM robustness test for coupling coordination.

Variable	Definition	Baseline System GMM	Extended Instrument Lags
L.D_coord	Lagged coordination degree	1.0173 *** (0.0500)	1.0439 *** (0.0165)
lnx1	Per-capita GDP	−0.0007 (0.0038)	0.0004 (0.0026)

Table A8. Cont.

Variable	Definition	Baseline System GMM	Extended Instrument Lags
lnx2	Average wage; proxy for disposable income	−0.0012 (0.0023)	−0.0089 *** (0.0011)
x3	Higher-education fiscal expenditure/GDP	0.0001 *** (8.87×10^{-6})	0.0001 *** (2.36×10^{-6})
x4	Tertiary-industry share	−0.0365 (0.0240)	−0.0201 ** (0.0098)
lnx5	Urbanization rate; proxy for urban construction land	0.0085 (0.0057)	0.0256 *** (0.0023)
x6	Higher-education enrollment scale	3.96×10^{-9} (2.00×10^{-8})	-2.37×10^{-8} *** (7.25×10^{-9})
AR(1) <i>p</i> -value	First-order serial correlation test	0.0000	--
AR(2) <i>p</i> -value	Second-order serial correlation test	0.5017	0.7556
Hansen J <i>p</i> -value	Overidentifying restrictions	0.9997	1.0000
Diff-in-Hansen <i>p</i> -value	Additional moment conditions in level equation	1.0000	--
Observations	Difference and level equations combined	2152	2152
Cities	Number of cross-sectional units	90	90
Instruments	Collapsed instrument count	14	28
Overidentification restrictions	Instruments minus estimated parameters	7 (=14 − 7)	21

Notes: Coefficients are reported with significance stars, and city-clustered robust standard errors are shown in parentheses. ** $p < 0.05$, *** $p < 0.01$. The baseline specification uses collapsed t-2 instruments; the extended specification adds t-3 lags. AR(1) is expected to be significant, AR(2) and Hansen tests should be insignificant. lnx2 and lnx5 use the proxy definitions available in the source workbook.

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