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Educational responsiveness to industrial upgrading: a longitudinal evaluation of higher vocational education in Shandong

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ABSTRACT

Shandong provides a concrete case for examining whether higher vocational education (HVE) can keep pace with industrial upgrading. Since the new and old kinetic energy conversion (NOKEC) strategy began in 2018, provincial policy has prioritized high-tech manufacturing and the "ten strong industries," while HVE program structures have adjusted more slowly. This study evaluates the coordination between industrial upgrading and HVE program structure across 16 prefecture-level cities from 2016 to 2023. A dual-system indicator framework was built from official statistical yearbooks, education quality reports, and provincial bulletins. After min-max standardization, the entropy weight method (EWM), coupling coordination degree (CCD) model, and obstacle degree model were used to measure temporal evolution, spatial variation, and main constraints. The results show that coordination improved from marginal to good, but the HVE subsystem remained below the industrial subsystem throughout the period. Qingdao, Jinan, and Yantai reached high-quality coordination, while Heze remained relatively constrained. Graduate employment in strategic industries was the leading obstacle factor. The findings suggest that curriculum renewal, teacher development, enterprise co-designed modules, and graduate tracking should be strengthened to improve HVE responsiveness to regional industrial change.

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1. INTRODUCTION

The effectiveness of vocational education systems is increasingly judged by a practical question: can program structures, curricula, and talent-development routines keep up with changing industrial demand? [1], [2]. For higher vocational education (HVE), the fourth industrial revolution makes this question harder to treat as a slogan. Curriculum responsiveness, graduate employability, and quality assurance have to be examined against shifting occupational requirements, not only against enrollment scale or institutional expansion. Shandong Province is a useful case because the new and old kinetic energy conversion (NOKEC) strategy, launched in 2018, gave explicit priority to high-tech manufacturing and the "ten strong industries" [3], [4]. That policy shift pushed HVE institutions toward program revision, course updating, faculty development, and renewed talent-cultivation pathways for advanced, interdisciplinary, and digital technical work [5], [6].

The difference in speed matters. Curriculum planning and program approval are shaped by institutional routines, quality-control procedures, and inherited path dependence [7], [8]. In Shandong, part of the program structure still reflects traditional heavy-industry fields, while strategic sectors require more digital, interdisciplinary, and technology-intensive skill sets [9]. The mismatch is concrete rather than only conceptual. Some graduates are prepared for occupational spaces that are no longer expanding quickly. Emerging-sector employers, meanwhile, ask for competencies that have not yet been embedded deeply in programs. Prior studies show that curriculum design, faculty development, and educational planning affect graduate competence and labor-market outcomes [8], [10]. What those studies leave less visible is the pace of adjustment: how long it takes a regional HVE system to respond once industrial demand has already changed [11]–[14].

Much of the existing literature treats vocational education and industrial upgrading as separate policy or economic domains [7], [15]. What remains difficult to see is the temporal pattern of HVE responsiveness and the specific educational dimensions that become constraints once industry-education alignment is measured regionally [16]. This article addresses that problem by combining human capital theory, the regional economy-industrial structure- program structure (REP) Helix model, and system dynamics [5]. The theoretical work is deliberately limited. It links human-capital formation with regional educational responsiveness, treats delayed curriculum renewal and faculty retraining as possible sources of localized human-capital depreciation, and translates the REP Helix into indicators that can be examined empirically. The longitudinal design then asks whether the time-lag effects predicted by system dynamics appear in HVE program adaptation. Three questions guide the analysis:

- How did coupling coordination between industrial upgrading and HVE program structures evolve in Shandong from 2016 to 2023?
- How was this coordination distributed across the 16 prefecture-level cities?
- Which obstacle factors most restricted the coordinated development of the two systems?

Figure 1 presents the conceptual framework, linking macro-level industrial upgrading, REP Helix interactions, HVE program adaptability, human-capital investment, and talent supply efficiency [11], [17]–[19].

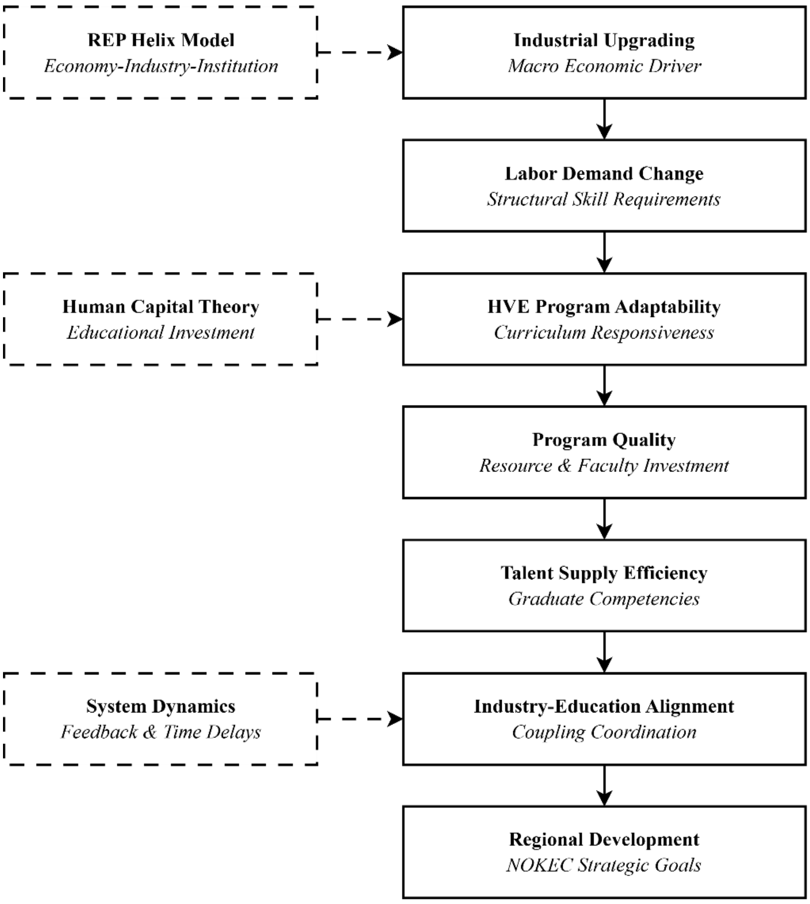

Figure 1. Integrated conceptual framework

2. METHOD
2.1. Research design
This article uses a longitudinal quantitative design based on panel data for 16 prefecture-level cities in Shandong from 2016 to 2023. Figure 2 shows the empirical procedure. The first phase screened, cleaned, and standardized the indicators. The second phase applied the entropy weight method (EWM) to calculate objective weights and construct the two subsystem indices. The third phase used the coupling coordination degree (CCD) model and the obstacle degree model to evaluate system interaction and locate bottleneck indicators. Data pre-processing, min-max standardization, and EWM calculation were conducted in MATLAB R2023a. CCD and obstacle calculations were completed in the same environment, and one-way analysis of variance (ANOVA) in IBM SPSS Statistics 27 was used to test spatial differences among economic circles [7], [20], [21].

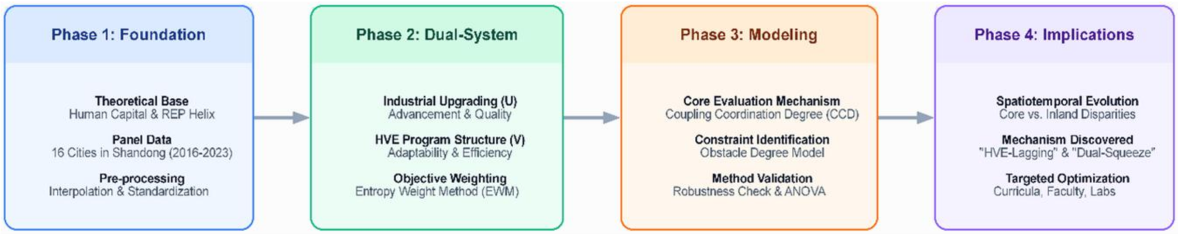

Figure 2. Comprehensive research flowchart outlining data processing, mathematical modeling, and spatial diagnostic phases

2.2. Study context and data sources
The study focuses on Shandong Province from 2016 to 2023, a period that covers both the pre-NOKEC baseline and the years after the comprehensive pilot zone was launched in 2018 [3]. The sample includes all 16 prefecture-level cities and is grouped into three economic circles: Jiaodong, Provincial Capital, and Southern Shandong. Data came from three source groups: the Shandong statistical yearbook (2017–2024) [22]–[29]; China Statistical Yearbook [30]; and annual quality reports of higher vocational colleges in Shandong [31] together with official bulletins from the Shandong Provincial Department of Education [31]. Missing values accounted for less than 5% of the dataset and appeared mainly in Heze and Dezhou during 2016–2017. Linear interpolation was used to maintain the panel structure. A robustness check excluding the imputed values changed final coordination metrics only negligibly (delta<=0.003).

2.3. Indicator system construction
Following the conceptual framework and the principles of scientific, systematicity, and data availability, the study constructs a dual-system indicator system. Indicator selection is grounded in the regional economy-industrial structure- program structure (REP) Helix model [3], [4] and human capital theory [1], [5], [6]. The industrial subsystem is tied to the “ten strong industries” specified in Shandong’s NOKEC strategy, while the HVE subsystem captures program adaptability, construction quality, and talent supply efficiency. For example, high-tech manufacturing value added (U12) represents demand for advanced technical skills, whereas the dual-teacher faculty ratio (V22) indicates whether colleges have the teaching capacity to support practice-oriented training. Some micro-level variables were left out. Graduate satisfaction and wage outcomes would be useful, but comparable longitudinal data were not available for all 16 cities, and subjective reporting bias would be difficult to control. For that reason, Tables 1 and 2 rely on verifiable macro-structural indicators.

2.4. Methodological justification
The raw indicators used different units and directions. They were standardized with the extreme value method, and EWM was then used to assign weights from observed city-year variation. This keeps the index data-driven, although the choice of indicators still reflects the theoretical framework [7], [20].

2.5. CCD model
After weighting, industrial upgrading (U) and HVE program structure (V) were calculated by linear aggregation. The coupling degree (C) model then described how closely the two subsystems moved together. Here, C is read as interdependence, not as proof of one-way causality [7], [20], [21]. C alone can be misleading. Two weak systems may still appear tightly coupled. The D model was added because it reads

interaction together with development level, asking whether industrial upgrading and HVE program structures are moving together at a comparable standard [20], [21].

Within this coordination framework, T represents the comprehensive coordination index, while alpha and beta represent the contribution coefficients of the industrial and educational subsystems. Both coefficients are set at 0.5 in the baseline model, reflecting the assumption that industrial innovation and HVE program structures are jointly necessary for regional high-quality development. Sensitivity checks using alternative coefficient settings confirmed that city rankings and development grades remained stable. Grades run from extreme incoordination [0.000-0.099] to high-quality coordination [0.900-1.000] [20].

Table 1. Conceptual mapping of the dual-system evaluation framework

System	Dimension	Theoretical foundation	Justification for selection
Industrial upgrading (U)	Industrial structure advancement (U1) and rationalization (U2)	Structural transformation theory	Measures the macro-shift from traditional to high-value-added sectors, directly reflecting the core structural mandate of the NOKEC strategy.
	Industrial development quality (U3)	Endogenous growth theory	Captures the internal innovation capacity and sustainability (R&D, patents) necessary to drive new kinetic energy.
HVE program structure (V)	Program structure adaptability (V1)	REP helix model (demand-pull)	Assesses how quickly educational supply responds to shifting industrial demand, capturing the system's structural agility and alignment.
	Program construction quality (V2)	Human capital theory	Evaluates the strategic investment in educational resources (faculty, industry co-development) required to produce high-skill talent.
	Talent supply efficiency (V3)	Labor market matching theory	Measures the ultimate effectiveness of HVE output in fulfilling the specific structural talent gaps of strategic emerging industries.

Table 2. Evaluation indicator system for industrial upgrading and HVE program structure dual system

System	Dimension	Indicator	Indicator attribute	Weight (%)
Industrial upgrading system (U)	Industrial structure advancement (U1)	U11: share of tertiary industry in GDP (%)	Positive	7.10
		U12: share of high-tech manufacturing in industrial output value (%)	Positive	21.30
		U13: share of "ten strong industries" in industrial output value (%)	Positive	21.40
		U14: ratio of output value of emerging industries to traditional industries	Positive	7.60
	Industrial structure rationalization (U2)	U21: Theil index of industrial structure	Negative	5.40
		U22: labor productivity of secondary and tertiary industries (yuan/person)	Positive	4.40
		U23: coordination degree between industrial structure and employment structure	Positive	4.10
	Industrial development quality (U3)	U31: R&D expenditure intensity of industrial enterprises (%)	Positive	17.20
		U32: number of invention patents per 10,000 industrial employees	Positive	3.30
		U33: energy consumption per unit of GDP (tons of standard coal/10,000 yuan)	Negative	3.40
		U34: total factor productivity growth rate of industrial enterprises (%)	Positive	4.80
HVE program structure system (V)	Program structure adaptability (V1)	V11: coverage rate of programs corresponding to "ten strong industries" (%)	Positive	15.50
		V12: matching degree between program enrollment scale and industrial employment scale	Positive	3.70
		V13: proportion of enrollment in emerging industry-related programs (%)	Positive	3.90
		V14: number of program adjustments (new additions/withdrawals) per year	Positive	3.90
	Program construction quality (V2)	V21: number of national/provincial high-level specialty clusters	Positive	5.10
		V22: proportion of "dual-teacher" faculty in total faculty (%)	Positive	5.60
		V23: number of off-campus practical training bases per 1,000 students	Positive	3.30
		V24: proportion of industry-enterprise co-developed curricula in total curricula (%)	Positive	19.50
	Talent supply efficiency (V3)	V31: average graduate employment rate (%)	Positive	5.10
		V32: job-major match rate of graduates (%)	Positive	3.20
		V33: proportion of graduates employed in "ten strong industries" (%)	Positive	24.40
		V34: employer satisfaction rate with graduates (%)	Positive	6.80

2.6. Obstacle degree model

To transition from macro-level evaluation to precise structural diagnostics and fully answer the third research question (RQ3), the obstacle degree model is utilized [8]. This diagnostic mechanism isolates, quantifies, and ranks the core individual indicators that restrict the coordinated development of the dual system across different prefecture-level cities. The mathematical formula for calculating the obstacle degree of each individual metric within the evaluation matrix is formulated as in (1).

$$O_{ij} = \frac{w_j \times (1 - x'_{ij})}{\sum_{j=1}^{m} w_j \times (1 - x'_{ij})} \times 100\% \quad (1)$$

Where, Oij denotes the obstacle degree of indicator j in sample i, wj is the EWM weight, and x'ij is the standardized value of that indicator. A high obstacle value combines two conditions: the indicator matters in the index, and its relative performance is weak. The model is used here as a diagnostic device. It points to the part of the dual system where constraints are most visible, which can then inform resource allocation, curriculum adjustment, and human-capital intervention [7], [20].

3. RESULTS AND DISCUSSION

This section reports the descriptive statistics, weights, CCD results, and obstacle findings. The scores are interpreted through the REP Helix and Shandong's policy context; they are not treated as automatic proof of educational responsiveness.

3.1. Descriptive statistics of core indicators

Tables 3 and 4 report descriptive statistics and EWM weight allocations. In the industrial upgrading subsystem (U), U13, the share of "ten strong industries" (0.214), and U12, the share of high-tech manufacturing (0.213), receive the highest weights; U31 follows at 0.172. In the HVE program structure subsystem (V), V33, the proportion of graduates employed in "ten strong industries" (0.244), and V24, industry-enterprise co-developed curricula (0.195), carry the largest weights. This pattern makes the model less dependent on general scale indicators and more sensitive to the connection between strategic industrial demand, curriculum cooperation, and graduate destinations.

The coefficient of variation in Table 3 shows uneven regional conditions. U32 reaches 46.30%, and V21 reaches 32.39%, so cities differ sharply in high-tech investment conditions and graduate retention. Trend growth rate values add a timing issue. Industrial indicators such as U32 changed quickly, while curriculum and employment-related indicators, including V32, moved more slowly. The later CCD results are easier to understand in this light: industrial upgrading can accelerate before the educational subsystem has fully adjusted its programs, training resources, and graduate pathways [11], [32].

Table 3. Descriptive statistics of core indicators (2016–2023)

Indicator	Observations	Mean	Std. Dev.	Minimum	Maximum	CV (%)	TGR (%)
U11	8	51.26	2.6	47.3	53.8	5.07	1.86
U12	8	11.82	2.8	9.1	15.1	23.69	7.50
U13	8	28.18	5.02	20.7	34.8	17.81	7.70
U14	8	0.42	0.08	0.31	0.54	19.05	8.25
U21	8	0.14	0.02	0.11	0.17	14.29	6.42
U22	8	14.25	2.38	11.02	17.58	16.70	6.90
U23	8	0.86	0.04	0.81	0.91	4.65	1.68
U31	8	2.41	0.1	2.3	2.59	4.15	1.71
U32	8	13.24	6.13	5.1	23.96	46.30	24.73
U33	8	-6.4	3.9	-15.8	-3.8	-60.94	26.79
U34	8	3.15	0.45	2.5	3.8	14.29	6.16
V11	8	74.62	13.19	54.5	93.15	17.68	7.96
V12	8	0.78	0.06	0.71	0.88	7.69	3.11
V13	8	68.4	10.6	53.2	81.5	15.50	6.28
V14	8	382.5	45.2	315	458	11.82	5.49
V21	8	13.12	4.25	0	15	32.39	16.33
V22	8	57.1	7.97	45.3	69.5	13.96	6.31
V23	8	235.62	56.53	165	320	23.99	9.92
V24	8	43.81	11.92	28	61.5	27.21	11.90
V31	8	91.27	0.93	89.4	92.1	1.02	0.43
V32	8	67.65	3.41	62.4	72.5	5.04	2.17
V33	8	64.25	5.8	55.4	72.1	9.03	3.84
V34	8	90.85	2.35	87.5	94.6	2.59	1.12

The weight allocation fits the structural demands created by regional economic transformation. The prominence of U13 and U12 indicates that differences among prefecture-level cities are closely tied to the expansion of strategic emerging sectors [8]. On the educational side, V33 and V24 show that responsiveness depends on labor-market integration and the depth of industry-education curriculum cooperation, rather than on enrollment expansion alone [9], [16]. A program portfolio may look aligned in administrative terms while graduates still fail to enter the sectors that motivated the adjustment.

Table 4. Weights of indicators for industrial upgrading and HVE program structure systems

System	Indicator	Weight	Rank
Industrial upgrading system	U11	0.071	5
	U12	0.213	2
	U13	0.214	1
	U14	0.076	4
	U21	0.054	6
	U22	0.044	8
	U23	0.041	9
	U31	0.172	3
	U32	0.033	11
	U33	0.034	10
	U34	0.048	7
HVE program structure system	V11	0.155	3
	V12	0.037	10
	V13	0.039	9
	V14	0.039	8
	V21	0.051	6
	V22	0.056	5
	V23	0.033	11
	V24	0.195	2
	V31	0.051	7
	V32	0.032	12
	V33	0.244	1
	V34	0.071	4

3.2. Overall temporal evolution of coupling coordination level (2016–2023)

Table 5 and Figure 3 show D rising from 0.584 in 2016 to 0.854 in 2023. That movement from marginal to good coordination supports a positive reading of the NOKEC period. It still leaves open a narrower question: did HVE adjustment actually catch up with industrial upgrading? The subsystem indices give a more cautious answer. V remains below U in every year; in 2023, V is 0.692 and U is 0.768. Coordination improved, but full alignment did not appear. In this dataset, the educational subsystem followed the industrial subsystem rather than closing the gap.

Table 5. Overall CCD of the dual system in Shandong Province (2016-2023)

Year	Industrial upgrading	HVE program structure	Coupling degree	CCD	Coordination grade	Coordination level
2016	0.362	0.321	0.998	0.584	5	Marginal coordination
2017	0.401	0.354	0.998	0.614	4	Primary coordination
2018	0.455	0.398	0.998	0.652	4	Primary coordination
2019	0.531	0.462	0.998	0.704	3	Intermediate coordination
2020	0.598	0.525	0.998	0.749	3	Intermediate coordination
2021	0.652	0.589	0.999	0.787	3	Intermediate coordination
2022	0.715	0.643	0.999	0.823	2	Good coordination
2023	0.768	0.692	0.999	0.854	2	Good coordination

The HVE-lagging pattern is consistent with a system dynamics interpretation of structural inertia and time delay in vocational education [15], [21], [33]. Industrial systems can respond quickly to investment, market demand, and policy concentration. HVE adjustment is slower because it depends on several processes that do not move together. Curriculum approval affects V14; equipment renewal depends on the technological environment represented by U12; faculty retraining is connected with V22 and V24; graduate matching within strategic sectors appears in V33. The gap between U and V is best read, to some extent, as a structural response delay. It is not a temporary fluctuation that disappears once both indices rise.

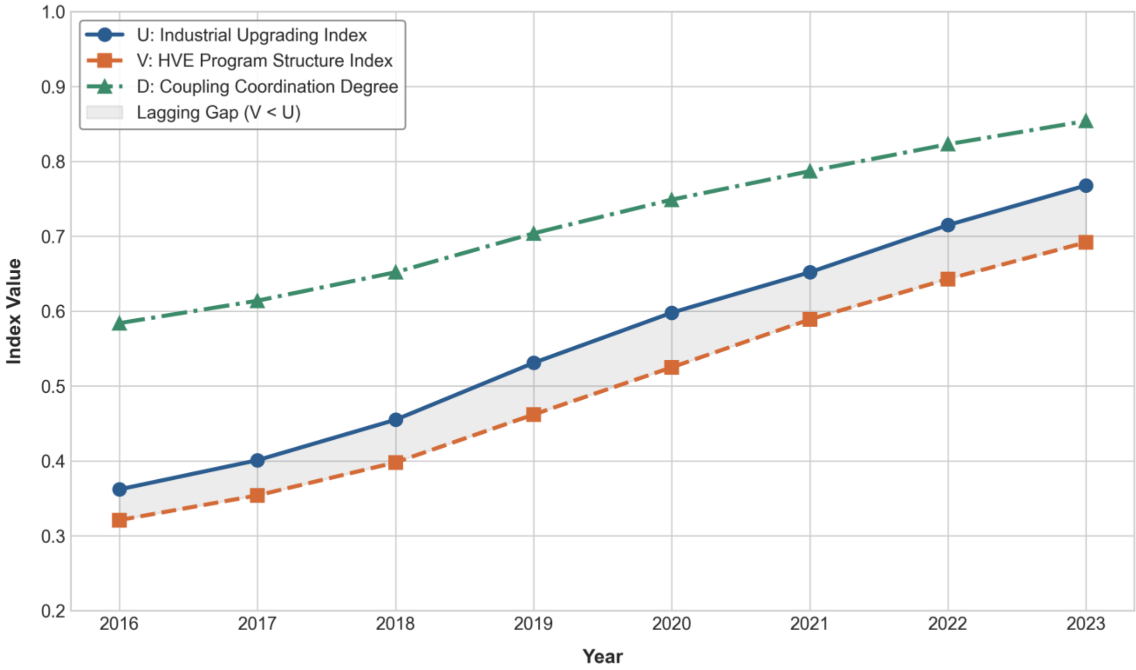

Figure 3. Temporal evolution of industrial upgrading (U), HVE program structure (V), and CCD (D) (2016-2023)

3.3. Spatial heterogeneity analysis across 16 cities

Table 6 shows spatial heterogeneity in 2023 coordination levels across the 16 prefecture-level cities. Qingdao (0.945), Jinan (0.932), and Yantai (0.918) reach high-quality coordination, while Heze (0.755) remains at the intermediate level. One-way ANOVA across the three economic circles gives a regional difference that is just at the conventional threshold ($F=3.80$, $p=0.050$). Figure 4 maps the temporal-spatial evolution, and Figure 5 presents the non-linear coordination surface based on the 2023 city-level observations.

The coastal-inland gradient is consistent with the REP Helix model and with evidence on regional disparities in industry-education coupling systems [21], [34]. Coastal and provincial-capital cities have stronger fiscal capacity, denser enterprise networks, and more concentrated “ten strong industries” activity. These conditions make curriculum cooperation, teacher development, and graduate placement easier to organize. Inland cities face thinner industrial networks and fewer high-quality matching opportunities. The spatial pattern is not only a matter of college performance; it also reflects the local opportunity structure in which HVE responsiveness has to be produced.

Table 6. CCD of 16 prefecture-level cities in Shandong Province (2023)

City	D (CCD)	Coordination grade	Coordination level	Economic circle
Jinan	0.932	1	High-quality coordination	Provincial Capital
Qingdao	0.945	1	High-quality coordination	Jiaodong
Yantai	0.918	1	High-quality coordination	Jiaodong
Weifang	0.875	2	Good coordination	Jiaodong
Zibo	0.88	2	Good coordination	Provincial Capital
Linyi	0.805	2	Good coordination	Southern Shandong
Jining	0.815	2	Good coordination	Southern Shandong
Weihai	0.862	2	Good coordination	Jiaodong
Dongying	0.855	2	Good coordination	Provincial Capital
Rizhao	0.84	2	Good coordination	Jiaodong
Tai’an	0.835	2	Good coordination	Provincial Capital
Binzhou	0.785	3	Intermediate coordination	Provincial Capital
Dezhou	0.795	3	Intermediate coordination	Provincial Capital
Liaocheng	0.77	3	Intermediate coordination	Provincial Capital
Heze	0.755	3	Intermediate coordination	Southern Shandong
Zaozhuang	0.765	3	Intermediate coordination	Provincial Capital

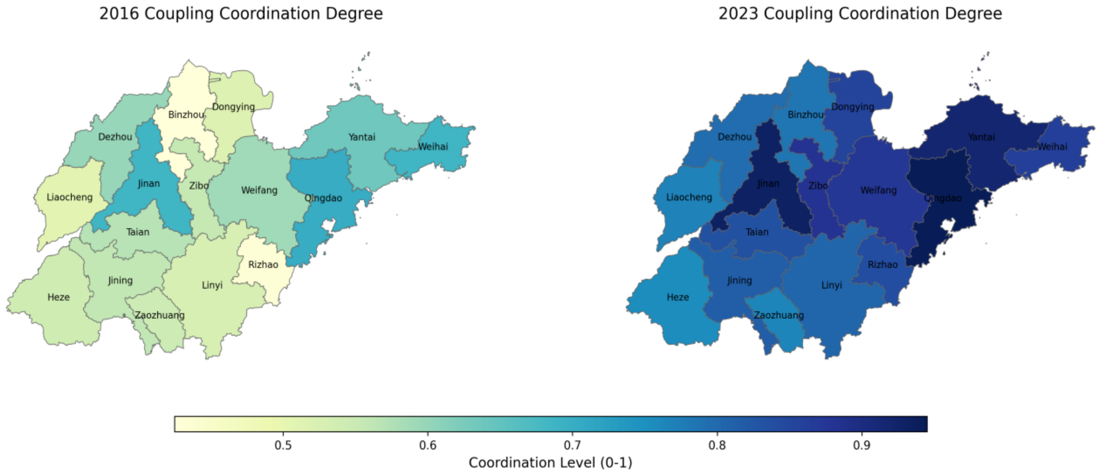

Figure 4. Spatial-temporal evolution of the CCD in Shandong province (2016 vs. 2023)

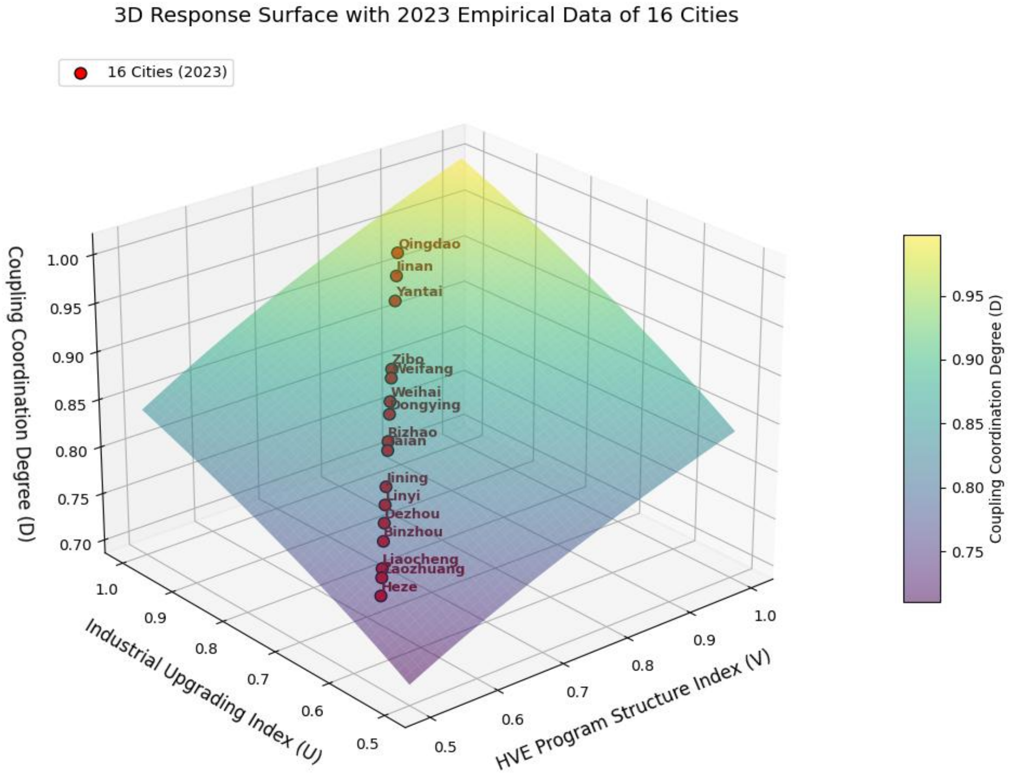

Figure 5. 3D response surface of the dual-system coupling coordination model mapped with the 2023 empirical data of 16 prefecture-level cities in Shandong Province

3.4. Obstacle factor analysis

As shown in Figure 6, the diagnostic results point to a reciprocal-constraint mechanism. On the demand side, weak high-tech manufacturing or industrial R&D capacity (U12 and U31) can reduce the number and quality of technical posts available to new graduates. On the supply side, rigid HVE offerings can create a pseudo-supply of talent: graduates are available, but their competencies do not match the tasks emerging sectors require [35]. The bottleneck is not simply institutional scale, and it is not solved by opening more programs with familiar content. It lies in curriculum rigidity and slow knowledge transfer. These two pressures limit the capacity of programs to keep pace with technological change in the workplace [9], [11], [13], [14], [16].

From a pedagogical perspective, the leading position of V33 links graduate employment in strategic sectors with the transfer of tacit knowledge. High-end manufacturing and emerging industries require non-routine problem solving, coordination across technical roles, and practical judgement under changing production conditions. These competencies are difficult to build through lecture-based instruction or simulated training that is detached from current workplace practice. Work-integrated learning (WIL) and authentic workplace pedagogy matter here because they can bring students closer to the cognitive and collaborative demands of the "ten strong industries" [35], [36].

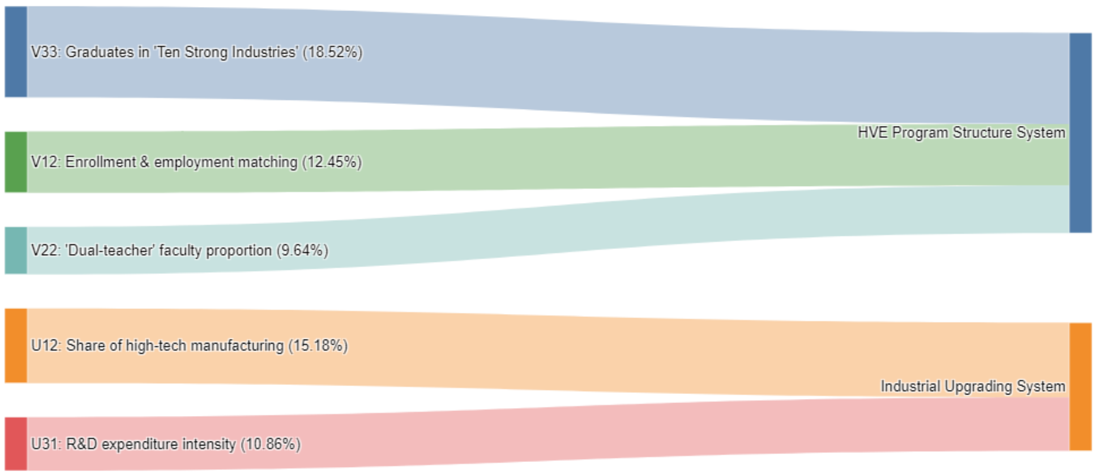

Figure 6. Sankey diagram of the top 5 obstacle factors restricting the coordinated development of the dual system (2023)

3.5. Discussion

3.5.1. Interpretation of empirical findings and system rationale

The lag between HVE and industrial upgrading can be explained through several institutional mechanisms. Centralized curriculum governance creates approval cycles that make rapid program adjustment difficult, especially when strategic emerging sectors change their technical requirements quickly [33]. Public HVE institutions also depend on fiscal and procurement arrangements that slow training-equipment renewal, even when local firms have already adopted newer technologies. Faculty development adds a third delay. Teachers may have formal qualifications but limited access to frontier corporate R&D, and this matters because much advanced industrial knowledge is tacit rather than written into textbooks. These mechanisms explain why the educational subsystem (V) can improve over time and still remain behind the industrial subsystem (U) [37]–[42].

Spatially, the coastal-inland gradient supports the REP Helix interpretation. High-GDP coastal hubs have stronger fiscal capacity and more concentrated industrial clusters, making enterprise cooperation, shared training facilities, and knowledge spillovers easier to organize [3]. Weaker local innovation capacity can reduce high-quality technical employment, while rigid educational offerings intensify mismatch on the supply side [8]. The observed spatial gap is best understood as an interaction between college capacity and local industrial opportunity, rather than as a simple ranking of institutional effort.

Human capital theory clarifies why this gap matters educationally [43]. As regional economies move from labor-intensive manufacturing toward knowledge-intensive and high-tech sectors, the value of vocational skill depends more on adaptability, technical judgement, and familiarity with changing tools. If curriculum renewal and teacher learning lag behind this shift, the human capital produced by HVE institutions can lose value before graduates enter the labor market. The difference between U and V captures this depreciation at the system level. It also helps explain why a high employment rate is not enough evidence of responsiveness: graduates may be employed, but not necessarily in the strategic sectors where the skill demand is changing fastest [44].

3.5.2. Theoretical and practical contributions

Implications for policymakers: quality assurance reform. The findings suggest that HVE quality assurance would benefit from a stronger focus on alignment-related outcomes. Enrollment scale, floor space, and approved program numbers remain useful administrative indicators, but they do not show whether graduates enter strategic sectors or whether curricula reflect current industrial tasks. Policy evaluation can include employment matching in strategic emerging sectors and evidence of substantive enterprise participation. Curriculum autonomy for high-level specialty clusters may also help selected programs respond more quickly while remaining within a quality-assurance framework [19], [45], [46].

– Implications for institutions: demand monitoring and infrastructure. HVE colleges need evidence about local skill demand that is closer to the labor market than delayed administrative reports. Graduate tracking, vacancy analysis, employer advisory boards, and regular consultation with "ten strong industries" firms can show where program adjustment is most urgent. Infrastructure renewal remains a separate constraint. Where advanced equipment is too costly for a single college, shared training laboratories and enterprise-supported platforms may reduce the gap between classroom training and workplace technology [42], [45], [46].
– Implications for program heads: agile curriculum redesign. Program leaders can keep the degree program stable while updating selected modules more often. Short micro-credential units co-designed with enterprises may carry new content into the curriculum before full program redesign is possible. Local vacancy data can guide which credits are adjusted and which are left unchanged [12], [47], [48].
– Implications for teachers: pedagogical adaptation. Teachers move tacit industrial knowledge into the classroom. Project-based learning is useful when projects come from current enterprise tasks, not generic cases. Periodic industrial residency can update instructors' knowledge of equipment, workflow, quality control, and collaborative problem solving [39]–[41], [49].

3.5.3. Limitations and future research

Admittedly, several limitations need to be considered. Shandong is a national comprehensive NOKEC pilot zone, so the coordination path observed here may not be reproduced in provinces without similar policy support or fiscal resources. The study relies on macro-level secondary data, which means it cannot directly observe curriculum quality, classroom implementation, graduate skill use, or employer judgement. ANOVA helps validate spatial heterogeneity, but the eight-year panel and the structural nature of the indicators limit the use of more complex causal models. Future research can combine this macro-level diagnostic approach with institutional case studies, graduate surveys, employer interviews, and specialty-cluster analysis. That evidence is needed to see how technology-transfer frictions appear inside specific programs rather than only at the city- system level [45], [50], [51].

4. CONCLUSION

Future research: because this study relies on macro-level secondary data from a national pilot zone, the generalization of the findings requires caution. Current structural indices cannot show what happens inside a curriculum module, a training base, or a hiring decision. Future research needs institutional case studies, graduate surveys, and human resources (HR) interviews, especially in specialty clusters such as intelligent manufacturing or new-energy vehicle technology. Such evidence would help identify whether the observed lag comes mainly from program design, teacher capacity, enterprise participation, or the local structure of entry-level technical jobs.

The policy implications are selective rather than simply expansionary. Teachers need closer contact with enterprise projects through project-based learning and workplace-based professional development. Program heads can use modular micro-credentials to update a limited share of curriculum content around local vacancies. Institutions can build real-time data links with enterprise clusters and share advanced training infrastructure where costs exceed the capacity of a single college. Policymakers can strengthen quality assurance by moving from input-centric indicators toward employment and alignment indicators tied to strategic sectors.

This research contributes to educational evaluation in three ways. First, it links human capital theory with regional educational responsiveness by showing how institutional delay can produce localized human-capital depreciation. Second, it translates the REP Helix framework into a measurable dual-system indicator structure. Third, it provides longitudinal evidence of time-lag effects in vocational education adaptation. The contribution is diagnostic: it shows why HVE program structures may improve and still trail industrial upgrading. The study evaluated structural alignment between industrial upgrading and HVE program structures in Shandong from 2016 to 2023. Overall coupling coordination improved from marginal to good coordination, but the HVE subsystem remained below the industrial subsystem throughout the period. Spatially, the province showed a layered pattern, with Qingdao, Jinan, and Yantai reaching high-quality coordination and several inland cities remaining at intermediate coordination. The obstacle analysis located the main bottleneck in V33, graduate employment in the "ten strong industries". The central challenge is not general HVE expansion, but the match between specific programs and specific industrial destinations.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

ETHICAL APPROVAL

This study relies exclusively on secondary, publicly available aggregated data at the regional level. No human participants, animal subjects, or personal identifying information were involved in this research. Consequently, formal ethical approval from an Institutional Review Board (IRB) was not required.

DATA AVAILABILITY

The data that support the findings of this study are openly available in the official public repository of the Shandong Provincial Bureau of Statistics at http://tjj.shandong.gov.cn/ and the Annual Quality Reports of Higher Vocational Colleges in Shandong Province via the Shandong Provincial Department of Education at http://edu.shandong.gov.cn/.

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