Supplementary Materials

Manuscript: Land-System Comparability for Pilot-Zone Learning: A Contribution-Structure Audit of China's Urban-Rural Integration Pilot Units

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Supplementary Section S1. Study Area, Candidate Audit, and Diagnostic Checks

This supplementary section contains the eight outputs referenced by the manuscript: pilot-zone membership, the full baseline shortlist, consolidated robustness results, the POI quality audit, the random-coupling baseline, additional specification diagnostics, initial-level dependence, and administrative-type composition.

S1.1. Pilot-Zone Membership

Supplementary Table S1 lists the county-level analytical units represented by the 11 numbered pilot-zone locations in Figure 2. Chinese policy and administrative names are retained to avoid treating functional areas as conventional counties or assigning unofficial English administrative titles.

Supplementary Table S1. Policy-designated pilot zones and their county-level analytical units.

No.	Policy-designated Chinese name	Author English rendering	Analytical units, n	County-level analytical units (Chinese names)
1	浙江嘉湖片区	Zhejiang Jiaxing-Huzhou	12	南湖区、秀洲区、平湖市、海宁市、桐乡市、嘉善县、海盐县、吴兴区、南浔区、德清县、长兴县、安吉县
2	福建福州东部片区	Fujian Fuzhou Eastern	9	仓山区、长乐区、马尾区、福清市、闽侯县、连江县、罗源县、平潭综合实验区、霞浦县
3	广东广清接合片区	Guangdong Guangzhou-Qingyuan	7	增城区、花都区、从化区、清城区、清新区、佛冈县、英德市连樟样板区
4	江苏宁锡常接合片区	Jiangsu Nanjing-Wuxi-Changzhou	5	溧水区、高淳区、宜兴市、金坛区、溧阳市
5	山东济青局部片区	Shandong Jinan-Qingdao	10	历城区、长清区、市中区、章丘区、济南高新技术产业开发区、淄川区、博山区、即墨区、平度市、莱西市
6	河南许昌	Henan Xuchang	6	魏都区、建安区、禹州市、长葛市、鄢陵县、襄城县
7	江西鹰潭	Jiangxi Yingtan	3	月湖区、余江区、贵溪市
8	四川成都西部片区	Sichuan Chengdu Western	8	温江区、郫都区、都江堰市、彭州市、崇州市、邛崃市、大邑县、蒲江县
9	重庆西部片区	Chongqing Western	9	荣昌区、潼南区、大足区、合川区、铜梁区、永川区、璧山区、江津区、巴南区
10	陕西西咸接合片区	Shaanxi Xi'an-Xianyang	8	高陵区、阎良区、西咸新区、富平县、兴平市、武功县、三原县、杨凌农业高新技术产业示范区

No.	Policy-designated Chinese name	Author English rendering	Analytical units, n	County-level analytical units (Chinese names)
11	吉林长吉接合片区	Jilin Changchun-Jilin	9	九台区、双阳区、长春新区、长春净月高新技术产业开发区、吉林（中国-新加坡）食品区、船营区、昌邑区、丰满区、永吉县
	Total		86	

Note: The cover term “county-level analytical units” includes municipal districts, county-level cities, counties, and the listed functional-area units. English pilot-zone names are author renderings for readability.

S1.2. Evidence-Graded Shortlist

Supplementary Table S2 reports the 11 pairs selected by the main same-zone strict Q25/Q75 screen. Pairs are ordered by contribution-structure distance so that the largest structural divergence appears first. Evidence grades distinguish hard-signal-led divergence, benchmark-supported POI divergence, and divergence led by POI categories requiring additional local verification.

Supplementary Table S2. Evidence-graded within-zone strict shortlist, ordered by contribution-structure distance.

Rank	Pair	Pilot zone	D^{pos}	$D^{contrib}$	Leading divergent indicators	Evidence grade
1	Shuangyang District–Fengman District	Jilin Changchun-Jilin	0.704	0.791	relative built-up expansion (0.458); NTL (0.443)	Hard-signal-led
2	Fengman District–Yongji County	Jilin Changchun-Jilin	0.741	0.720	NTL (0.471); transport POI (0.371)	Hard-signal-led
3	Shuangyang District–Changyi District	Jilin Changchun-Jilin	0.438	0.716	NTL (0.502); transport POI (0.342)	Hard-signal-led
4	Rongchang District–Jiangjin District	Chongqing Western	0.743	0.673	transport POI (0.487); public-leisure POI (0.438)	Cautious-POI-led
5	Pengzhou City–Pujiang County	Sichuan Chengdu Western	0.474	0.669	transport POI (0.591); public-leisure POI (0.276)	Cautious-POI-led
6	Zhangqiu District–Laixi City	Shandong Jinan-Qingdao	0.448	0.648	transport POI (0.433); public-leisure POI (0.332)	Cautious-POI-led
7	Zichuan District–Laixi City	Shandong Jinan-Qingdao	0.589	0.647	public-leisure POI (0.466); transport POI (0.443)	Cautious-POI-led
8	Dujiangyan City–Pujiang County	Sichuan Chengdu Western	0.474	0.629	transport POI (0.528); NTL (0.206)	Cautious-POI-led
9	Rongchang District–Hechuan District	Chongqing Western	0.503	0.624	transport POI (0.463); education POI (0.299)	Cautious-POI-led
10	Shizhong District–Laixi City	Shandong Jinan-Qingdao	0.724	0.609	medical POI (0.452); transport POI (0.298)	Verified-POI-led
11	Zhangqiu District–Jimo District	Shandong Jinan-Qingdao	0.377	0.598	transport POI (0.399); education POI (0.377)	Cautious-POI-led

Hard signals refer to nighttime-light change, built-up share change, and relative built-up expansion. Verified POI refers to education and medical categories with external benchmark checks. Cautious POI refers to public-leisure and transport-node categories that require additional local verification.

S1.3. Consolidated Robustness Summary

Supplementary Table S3 compares the position-structure discrepancy across grouped indicators, sample restrictions, outlier treatment, POI exclusions, alternative distance definitions, and threshold rules. The reported shortlist sizes refer to the same-zone strict comparison. The baseline shortlist is not expected to be invariant; the diagnostic claim is retained when low-position-distance/high-contribution-distance pairs remain under the alternative specification.

Supplementary Table S3. Consolidated robustness summary for the position-structure discrepancy.

Specification	Exception pairs present	Shortlist size	Overlap with baseline 11
Seven-indicator baseline	Yes	11	11
Four grouped dimensions	Yes	7	4
Strict-sample PCA refit	Yes	9	9
Winsorized at 1%	Yes	8	7
Winsorized at 5%	Yes	6	3
Transport POI removed	Yes	9	4
All POI indicators removed	Yes	2	0
Alternative distance: cosine	Yes	10	10
Alternative distance: correlation	Yes	12	11
Alternative distance: original indicator vectors	Yes	2	2
Threshold rule Q20/Q80	Yes	5	5
Threshold rule Q30/Q70	Yes	12	11

Note: "Exception pairs present" means that at least one low-position-distance/high-contribution-distance pair remains; it does not imply stable incidence or invariant shortlist membership. Indicators are re-standardized and PCA is re-estimated within the relevant sample or indicator specification.

S1.4. POI Data-Quality Diagnostic

The POI diagnostic distinguishes computational correction from substantive validation. Category-year scaling attenuates sample-wide changes in platform counts, but it cannot establish equivalence with official facility stocks, capacity, quality, or accessibility. The raw category-year totals and scaling factors are reported with the treatment decisions so that large platform shifts, especially the transport jump, remain visible.

Supplementary Table S4. POI data-quality diagnostics and analytical treatment.

POI input	Observed diagnostic	Interpretive risk	Treatment in analysis
Civic/social POI	The 2022 category-year total is zero (2019 total: 99,164).	Category-year interruption, not facility disappearance.	Excluded from the seven-indicator main specification.
Transport POI	Total increases from 25,508 (2019) to 181,447 (2020) and 178,740 (2023).	Strong platform/category coverage shift.	Category-year scaled; interpreted cautiously; transport-removed specification reported.
Public-leisure POI	Public-facility and sports/leisure source categories have different annual scaling factors and no comparable county benchmark.	A combined pre-scaling factor would mask category-specific shifts; external validity remains limited.	Subcategories scaled separately before aggregation; interpreted as an auxiliary proxy and tested through exclusion.
All retained POI categories	Annual platform totals vary substantially across 2019–2023.	Raw inter-year counts are not directly comparable.	Scale each category-year to its 2019 analytical-sample total before endpoint density change.

POI input	Observed diagnostic	Interpretive risk	Treatment in analysis
POI density denominator	Built-up-area denominator is available for 81 units.	Potential mechanical dependence on total land area.	Sensitivity PCA retained the PC1 direction (cosine = 0.999).
External benchmarks	Education and medical benchmarks cover 57 matched units; public-leisure and transport lack comparable benchmarks.	Validation strength differs by POI category.	Education/medical treated as benchmark-supported node proxies; public-leisure/transport require local verification.

Supplementary Table S4 continued. Raw POI totals and category-year scaling factors used for the retained and diagnostic source categories.

Source category	2019 total	2020 raw total	2020 factor	2021 raw total	2021 factor	2022 raw total	2022 factor	2023 raw total	2023 factor	Modeling treatment
Education	73,695	64,479	1.143	114,182	0.645	86,281	0.854	84,619	0.871	Retained as education indicator
Medical	89,198	70,831	1.259	100,147	0.891	87,455	1.020	82,970	1.075	Retained as medical indicator
Civic/social	99,164	74,315	1.334	115,251	0.860	0	NA	103,218	0.961	Excluded because the 2022 total is zero
Public-facility	15,793	19,100	0.827	22,378	0.706	16,284	0.970	18,796	0.840	Scaled separately, then combined into public-leisure
Sports/leisure	25,158	43,440	0.579	55,554	0.453	18,308	1.374	45,651	0.551	Scaled separately, then combined into public-leisure
Transport	25,508	181,447	0.141	122,365	0.208	116,451	0.219	178,740	0.143	Retained as a cautious proxy and tested by exclusion

Note: The factor rescales each source category-year to its 2019 analytical-sample total before unit-level endpoint density changes are calculated. It preserves within-year cross-unit relative differences but does not validate the scaled totals as real annual facility stocks.

S1.5. Random-Coupling Baseline

The Q25/Q75 rule would flag approximately 6.25% of pairs if low composite-position distance and high contribution-structure distance were independently distributed. Because pair observations share units, the manuscript supplements this arithmetic reference with a unit-label permutation. PC1–PC2 positions are held fixed while signed normalized contribution vectors are reassigned among eligible units for 10,000 draws. Reassignment is global in the all-pair and strict-pair scopes and occurs within each pilot zone for the same-zone strict scope. This preserves the observed configurations at each level while breaking their unit-level alignment.

Supplementary Table S5. Association between the two distances and the unit-label random-coupling baseline.

Scope	Eligible pairs	Pearson r	Spearman ρ	Observed candidates	Random-coupling mean (95% interval)	Lower-tail permutation p
All pairs	3,655	0.543	0.543	57	228.1 (183–270)	<0.001
Strict pairs	2,850	0.578	0.588	39	178.3 (139–213)	<0.001
Same-zone strict pairs	258	0.121	0.123	11	17.2 (11–23)	0.036

Note: The one-sided lower-tail probability is the proportion of draws producing no more candidates than observed, calculated with the standard plus-one correction. The random seed is 20260624. Pairwise correlations are descriptive because dyads share units. The permutation is a random-coupling baseline: it deliberately breaks the analytic link between PCA position and unit-specific contributions and therefore does not represent a generative null in which mixed-sign compensability has been removed.

The results show broad concordance rather than widespread divergence. Position and contribution distances are positively associated, and observed Q25/Q75 candidates are less frequent than under random coupling. The empirical contribution of the audit lies in identifying and evidence-grading the limited exception tail, not in demonstrating the already-known mathematical possibility of compensating indicator contributions.

S1.6. Additional Specification Diagnostics

Supplementary Table S6 separates stability of the PC1 direction, strength of the axis, and composition of the candidate pool. A high cosine does not by itself imply that explained variance or shortlist membership is stable.

Supplementary Table S6. Direction, strength, and shortlist sensitivity under additional specifications.

Specification	Units	PC1 explained	PC1 cosine	Eligible same-zone strict pairs	Candidates	Overlap with baseline 11
Seven-indicator baseline	86	50.9%	1.000	258	11	11
Zhejiang removed and PCA refitted	74	34.1%	0.917	192	2	1
Public-leisure POI removed	86	46.0%	0.999	258	11	7
Unadjusted NTL and built-up share	86	56.4%	0.972	258	9	2
Initial-level residualized changes	81	51.8%	0.994	258	15	5
PC1-only composite-position distance	86	50.9%	1.000	258	12	7

Note: Zhejiang contains 12 of 86 units but accounts for 72.0% of the full-sample PC1 score sum of squares. Cosines compare the oriented PC1 vector with the baseline over common indicators. The residualized specification uses the 81 units with complete 2019 built-up-share and POI-density baselines; its same-zone strict pair count remains 258 because the omitted boundary-incomplete units are outside the strict comparison. The PC1-only row changes the position-distance definition without re-estimating PCA, so baseline PC1 values are repeated. Candidate overlap is diagnostic rather than a stability requirement.

S1.7. Initial-Level Dependence

Supplementary Table S7 reports whether units with high 2019 levels tend to exhibit systematically different subsequent changes. The values diagnose convergence and low-base dependence rather than causal effects.

Supplementary Table S7. Correlations between 2019 initial levels and 2019–2023 change indicators.

Change indicator	Initial-level indicator	Pearson r
Nighttime-light change	2019 nighttime-light level	-0.079
Built-up share change	2019 built-up share	+0.493
Relative built-up expansion	2019 built-up share	-0.032
Education-node change	2019 education-node density	-0.160
Medical-node change	2019 medical-node density	-0.152
Public-leisure-node change	2019 public-leisure-node density	-0.436
Transport-node change	2019 transport-node density	-0.613

Note: The current seven-indicator residualized PCA is reported in Supplementary Table S6.

S1.8. Administrative-Type Composition

Supplementary Table S8 tests whether the score representation or exception rate is mainly an artifact of mixing municipal districts, counties and county-level cities, and functional areas.

Supplementary Table S8. Administrative-type composition diagnostics.

Diagnostic	Scope	Value
Administrative-type share of PC1 variation (η^2)	All 86 units	0.010
Administrative-type share of PC2 variation (η^2)	All 86 units	0.170
Q25/Q75 candidate rate	Same administrative type: 7/155 pairs	0.045
Q25/Q75 candidate rate	Different administrative types: 4/103 pairs	0.039

Note: Candidate rates use the 258 same-zone strict pairs; functional areas are excluded from this pair scope. Cross-type pairs are not overrepresented among baseline candidates.