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DOES COAL WEALTH DRIVE REGIONAL GROWTH OR DEEPEN INEQUALITIES IN LOCAL ECONOMIES? EVIDENCE FROM SCALOGRAM AND GRAVITY ANALYSIS

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Abstract

Resource-rich regions frequently face structural disparities when extractive activities operate with limited spatial integration. This study examines whether coal production is associated with the spatial hierarchy of public and economic facilities across 24 sub-districts in Lahat Regency, South Sumatra. Using a cross-sectional dataset, Scalogram analysis identifies service-center hierarchies, while a potential Gravity model estimates the intensity of spatial interaction between core hubs and peripheral areas. The findings reveal a sharp spatial concentration: Lahat (the regency capital, Hierarchy I) and Merapi Barat (Hierarchy II) dominate service provision, whereas three of the five coal-producing sub-districts—Merapi Timur (Hierarchy IV), Merapi Selatan (Hierarchy VI), and Gumay Talang (Hierarchy VI)—exhibit severe service deficits. These patterns indicate that local coal extraction does not automatically translate into localized service infrastructure, reflecting potential enclave dynamics rather than broad spatial spillovers. Furthermore, potential spatial interaction decays rapidly outside the central corridor. Bridging these spatial gaps requires targeted transport connectivity, decentralized industrial zoning, and horizontal supply chain linkages to integrate peripheral producing sub-districts into the broader regional economy.

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1. Introduction

The global economic landscape increasingly highlights a developmental paradox known as the "resource curse," where regions abundant in non-renewable natural resources often

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experience slower structural transformation and higher economic volatility compared to resource-poor counterparts (Auty, 1993; Lotfalipour et al., 2022; Kinnaman, 2023). This phenomenon is frequently driven by a heavy reliance on commodity exports, which leaves regional economies vulnerable to global price fluctuations (Zuo & Zhong, 2020). When commodity prices surge, GDP may show significant short-term growth; however, without diversification into non-resource-based sectors, this growth often remains superficial and fails to foster long-term resilience (Kinnaman, 2023; Yang & Li, 2024). In emerging economies like Indonesia, the challenge lies in leveraging massive mineral wealth to catalyze broad-based regional development rather than creating isolated "enclave" economies that offer limited benefits to the local population.

The localized economic dependence of Lahat Regency is reflective of broader trends within the provincial and national contexts. At the provincial level, South Sumatra's economy remains heavily anchored by the extractive sector, with the Mining and Quarrying sector contributing approximately 27.64% to the Gross Regional Domestic Product (GRDP) in 2022, representing a significant increase from 20.17% in 2018 (BPS South Sumatra Province, 2023). This provincial performance was primarily bolstered by a 6.27% growth rate in the mining sector during 2022, fueled by the recovery of global commodity prices and heightened production in regional energy hubs (BPS South Sumatra Province, 2023). On a national scale, the importance of the mining sector is equally evident, contributing 12.22% to Indonesia's Gross Domestic Product (GDP) in 2022, with the coal sub-sector alone accounting for a substantial 6.62% share of the national output (Statistics Indonesia [BPS], 2022). While these figures underscore the sector's vital role in national revenue and energy security, they also highlight the systemic vulnerability of regional growth to the inherent volatility of global commodity markets and the risks of pro-cyclical economic fluctuations (Abdillah et al., 2023).

Lahat Regency, situated in South Sumatra Province, serves as a critical case study for examining the spatial distribution of infrastructure in a resource-intensive economy. According to regional geological and energy statistics, the regency holds estimated coal reserves of 2,714.97 million tons and recorded an annual production volume of approximately 40 million tons in 2022 (Ministry of Energy and Mineral Resources [ESDM], 2023; BPS Lahat Regency, 2023). This extractive output supports national electricity generation through the Banjarsari (270 MW) and Keban Agung (300 MW) mine-mouth coal-fired power plants (PT PLN, 2023). Economically, the mining and quarrying sector accounted for an average of 38.14% of Lahat's Gross Regional Domestic Product (GRDP) between 2010 and 2022, with coal mining contributing nearly 30% of total GRDP in 2022 (BPS Lahat Regency, 2023). Despite this substantial extractive output, whether coal-producing sub-districts exhibit superior public and economic service infrastructure remains an open empirical question.

Growth pole theory posits that economic activity concentrates in specific urban or industrial centers before diffusing to surrounding hinterlands through "spread effects" (Perroux, 1950; Richardson, 1976). Conversely, when extractive industries operate as isolated enclaves, "backwash effects" may draw capital and labor toward established administrative centers, leaving peripheral areas underserved (Myrdal, 1957; Corrocher et al., 2020). Evaluating the

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spatial distribution of educational, healthcare, government, and economic facilities provides a structural indicator of how service provision aligns with extractive activity across sub-districts. Furthermore, modeling potential spatial interaction based on economic mass and distance helps identify corridors where logistical friction may constrain inter-sub-district integration (Wang, 2017; Šveda & Madajová, 2023).

Accordingly, this study addresses two objectives: (1) to determine whether coal production is associated with a higher hierarchical status of service facilities across the 24 sub-districts of Lahat Regency using Scalogram analysis, and (2) to estimate the potential spatial interaction intensity between primary service hubs and peripheral sub-districts using a Gravity model. Rather than inferring longitudinal growth from cross-sectional data, this research evaluates structural spatial disparities and tests whether coal-producing sub-districts function as integrated service centers or service-deficient extraction zones. The remainder of this paper is structured as follows: Section 2 reviews the theoretical and empirical literature on growth poles, resource extraction, and spatial interaction; Section 3 details the data sources, facility classification, and analytical models; Section 4 presents the empirical results and discusses their spatial implications; and Section 5 provides conclusions, policy recommendations, and research limitations.

2. Literature Review

2.1. Growth Pole Theory: From Functional to Geographic Space

The conceptual foundation of regional development is rooted in the Growth Pole theory, initially proposed by Perroux (1950). Perroux argued that economic growth does not appear everywhere at once; instead, it manifests in specific points or "poles" with varying intensities before spreading throughout the economy via diverse channels. Crucially, Perroux's original formulation was focused on "economic space" rather than geographic location, defining a growth pole as a propulsive industry—a large, innovative, and fast-growing sector that exerts significant influence over other sectors through intense forward and backward linkages (Capello, 2015). The transition from Perroux's functional abstraction to a geographic application was formalized by Kuklinski (1970), who redefined growth poles as a set of expanding industries located in an urban center, which induces further economic activity throughout its zone of influence. In this context, the coal mining industry in resource-rich regions acts as the propulsive sector. Its presence stimulates the development of ancillary services, infrastructure, and energy production, theoretically transforming a mining site into a geographic pole of attraction for capital and labor (Dobrescu & Dobre, 2014; Capello, 2015).

2.2. Spatial Dynamics: Spread and Backwash Effects

The spatial impact of a growth pole on its hinterland is governed by two competing forces: "spread effects" and "backwash effects" (Myrdal, 1957). Through circular and cumulative causation, an expanding center can stimulate peripheral economies by increasing demand for agricultural goods and local inputs (spread effects). However, higher returns in the core frequently attract capital, skilled labor, and infrastructure investment away from the periphery, widening regional disparities (backwash effects) (Myrdal, 1957; Capello, 2015).

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Richardson (1976, 1980) argued that polarized development persists until a region reaches the threshold of "polarization reversal"—the turning point at which congestion costs in the core and improved inter-regional infrastructure induce spatial deconcentration toward secondary centers. In resource-dependent regions, however, if mining operates as an enclave with weak local backward and forward linkages (Hirschman, 1958; Shiquan et al., 2022; Animashaun & Emediegwu, 2025), polarization reversal is delayed and peripheral producing areas remain structurally underserved.

2.3. Spatial Interaction and Centrality

Spatial interaction models posit that potential flows of goods, labor, and services between two locations are positively related to their economic masses and inversely related to the distance separating them (Haynes & Fotheringham, 1984; Roy & Thill, 2004; Wang, 2017). Complementing this, the Scalogram method rooted in central place theory and adapted for regional planning by Rondinelli (1985) evaluates functional hierarchy by measuring the presence and concentration of public and economic facilities across settlements, an approach closely aligned with modern spatial accessibility frameworks (Mercier et al., 2021). Together, Scalogram and Gravity analyses assess both the internal service capacity of sub-districts and their potential spatial connectivity (Osiobe, 2019; Roy & Thill, 2004; Yang et al., 2023). Together, these theories provide the necessary framework to evaluate whether extractive industries in regions like Lahat serve as genuine engines of regional integration or merely as isolated nodes of production.

2.4. Empirical Evidence on Local Resource Extraction and Spatial Hierarchy

Empirical studies on the sub-national impacts of resource extraction reveal mixed local outcomes. While resource booms can raise local wages and fiscal revenues, van der Ploeg (2011) and Cust & Poelhekke (2015) emphasize that localized benefits depend heavily on institutional quality and spatial market integration. In Peru, Aragón & Rud (2013) demonstrated that positive local spillovers from mining occur primarily when firms procure local inputs and labor rather than operating as isolated enclaves. Within Indonesia, sub-national studies indicate that fiscal decentralization and regional autonomy have uneven spatial effects when inter-district infrastructure remains fragmented (Abdillah et al., 2023; Sulista & Rosyid, 2022; Muhdar et al., 2023). Cross-country spatial analyses similarly confirm that geographic isolation and inadequate transport infrastructure severely restrict growth spillovers from core hubs to peripheral regions (Roberts & Deichmann, 2011; Ahmad & Hall, 2017). Prior regional planning studies in Indonesia applying Scalogram and Gravity methods consistently show that administrative capitals dominate service hierarchies, whereas resource-producing sub-districts often lag in social infrastructure. This study builds on that literature by explicitly separating administrative capital effects from coal-production status in Lahat Regency.

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3. Research Methods

3.1. Data

This study covers all 24 sub-districts (Kecamatan) in Lahat Regency, South Sumatra Province. Facility availability data were obtained from Lahat Regency in the 2023 figures published by Statistics Indonesia (BPS Lahat Regency, 2023), reflecting conditions as of 2022. Population and road distance data were sourced from the same BPS publication. Sub-districts are classified into coal-producing (n = 5) and non-coal-producing (n = 19) groups based on active Mining Business Permits (*Izin Usaha Pertambangan*/IUP) and recorded coal production data from the Ministry of Energy and Mineral Resources (Ministry of Energy and Mineral Resources, 2023). The five coal-producing sub-districts are Lahat, Merapi Barat, Merapi Timur, Merapi Selatan, and Gumay Talang.

Table 1. Summary of Coal Mining Business Permit (IUP) Concession Areas by Sub-district in Lahat Regency

No.	Company	Area (ha)	Location	IUP Expiry
1	PT Aman Toebillah Batubara	687	Merapi Barat	2022
2	PT Andalas Bara Sejahtera	150	Merapi Timur	2016
3	PT Asta Maharanita	476	Merapi Barat	2030
4	PT Banjar Sari Pribumi	519.84	Merapi Timur	2030
5	PT Bara Alam Utama	799.60	Merapi Timur	2027
6	PT Bara Manunggal Sakti	433	Lahat	2023
7	PT Batubara Lahat	500	Lahat	2030
8	PT Batu Alam Selaras	8,139	Gumay Talang	2038
9	PT Bima Putra Abadi Citranusa	286	Merapi Selatan	2029
10	PT Budi Gema Gempita	1,524	Merapi Timur	2026
11	PT Bukit Telunjuk	500	Merapi Timur	2026
12	PT Bukit Bara Alam	799.60	Merapi Timur	2032
13	PT Bumi Merapi Energi	1,881	Merapi Barat	2030
14	PT Citra Bara Raya	804	Lahat	2026
15	PT Cakramas Gemilang Energi	413	Merapi Timur	2027
16	PT Dianrana Petrojasa	1,001	Lahat	2024
17	PT Dianrana Petrojasa	994.60	Lahat	2024
18	PT Dirar Duage Energi	1,011	Merapi Selatan	2031
19	PT Duta Alam Sumatera	357	Merapi Barat	2024
20	PT Dizamatra Powerindo	971	Merapi Barat	2030
21	PT Era Mandiri Energi	1,359	Merapi Selatan	2022
22	PT Golden Great Borneo	1,913	Merapi Timur	2030
23	PT Indah Jaya Abadi Pratama	1,261	Merapi Barat	2027
24	PT Lahat Pulau Pinang Bara Jaya	850.50	Merapi Selatan	2035

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No.	Company	Area (ha)	Location	IUP Expiry
25	PT Mandiri Nusa Pratama	433	Merapi Barat	2030
26	PT Muara Alam Sejahtera	1,745	Merapi Barat	2032
27	PT Mustika Indah Permai	2,000	Merapi Barat	2030
28	PT Priamanaya Energi	1,000	Lahat	2030
29	PT Satria Mayangkara Sejahtera	730	Lahat	2030
30	PT Sriwijaya Bangkit Energi	1,000	Lahat	2035
31	PT Sarana Cipta Gemilang	388	Merapi Barat	2021
32	PT Tri Mandiri Perkasa	582	Merapi Barat	2022

Source: Ministry of Energy and Mineral Resources (2023).

3.2. Analysis Method

The analysis proceeds in three sequential stages: (1) Guttman Scalogram reproducibility testing, (2) weighted Centrality Index and population-normalized hierarchy classification, and (3) potential spatial interaction modeling using the Gravity equation.

Stage 1: Scalogram Analysis and Reproducibility

Scalogram analysis orders sub-districts and facilities to assess whether service provision follows a cumulative hierarchical pattern (Rondinelli, 1985). To avoid circularity—wherein counting coal companies mechanically inflates the service scores of coal-producing sub-districts—we distinguish between 18 core public and economic service facilities and 2 extractive/plantation enterprise categories (mining companies and plantation companies). The 18 core service facilities span four functional domains:

1. **Education** (4 types): Kindergarten, elementary school, junior high school, and senior high school.
2. **Health** (3 types): Community health center (*Puskesmas*), village maternity post/polyclinic (*Polindes/Poskesdes*), and pharmacy.
3. **Government** (5 types): Village representative board (*BPD*), village hall, police sector office (*Polsek*), postal service, and sub-district office.
4. **Economic Services** (6 types): Banking institutions, shops/markets, restaurants/eateries, hotels/lodging, village public transport, and cooperatives.

Internal consistency is evaluated using the Coefficient of Reproducibility (COR). The initial coefficient (COR_t) before error correction is defined as:

$$COR_t = 1 - \Sigma_{i=1}^{N} e_i / (N \times k) \quad (1)$$

where e_i denotes the number of Guttman scaling errors (instances where a sub-district lacks a lower-order facility expected given its rank, or possesses an anomalous higher-order facility), N = 24 is the number of sub-districts, and k is the number of facility types. Following Guttman scaling procedures, error correction is performed by minimizing deviations from the ideal triangular step pattern to obtain the corrected coefficient (COR_c):

$$COR_c = 1 - \Sigma_{i=1}^{N} e_{c,i} / (N \times k) \quad (2)$$

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where $e_{c,i}$ represents residual errors after sorting rows and columns by marginal frequencies. A scale is considered structurally valid if $0.90 \leq COR_c \leq 1.00$ (Rondinelli, 1985). To ensure robustness and prevent mechanical circularity—wherein counting extractive enterprises artificially inflates the service scores of coal-producing sub-districts, COR_c is evaluated under two specifications: the baseline 20-facility matrix ($N \times k = 24 \times 20 = 480$ cells) and the core 18-facility matrix excluding mining and plantation companies ($N \times k = 24 \times 18 = 432$ cells).

Stage 2: Centrality Index, Normalization, and Hierarchy Classification

To account for differences in functional reach across facility tiers (Rondinelli, 1985), each facility count F_{ij} in sub-district i is weighted by its functional importance score B_j:

$$SB_i = \Sigma_{j=1}^{m} (F_{ij} \times B_j) \quad (3)$$

Functional domain weights are assigned hierarchically: education (5), health (4), economic services (3), and government facilities (2), with within-group tiers ordered from lowest to highest service threshold (e.g., kindergarten = 1 to senior high school = 4). The standardized Centrality Index (CI_i) is computed by scaling the weighted score relative to the regional facility distribution:

$$CI_i = SB_i \times W_r \quad (4)$$

where $W_r = 0.25$ denotes the regional standardization scaling factor applied across the weighted facility matrix to normalize the index scale (such that a raw score of 4,653 yields the regency capital peak of 1,163.25 for Lahat). To address size bias, where populous sub-districts achieve higher raw scores solely due to demographic scale, we also compute the Population-Normalized Centrality Index (NCI_i) per 1,000 residents:

$$NCI_i = (CI_i / P_i) \times 1{,}000 \quad (5)$$

as well as an unweighted facility count index as a sensitivity check. The number of hierarchical classes (K) is determined using Sturges' rule:

$$K = 1 + 3.3 \log_{10}(24) = 5.55 \approx 6 \quad (6)$$

The class interval width (I_w) is calculated as:

$$I_w = [\max(CI_i) - \min(CI_i)] / K = (1{,}164 - 354) / 6 \approx 134.83 \quad (7)$$

Table 2 presents the corrected hierarchical intervals. Sub-districts in Hierarchies I and II act as primary and secondary regional service centers; Hierarchies III and IV represent intermediate local centers; and Hierarchies V and VI denote service-deficient peripheral sub-districts.

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Table 2. Corrected Class Interval Ranges for Sub-district Service Hierarchy

Interval	Hierarchy	Description
1,029.13–1,164	I	Able to serve all sub-district areas
893.13–1,029	II	Able to serve the nearest areas
759.13–893	III	Relatively capable of serving its own area and its surroundings
624.13–759	IV	Able to serve its own area but less able to serve the surrounding areas
489.13–624	V	Less able to serve its own area or the surrounding areas
354.13–489	VI	Incapable of serving its own area or the surrounding areas

Source: Authors' calculation.

Stage 3: Potential Spatial Interaction (Gravity Model)

Potential spatial interaction (I_{AB}) between a primary growth center (A, defined as sub-districts in Hierarchies I and II: Lahat and Merapi Barat) and destination sub-district (B) is estimated using the standard Gravity formulation (Haynes & Fotheringham, 1984; Isard, 2017):

$$I_{AB} = k \times (P_A \times P_B) / (D_{AB})^{\beta} \quad (8)$$

where P_A and P_B denote total sub-district populations (BPS Lahat Regency, 2023), D_{AB} is the road network distance in kilometers between sub-district administrative capitals, $k = 1$ is a scaling constant, and $\beta = 2$ is the baseline distance-decay exponent. Because observed inter-sub-district commuting and trade flow matrices are unavailable at the sub-district level in Indonesia, I_{AB} measures potential spatial interaction rather than realized physical flows.

Hinterlands are defined using a functional adjacency and distance threshold rule: sub-districts sharing a direct administrative border or located within a 25 km road radius of a Hierarchy I–II hub. Under this rule, Merapi Barat holds a dual structural role—functioning as a secondary service hub (Hierarchy II) for eastern mining sub-districts (e.g., Merapi Timur) while simultaneously acting as an immediate hinterland node to the regency capital, Lahat (13.25 km away). To test model robustness, we conduct sensitivity checks by varying the distance exponent ($\beta \in \{1.0, 1.5, 2.0\}$) and substituting population mass with the Centrality Index (CI).

4. Results and Discussion

4.1. Service Hierarchy, Capital-City Confounding, and Normalization

The Guttman Scalogram evaluation across all 24 sub-districts confirms a cumulative hierarchical pattern in service provision. In the baseline 20-facility specification ($N \times k = 24 \times 20 = 480$ cells), error minimization yields 45 residual errors and a corrected Coefficient of Reproducibility of $COR_c = 1 - 45/480 = 0.906$, exceeding the 0.90 validity threshold. When mining and plantation companies are excluded to eliminate circularity ($N \times k = 24 \times 18 = 432$ cells), residual scaling errors drop to 14 ($COR_c = 1 - 14/432 = 0.968$), confirming strong structural consistency across core public and economic services.

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Table 3 presents the corrected service hierarchy, raw facility counts, and population-normalized centrality scores across all 24 sub-districts. The distribution is highly skewed: Lahat holds Hierarchy I (CI = 1,163.25; 559 core service units), followed by Merapi Barat in Hierarchy II (CI = 938.46; 149 core units) and Kikim Timur in Hierarchy III (CI = 883.85; 159 core units). Four sub-districts occupy Hierarchy IV (Merapi Timur, Kikim Barat, Kota Agung, and Jarai), three occupy Hierarchy V (Kikim Selatan, Tanjung Sakti Pumi, and Pagar Gunung), and the remaining 14 sub-districts including Pseksu (CI = 456.15) fall into Hierarchy VI.

Table 3. Service Hierarchy, Facility Counts, and Population-Normalized Centrality in Lahat Regency (24 Sub-districts)

Sub-district	Population	Core Units (18 Types)	Total Units (20 Types)	Centrality Index (CI)	Hierarchy	Normalized CI (per 1,000)
Coal-producing						
Lahat	109,080	559	569	1,164.00	I	10.66
Merapi Barat	26,920	149	163	938.46	II	34.86
Merapi Timur	26,170	142	150	750.00	IV	28.66
Merapi Selatan	8,570	67	70	455.00	VI	53.09
Gumay Talang	13,590	89	90	427.83	VI	31.48
Non-coal-producing						
Kikim Timur	33,150	159	159	883.85	III	26.66
Kikim Barat	18,510	145	149	699.29	IV	37.78
Kota Agung	13,900	141	141	665.00	IV	47.84
Jarai	20,680	147	147	630.71	IV	30.50
Kikim Selatan	17,800	124	124	601.48	V	33.79
Tanjung Sakti Pumi	17,110	112	112	556.30	V	32.51
Pagar Gunung	13,180	114	114	540.74	V	41.03
Muara Payang	8,980	46	46	473.33	VI	52.71
Pajar Bulan	13,060	103	103	460.00	VI	35.22
Mulak Ulu	12,780	98	98	457.04	VI	35.76
Pseksu	9,230	75	77	456.15	VI	49.42
Tanjung Sakti Pumu	14,710	92	92	449.23	VI	30.54
Tanjung Tebat	9,010	82	82	449.17	VI	49.85
Lahat Selatan	14,480	73	73	446.00	VI	30.80
Kikim Tengah	10,400	75	75	429.17	VI	41.27
Pulau Pinang	10,260	66	66	419.00	VI	40.84
Gumay Ulu	5,680	83	83	417.69	VI	73.54
Sukamerindu	8,150	55	55	407.00	VI	49.94
Mulak Sebingkai	5,770	60	60	354.00	VI	61.35

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Source: Authors' calculation.

Two empirical patterns stand out in Table 3. First, Lahat's dominant Hierarchy I status reflects its institutional role as the regency administrative capital rather than coal extraction alone. Second, and crucially, three of the five coal-producing sub-districts occupy lower service hierarchies: Merapi Timur ranks in Hierarchy IV (CI = 750.00), whereas Merapi Selatan (CI = 455.00) and Gumay Talang (CI = 427.83) fall into Hierarchy VI. Excluding the regency capital (Lahat), a two-sided Mann–Whitney U test comparing coal-producing sub-districts (n = 4, median CI = 602.50) with non-coal-producing sub-districts (n = 19, median CI = 457.04) confirms no statistically significant difference in service centrality (U = 49.00, p = 0.4095) or core service units (U = 47.00, p = 0.4904).

Table 4. Sectoral Weighted Scores and Sensitivity Analysis across Alternative Specifications

Sub-district	ED (w = 5)	H (w = 4)	EC (w = 3)	GV (w = 2, 1)	SB_i	Adj. Score	Rank	Core Units
Lahat	1,110	352	2,832	359	4,653	4,443	1	5.12
Merapi Barat	235	100	648	237	1,220	926	3	5.53
Kikim Timur	495	112	339	203	1,149	1,107	2	4.80
Merapi Timur	260	128	558	179	1,125	957	6	5.43
Kikim Barat	205	108	429	237	979	895	5	7.83
Kota Agung	235	160	261	275	931	931	7	10.14
Jarai	225	140	255	263	883	883	4	7.11
Kikim Selatan	285	104	198	225	812	791	8	6.97
Tanjung Sakti Pumi	255	80	189	227	751	751	10	6.55
Pagar Gunung	235	104	147	244	730	730	9	8.65
Muara Payang	125	52	339	123	639	639	24	5.12
Mulak Ulu	200	96	129	192	617	617	12	7.67
Pajar Bulan	205	92	63	238	598	598	11	7.89
Pseksu	145	84	195	169	593	551	17	8.13
Tanjung Sakti Pumu	220	76	96	192	584	584	13	6.25
Gumay Ulu	130	72	171	170	543	543	15	14.61
Tanjung Tebat	175	84	108	172	539	539	16	9.10
Kikim Tengah	155	52	168	140	515	515	17	7.21
Gumay Talang	175	72	78	167	492	471	14	6.55
Merapi Selatan	135	64	99	157	455	392	20	7.82
Lahat Selatan	135	64	102	145	446	446	19	5.04
Pulau Pinang	135	52	87	145	419	419	21	6.43
Sukamerindu	145	56	39	167	407	407	23	6.75
Mulak Sebingkai	120	48	42	144	354	354	22	10.40

Note: ED = education (w = 5); H = health (w = 4); EC = economic services (w = 3); GV = government and support (w = 2, 1); SB_i = baseline raw score; Adj. Score = adjusted score excluding mining and plantation

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companies; Rank = rank based on unweighted counts of the 18 core facilities; Core Units = core units per 1,000 population.
Source: Authors' calculation.

Population normalization (NCI per 1,000 residents) reveals sharp demographic scale effects. Because Lahat concentrates 109,080 residents, its per-capita centrality ratio is the lowest in the regency (10.66 per 1,000 residents), indicating high service congestion relative to population size. Conversely, sparsely populated rural sub-districts such as Gumay Ulu (73.54) and Mulak Sebingkai (61.35) exhibit high per-capita ratios driven by baseline village-level facilities, despite lacking higher-order commercial and healthcare institutions. Among coal-producing sub-districts, Merapi Timur (28.66) and Gumay Talang (31.48) exhibit below-median per-capita service ratios (regency median = 39.31), underscoring a structural lag between extractive activity and local social infrastructure. To verify that these hierarchical rankings are not artifacts of arbitrary weighting or the inclusion of mining enterprises, Table 4 compares raw weighted domain scores (SB_i) against an adjusted weighted score excluding mining/plantation companies, unweighted core facility counts (18 types), and population-normalized core facility density.

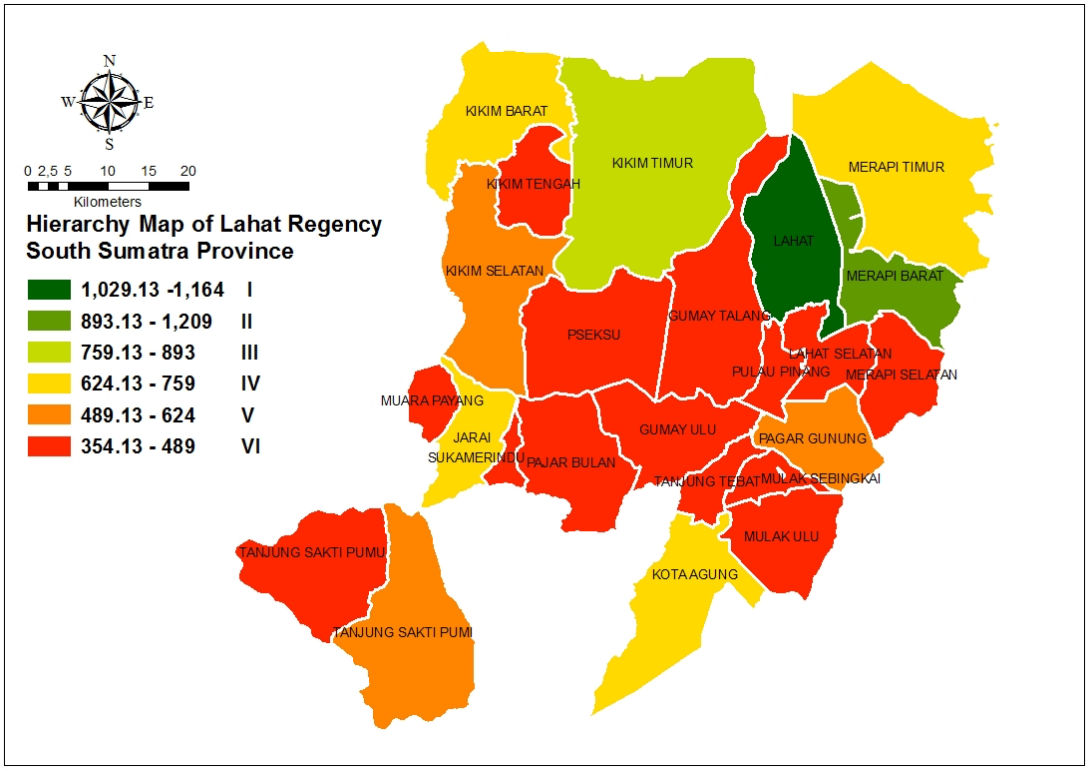


Figure 1. Hierarchical Map of Regions and Growth Centers in Lahat Regency
Source: Authors' calculation

The sensitivity checks in Table 4 demonstrate that the top-tier hierarchy is highly stable across specifications, with Lahat, Merapi Barat, and Kikim Timur consistently occupying the top three ranks. However, removing mining and plantation company weights lowers Merapi

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Barat's score by 24.1% (from 1,220 to 926, shifting it below non-coal Kikim Timur in raw adjusted points) and drops Merapi Selatan from rank 20 to rank 23 (392 points). This confirms that the apparent economic centrality of mining sub-districts is partially inflated by the physical presence of extractive firms rather than broad-based civilian service infrastructure (Myrdal, 1957; Richardson, 1976; Capello, 2015).

When cross-referencing the Scalogram-derived hierarchy (Table 3) with the Gravity-derived interaction scores, a critical pattern emerges. The sub-districts categorized in Hierarchy I and II function as "consumption and distribution centers," while those in the lower hierarchies (V and VI) act primarily as "resource extraction buffers", which is presented in Figure 1. This indicates a structural imbalance: the higher-hierarchy sub-districts attract service and industrial activity, while the lower-hierarchy sub-districts are disproportionately characterized by extractive labor participation. The lack of higher-order facilities in sub-districts such as Gumay Talang and Merapi Selatan limits their ability to capture the "value-added" components of the coal industry, effectively trapping them in a state of lower-tier economic participation. This finding aligns with the theories of Myrdal (1957) regarding cumulative causation, where the center continues to accumulate facilities and infrastructure, while the periphery experiences a relative stagnation in social service provision.

4.2. Potential Spatial Interaction and Hinterland Linkages

The Gravity index further explicates the intensity of these spatial linkages. The findings indicate that coal-producing sub-districts, particularly Lahat and Merapi Barat, act as the primary engines of the local economy. The agglomeration of industrial activities—ranging from food and beverage processing to construction and building materials is directly correlated with the presence of coal mining operations in these hubs. Meanwhile, the coal industry has successfully driven urban development in Lahat and Merapi Barat, the interaction with non-coal producing hinterlands shows signs of "backwash" rather than "spread." For instance, while sub-districts like Kikim Timur (Hierarchy III) show some capacity for self-sufficiency through commodity-based industries like palm oil and rubber processing, they remain largely disconnected from the industrial momentum of the coal-producing core. This lack of integration suggests that the coal sector in Lahat regency is currently functioning more as an "enclave economy" than a regional growth driver, as the industrial spillover is spatially confined to the core sub-districts (Capello, 2015; Osiobe, 2019). The dependency of these hinterlands on the agricultural and retail trade sectors, without significant integration into the coal-driven supply chain, further validates the concern that resource wealth has not yet been translated into equitable spatial development (Olaniyan & Ipinnaiye, 2026; Resende, 2013; Li & Li, 2018).

The spatial interaction between sub-districts, as measured by the Gravity index, reveals a stark polarization of economic activity. As demonstrated in the results, the interaction intensity (I_{AB}) is heavily weighted toward the corridors connecting the coal-producing hubs. Table 5 indicates that the strongest gravitational pull exists between Lahat and its adjacent sub-districts, particularly Lahat Selatan, and along the Lahat–Merapi Barat corridor, suggesting an intense exchange of industrial goods, labor, and service provision that validates the "Growth Pole" hypothesis within these specific boundaries. However, the model also

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reveals a significant decline in interaction intensity as distance from these coal-producing centers increases. Table 5 reports the estimated potential spatial interaction (I_{AB}) originating from the two primary service hubs Lahat (Hierarchy I) and Merapi Barat (Hierarchy II) toward all destination sub-districts, decomposed into forward (A_{ij}^{+}) and backward (A_{ij}^{-}) interaction indices.

Table 5. Potential Spatial Interaction from the Primary Hubs (Lahat and Merapi Barat)

Destination (B)	Population of A	Population of B	Distance (km)	Distance²	Interaction (I_{AB})	Forward (A_{ij}^{+})	Backward (A_{ij}^{-})
Growth center A: Lahat (Hierarchy I)							
Lahat Selatan	109,080	14,480	3.56	12.67	124,627,446	124,627,446	37,200,997
Pulau Pinang	109,080	10,260	6.16	37.95	29,493,823	29,493,823	8,803,836
Gumay Talang	109,080	13,590	9.03	81.54	18,179,799	18,179,799	5,426,627
Merapi Barat	109,080	26,920	13.25	175.56	16,725,859	16,725,859	4,992,629
Kikim Timur	109,080	33,150	20.47	419.02	8,629,646	8,629,646	2,575,929
Merapi Selatan	109,080	8,570	13.64	186.05	5,024,550	5,024,550	1,499,816
Pagar Gunung	109,080	13,180	17.10	292.41	4,916,639	4,916,639	1,467,605
Merapi Timur	109,080	26,170	25.80	665.64	4,288,540	4,288,540	1,280,119
Pseksu	109,080	9,230	22.97	527.62	1,908,204	1,908,204	569,594
Kikim Selatan	109,080	17,800	32.02	1,025.28	1,893,749	1,893,749	565,280
Gumay Ulu	109,080	5,680	19.60	384.16	1,612,803	1,612,803	481,418
Mulak Ulu	109,080	12,780	29.66	879.72	1,584,651	1,584,651	473,015
Tanjung Tebat	109,080	9,010	26.84	720.39	1,364,284	1,364,284	407,236
Mulak Sebingkai	109,080	5,770	22.26	495.51	1,270,196	1,270,196	379,150
Kota Agung	109,080	13,900	34.60	1,197.16	1,266,507	1,266,507	378,049
Jarai	109,080	20,680	43.94	1,930.72	1,168,357	1,168,357	348,752
Kikim Tengah	109,080	10,400	32.51	1,056.90	1,073,358	1,073,358	320,395
Kikim Barat	109,080	18,510	44.12	1,946.57	1,037,243	1,037,243	309,615
Pajar Bulan	109,080	13,060	38.72	1,499.24	950,206	950,206	283,634
Sukamerindu	109,080	8,150	42.63	1,817.32	489,184	489,184	146,020
Muara Payang	109,080	8,980	46.80	2,190.24	447,229	447,229	133,497
Tanjung Sakti Pumi	109,080	17,110	68.34	4,670.36	399,618	679,951	119,285
Tanjung Sakti Pumu	109,080	14,710	68.77	4,729.31	339,281	339,281	101,275
Total external interaction					**228,691,172**	**228,971,505**	**68,263,773**
Growth center A: Merapi Barat (Hierarchy II)							
Lahat Selatan	26,920	14,480	18.50	342.25	1,138,938	1,138,938	1,105,942
Pulau Pinang	26,920	10,260	22.90	524.41	526,686	526,686	511,427
Gumay Talang	26,920	13,590	24.90	620.01	590,060	590,060	572,965
Lahat	26,920	109,080	13.50	182.25	16,112,119	16,112,119	15,645,332
Kikim Timur	26,920	33,150	55.90	3,124.81	285,585	285,585	277,311
Merapi Selatan	26,920	8,570	24.40	595.36	387,504	387,504	376,278
Pagar Gunung	26,920	13,180	31.90	1,017.61	348,666	348,666	338,564

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Destination (B)	Population of A	Population of B	Distance (km)	Distance²	Interaction (I_{AB})	Forward (A_{ij}^{+})	Backward (A_{ij}^{-})
Merapi Timur	26,920	26,170	15.40	237.16	2,970,553	2,970,553	2,884,493
Pseksu	26,920	9,230	36.60	1,339.56	185,487	185,487	180,114
Kikim Selatan	26,920	17,800	61.60	3,794.56	126,280	126,280	122,621
Gumay Ulu	26,920	5,680	36.40	1,324.96	115,404	115,404	112,061
Mulak Ulu	26,920	12,780	58.20	3,387.24	101,569	101,569	98,626
Tanjung Tebat	26,920	9,010	48.50	2,352.25	103,114	103,114	100,126
Mulak Sebingkai	26,920	5,770	43.20	1,866.24	83,231	83,231	80,819
Kota Agung	26,920	13,900	54.20	2,937.64	127,377	127,377	123,687
Jarai	26,920	20,680	88.70	7,867.69	70,758	70,758	68,709
Kikim Tengah	26,920	10,400	57.00	3,249.00	86,171	86,171	83,674
Kikim Barat	26,920	18,510	71.50	5,112.25	97,470	97,470	94,646
Pajar Bulan	26,920	13,060	85.90	7,378.81	47,647	47,647	46,266
Sukamerindu	26,920	8,150	78.30	6,130.89	35,786	35,786	34,749
Muara Payang	26,920	8,980	89.50	8,010.25	30,179	30,179	29,305
Tanjung Sakti Pumi	26,920	17,110	102.00	10,404.00	44,272	45,554	42,989
Tanjung Sakti Pumu	26,920	14,710	107.00	11,449.00	34,588	34,588	33,586
Total external interaction					**23,649,444**	**23,650,726**	**22,964,330**

Note: Interaction values are computed with $k = 1$ and $\beta = 2$ and exclude self-interaction.
Source: Authors' calculation.

Table 5 reports external inter-sub-district interaction across the 23 destination sub-districts (excluding self-interaction). In the full 24 × 24 matrix, assigning a unit proxy distance (D_{ii} = 1 km) yields internal self-interaction values of 11,898,446,400 for Lahat and 724,686,400 for Merapi Barat, bringing cumulative totals to 12,127,137,572 and 748,335,844, respectively. Forward (A_{ij}^{+}) and backward (A_{ij}^{-}) indices reflect asymmetric directional attraction weighted by destination-to-origin service capacity ratios.

The Gravity estimates demonstrate steep spatial decay around the central Lahat–Merapi Barat axis. Within Lahat's immediate 15 km hinterland, potential interaction is heavily concentrated in Lahat Selatan (124.63×10^6), Pulau Pinang (29.49×10^6), Gumay Talang (18.18×10^6), and Merapi Barat (16.73×10^6), which together account for 82.7% of Lahat's total external interaction potential. Similarly, Merapi Barat exhibits a dual structural role: it acts as a secondary service pole for the eastern mining belt, generating its strongest outward linkage toward Merapi Timur (2.97×10^6, 15.40 km), while remaining closely integrated into Lahat's metropolitan orbit (16.11×10^6, 13.50 km).

Sub-districts in the northern and western clusters exhibit lower interaction scores, indicating that the "spread effect" the transmission of economic benefits is hindered by distance and a lack of integrated logistics infrastructure. This supports the observation that while coal mining provides a localized fiscal stimulus, its capacity to serve as a regional development engine is currently constrained by geographical friction and an enclave-oriented industrial structure.

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The empirical evidence suggests that the coal mining industry in Lahat Regency has not yet achieved a balanced "spread effect." To transition from the current enclave model, policy interventions must focus on bridging the infrastructural gap between the growth poles and their hinterlands. Strengthening the transport corridors between the core (Lahat and Merapi Barat) and the secondary hubs (Kikim Timur and Jarai) is essential to lower the "friction of distance" and stimulate more robust spatial interactions (Roy & Thill, 2004). Furthermore, the data suggest that diversification is necessary. The presence of non-coal potential—such as the coffee, palm oil, and rubber industries identified in Kikim Timur—presents an opportunity to leverage coal-derived capital for sectoral diversification. Promoting "forward linkages," where coal mining companies are incentivized to invest in local processing facilities within lower-hierarchy sub-districts, could serve to distribute economic benefits more equitably across the regency, thereby transforming the current polarization into a more cohesive regional system (Richardson, 1976).

4.3. Discussion

The spatial distribution of public and economic infrastructure in Lahat Regency exhibits a pronounced core-periphery polarization that challenges the foundational assumptions of classical growth pole theory. While Perroux (1950) posited that propulsive industries stimulate surrounding economic space through extensive forward and backward linkages, our empirical findings demonstrate that large-scale coal extraction operates largely as an isolated enclave. Although Lahat and Merapi Barat function as primary and secondary service hubs in Hierarchies I and II, three of the five coal-producing sub-districts—Merapi Timur, Merapi Selatan, and Gumay Talang—remain structurally deficient in basic educational, healthcare, and commercial infrastructure. This misalignment between extractive wealth and local service provision aligns with Myrdal's (1957) cumulative causation framework, wherein backwash effects outweigh spread effects, draining peripheral areas of vital developmental momentum.

Three interrelated institutional and spatial mechanisms explain why coal-producing peripheral sub-districts remain service-deficient despite substantial mineral output. First, the centralization of fiscal revenue-sharing transfers, such as the Regional Revenue Sharing Fund (*Dana Bagi Hasil*/DBH), ensures that royalties accrue primarily to regency and provincial budgets rather than being earmarked for producing sub-districts. Consequently, public capital expenditure concentrates overwhelmingly in the administrative capital, compounding its historical advantage (Wang & Gu, 2024). Second, large-scale mining operators typically establish self-contained operational compounds, captive energy systems, and private hauling networks. As Aragón and Rud (2013) demonstrated in Latin American mining contexts, extractive enclaves generate minimal local economic spillovers when firms bypass domestic commercial and retail networks (Li et al., 2023). Third, the close geographic proximity of producing zones such as Merapi Selatan and Gumay Talang to the urban core facilitates daily commuter leakage; skilled workers and corporate contractors reside and consume services in Lahat rather than generating sustained local demand for commercial banking, pharmacies, or secondary schools in the periphery.

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These sub-national dynamics mirror broader empirical evidence across developing resource economies indicating that geographic isolation and fragmented transport corridors severely restrict economic spillovers from growth poles to rural hinterlands (Roberts & Deichmann, 2011; Ahmad & Hall, 2017). When infrastructural investments are tailored exclusively for resource evacuation rather than multi-purpose regional integration, resource-rich regions frequently experience a spatial lock-in. This structural rigidity inhibits cross-sectoral diversification, leaving peripheral populations vulnerable to global commodity price volatility while locking them out of the industrial supply chain (Kinnaman, 2023; Wang & Gu, 2024; Butters, 2025; Weldegiorgis, 2025). Furthermore, institutional fragmentation across local government tiers often prevents coordinated spatial planning, leaving peripheral districts unable to capture the value-added components of the extractive economy (Abdillah et al., 2023). Significantly, our findings indicate that non-coal agricultural sub-districts, such as Kikim Timur and Jarai, achieve higher civic and commercial service rankings than several coal-producing zones. This suggests that broad-based smallholder agriculture and plantation economies foster more resilient local demand for retail, transport, and financial services than capital-intensive enclave mining. Supporting smallholder productivity through decentralized agro-industrial hubs creates dense horizontal linkages that stimulate local entrepreneurship and community-level capital accumulation (Olaniyan & Ipinnaiye, 2026; Hajdu et al., 2024). In contrast, capital-intensive extractive industries without mandated local content requirements fail to generate equivalent multiplier effects for local labor markets (Cust & Poelhekke, 2015).

The gravity-based spatial interaction estimates further underscore the friction of distance as a major bottleneck to regional integration. Potential interaction intensity decays exponentially outside the central Lahat–Merapi Barat corridor, isolating northern and western highland clusters from the regency's primary economic mass. In the absence of integrated transport logistics and adequate road infrastructure, physical separation acts as a severe barrier to trade, labor mobility, and information diffusion (Wang, 2017). Bridging this spatial divide requires targeted public investment in secondary road networks that connect peripheral service-deficient sub-districts directly to regional transport corridors, thereby reducing transit costs and expanding market access for local producers (Roy & Thill, 2004).

To overcome these structural limitations, regional development policy must transition from a mining-led extraction model toward an integrated spatial-led strategy (World Bank, 2024). This strategic realignment necessitates decentralized industrial zoning that encourages processing facilities to locate closer to peripheral production sites, transforming raw material extraction into localized manufacturing value (Zou et al., 2025). Concurrently, corporate social responsibility frameworks and local procurement regulations should be strengthened to incentivize mining enterprises to source maintenance, construction, and agricultural inputs from local enterprises in lower-hierarchy sub-districts (Li & Li, 2018; Sulista & Rosyid, 2022; He & Chen, 2024). Fostering such horizontal linkages converts extractive enclaves into symbiotic nodes within a diversified regional economy.

Moreover, addressing human capital disparities is paramount to ensuring that peripheral populations can participate meaningfully in regional economic transformation. Because educational and healthcare facilities remain disproportionately clustered in the administrative

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core, peripheral youth face structural barriers to acquiring the technical competencies demanded by modern industrial sectors (Osiobe, 2019; He & Chen, 2024). Earmarking a defined percentage of mining revenues for targeted educational and vocational infrastructure in underserved sub-districts will enhance local human capital capacity, enabling more equitable workforce participation across all hierarchical tiers (Resende, 2013).

Ultimately, achieving sustainable regional development in resource-dependent jurisdictions requires reconciling short-term fiscal revenue generation with long-term spatial equity. Rather than relying on the assumption that polarization reversal will occur organically over time (Richardson, 1980), regional authorities must actively deploy fiscal decentralization tools and strategic infrastructure planning to dismantle enclave structures (Zuo & Zhong, 2020; Wang & Gu, 2024). By aligning resource revenue reinvestment with targeted spatial connectivity, resource-rich regions can successfully transition from polarized extraction zones into cohesive, diversified, and resilient regional economies.

5. Conclusion and Suggestion

The empirical findings of this study demonstrate that large-scale coal extraction in Lahat Regency operates primarily as an isolated enclave rather than a generalized catalyst for regional growth. Although the administrative core of Lahat and the secondary node of Merapi Barat exhibit high concentrations of public and economic infrastructure, peripheral coal-producing sub-districts remain structurally underserved. This spatial mismatch indicates that extractive wealth does not automatically diffuse through surrounding territories, as cumulative causation mechanisms and backwash effects frequently outweigh potential spread benefits. Furthermore, potential spatial interaction decays rapidly outside the central urban corridor, leaving peripheral settlements hindered by the friction of distance and inadequate transport connectivity. Addressing these developmental disparities requires a fundamental policy transition from a mining-led extraction model toward an integrated spatial-led framework. Regional authorities must prioritize targeted infrastructural investments, decentralized industrial zoning, and localized procurement mandates to foster horizontal supply-chain linkages. By aligning fiscal revenue reinvestment with strategic spatial planning, resource-rich jurisdictions can successfully transform polarized extractive zones into cohesive, diversified, and resilient regional economies.

5.1. Limitations and Future Research

Several methodological limitations warrant consideration when interpreting these findings. First, the reliance on cross-sectional facility data captures static spatial hierarchies rather than longitudinal dynamics, precluding causal inference regarding infrastructure convergence over time. Second, because sub-district origin–destination commuting and commodity flow matrices are unavailable in Indonesian regional statistics, the Gravity model estimates potential spatial interaction rather than observed physical flows. Finally, facility counts reflect physical availability without accounting for variations in service quality, institutional staffing, or infrastructure capacity across sub-districts. Future research should integrate multi-year panel datasets, geospatial mobility tracking, and qualitative institutional

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assessments to evaluate how fiscal transfers and road upgrades reshape core–periphery linkages over time.

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