Comparative Study on the Coupling Coordination Relationship Between Economy and Roads in Underdeveloped and Developed Counties

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Abstract. The level and speed of regional economic development are closely intertwined with transportation infrastructure. In the context of limited resources, the mutual adaptation of economy and road construction is crucial for achieving maximum efficiency. To probe into the mutual influence between county economies and their road infrastructure in underdeveloped and developed counties, this study employs the coupling coordination degree model to explore the coordinated development of the county economy-road system. Detailed data analysis reveals significant differences in the coupling coordination degree of the economy-road system among different counties in China. Overall, the development of the economy and roads is still in a phase of mutual adaptation, indicating immense potential for future improvement. In terms of coupling degree, developed counties exhibit a benign mutually reinforcing trend between their economy and road development, while underdeveloped counties remain in a period of mutual adjustment. In terms of coordination degree, the overall coordination level of the economy-road system in developed counties is superior to that of underdeveloped counties. Additionally, the study finds that over half of the counties are ahead in road construction compared to their economic development. Developed counties' economies can better match their road construction levels, while underdeveloped counties' economies lag significantly behind their road construction progress.

Keywords: economy and roads; coupling coordination; counties; superiority degree

1 Introduction

Since the initiation of the "Silk Road Economic Belt" and "21st Century Maritime Silk Road" initiatives in 2013, China has maintained a firm commitment to building interconnected infrastructure both domestically and internationally. By 2020, China successfully lifted all impoverished counties out of poverty, a feat documented in the documentary "Endless Road." In the past, poor transportation hindered the circulation

A. K. Draman Mud et al. (eds.), *Proceedings of the 2024 5th International Conference on Big Data and Social Sciences (ICBDSS 2024)*, Advances in Computer Science Research 116,
https://doi.org/10.2991/978-94-6463-562-1_16

of goods and cultural exchanges in many impoverished counties, resulting in lagging economic development. However, with the improvement of road infrastructure, the living standards of residents in these counties have significantly improved. Roads, as the "arteries" of economic circulation, have an interdependent and mutually reinforcing relationship with economic development. On the one hand, convenient transportation can greatly boost regional economic prosperity[1-3]; on the other hand, rapid economic growth also prompts local governments to increase investment in further improving transportation infrastructure. The mutual influence between roads and the economy varies across different stages of regional economic development. Studies have found that transportation precedence contributes most to economic growth in central regions[4], while transportation investment in eastern regions has a more pronounced impact on economic growth than in central and western regions[2]. It is noteworthy that excessive road construction does not necessarily benefit the economy; instead, transportation investment should be compatible with local productive investment[5]. To delve into the relationship between road infrastructure and economic development at different socio-economic stages and regions in China's counties, this paper adopts the coupling coordination degree model and relative superiority degree analysis, conducting a comprehensive study of road mileage and GDP data from 437 poverty-alleviated counties and 82 affluent counties ranked among the top 100 in GDP in 2019. By analyzing these data, this study aims to provide a more comprehensive understanding of the dynamic relationship between roads and the economy, offering valuable insights for future infrastructure construction and economic development.

2 Method and Materials

2.1 Materials

Given the availability and standardization of data, this study selects the following four categories of counties as research objects: 68 counties that were lifted out of poverty in 2017, 169 counties in 2018, 200 counties in 2019, and 82 affluent counties ranked among the top 100 in 2019 county GDP ranking. These four categories will be referred to as "2017 Poverty-Alleviated Counties," "2018 Poverty-Alleviated Counties," "2019 Poverty-Alleviated Counties," and "2019 Affluent Counties" in subsequent analyses.

The data variables involved in this study primarily encompass road data and economic data. In terms of road data, various types of roads, including highways, expressways, main roads, secondary roads, branches and paths (non navigation roads), are differentiated. The road mileage data are based on the road network statistics from Amap from 2017 to 2019, and the road mileage of each county is used as an indicator of the level of road construction. For economic data, all data are sourced from the China County Statistical Yearbook (County-Level Cities Volume) from 2017 to 2019, and the GDP of each county is used as a quantitative indicator of the level of economic development.

2.2 Coupling Coordination Degree Model

The Coupling Coordination Degree Model is primarily employed to investigate the overall coordinated development status among two or more entities. This model comprises two components: coupling degree and coordination degree[6]. Originally applied in the field of physics, this model has been extensively extended and successfully adopted in various disciplines such as economics, geography, and urban planning [7-9]. In this paper, the model is adopted to treat road construction as one system and economic development as another, aiming to reveal the overall coordinated development level between county economy and roads.

(1) Coupling Degree

The coupling degree serves as a indicator for measuring the intensity of interaction between systems. During evolution, the state of related entities can grow from the initial to the mature stage[6]. By quantifying the coupling degree, this paper assesses the developmental stage of the coupling relationship between entities. When two entities are even, the coupling degree attains its maximum. And conversely, greatest disparities result in minimal coupling degree.

Standardized road mileage and gross domestic product (GDP) are adopted as quantitative indicators for roads and economy respectively. Utilizing the coupling model, this paper evaluates the intensity of the interaction between roads and the economy, as well as the developmental stage they are in. The calculation of the coupling degree relies on a specific coupling function formula (1).

$$C = 2\sqrt{\frac{(U_1 * U_2)}{(U_1 + U_2)^2}} \tag{1}$$

Where U_1 represents the road mileage of each county, serving as a quantitative standard for road construction level; U_2 represents the GDP of each county, measuring the level of economic development. The coupling degree ranges from [0,1], with its value directly reflecting the degree of interaction intensity between these two systems. A coupling degree approaching 0 indicates a huge difference in road construction and economic development, with minimal interaction and influence between them. Conversely, a coupling degree closer to 1 signifies a closer alignment in development levels, with more significant mutual promotion.

Based on the coupling degree, it can be categorized into different levels, which help assess the overall development status of counties. The detailed classification are presented in Table 1.

Table 1. Classification and levels of road-economy coupling degrees.

Coupling degree	Coupling level	Coupling characteristics
0	Minimum Coupling	Roads and the economy are in an irrelevant state.
(0,0.3]	Low-Level Coupling	Roads and the economy are intertwined but in a chaotic state.
(0.3,0.5]	Antagonistic	Roads and the economy restrain each other.

(0.5,0.8]	Adapting	Roads and the economy continuously adapt to each other's development.
(0.8,1)	High-Level Coupling	Roads and the economy mutually promote each other's development.
1	Maximum Coupling	Roads and the economy achieve a beneficial resonant coupling, trending towards a new ordered stage.

(2) Coordination Degree

While the coupling degree is an essential indicator of the interaction between roads and the economy, it fails to comprehensively reveal their overall "functional" and "synergistic" effects. As the values of both systems' variables converge, the coupling degree increases, yet this does not accurately reflect their individual developmental levels, which could both be high or low. Therefore, this paper introduces the coordination degree comprehensively considering the actual developmental levels of roads and the economy, to reflect their overall synergistic effects or contributions[6]. Applying the result of formula (1), the coordination degree is calculated as shown in formula (2) and formula (3).

$$D = \sqrt{C * T} \tag{2}$$

$$T = \alpha U_1 + \beta U_2 \tag{3}$$

Where α and β are the weight values of variables calculated using the coefficient of variation method. The coordination degree D ranges from [0,1], with values closer to 0 indicating a lower overall coupling coordination degree and values closer to 1 signifying an optimal state of overall coupling coordination[6]. Based on the specific values of the coordination degree, the degree of coordinated development of systems can be classified into levels as shown in Table 2.

Table 2. Classification and levels of road-economy coordination degrees.

Coordination Degree	Coordination Level	Coordination Characteristics
0	Incoordination	A state of incoordination where both roads and the economy are generally underdeveloped.
(0,0.3]	Low Coordination	Both roads and the economy are at a relatively low overall level.
(0.3,0.5]	Moderate Coordination	One of the two, either roads or the economy, begins to develop.
(0.5,0.8]	Good Coordination	The overall synergistic effect between roads and the economy reaches a high level.
(0.8,1)	High Coordination	Roads and economic development approach equilibrium, representing an ideal state.
1	Extreme Coordination	Roads and economic development mutually promote each other, achieving coordinated coexistence.

(3) Relative superiority degree

The value calculated by the coupling coordination degree model measures the level of mutual and coordinated development between two variables. However, it does not directly reflect the relative development level between the two variables. Therefore, the concept of relative superiority degree have been proposed, which is calculated by the ratio of the two variables[10]. The specific formula for calculating the relative superiority degree is as formula (4).

$$R = U_2 / U_1 \tag{4}$$

The relative superiority degree has a positive numerical range, and its value directly reflects the superiority of economic development compared to the road development. Theoretically, if this value exceeds 1, it indicates that economic development is ahead of road construction, potentially resulting in a situation where road infrastructure cannot meet the current economic development needs. Conversely, if the value is less than 1, it indicates that road construction is ahead of economic development, potentially resulting in a situation where road infrastructure temporarily exceeds the current economic development needs.

3 Results

3.1 Correlation Between Roads and Economy

Based on the distribution of sample data, the correlation between road and economy is more suitable to be evaluated by Spearman correlation coefficient[6]. The correlation coefficients of road data and economic data are shown in Table 3.

Table 3. Spearman correlation coefficients between county economy and roads from 2017 to 2019.

County Groups Year	2017	2018	2019
2019 Affluent Counties	0.49	0.50	0.41
2019 Poverty-Alleviated Counties	0.69	0.71	0.71
2018 Poverty-Alleviated Counties	0.82	0.83	0.85
2017 Poverty-Alleviated Counties	0.82	0.82	0.80

The Spearman correlation analysis reveals a moderately weak correlation between roads and the economy in affluent counties, whereas a strong correlation is observed in poverty-alleviated counties. This results suggest that the economic development of developed counties relies less on roads compared to underdeveloped counties. This study further delves into the evolution of the relationship between the economy and roads. To achieve this, economically lagging counties and economically advanced counties were selected as samples, and the coupling coordination model was employed to analyze the intrinsic relationship between the two systems.

3.2 Coupling Degrees Between Roads and Economy

Using formula (1), the coupling degrees was calculated with road mileage as variable 1 and GDP as variable 2 for each county. The results are summarized in Table 4.

Table 4. Average coupling degrees of various county groups from 2017 to 2019.

County Groups Years	2017	2018	2019
2019 Affluent Counties	0.95	0.94	0.94
2019 Poverty-Alleviated Counties	0.55	0.55	0.56
2018 Poverty-Alleviated Counties	0.61	0.60	0.61
2017 Poverty-Alleviated Counties	0.59	0.59	0.59

The coupling degree analysis indicates that poverty-alleviated counties have consistently maintained an average coupling degree within the range of 0.55 to 0.61 over the years. Referring to the coupling degree classification standards (Table 1), this result suggests that poverty-alleviated counties are in a stage of antagonism and adjustment between road construction and economic development. Although there is a certain degree of imbalance, the two are beginning to adapt to each other and seek harmonious progress. In contrast, affluent counties have consistently achieved average coupling degrees significantly exceeding 0.9, approaching the maximum level of 1, indicating a high level of coupling between economic development and road construction. This data demonstrates that in all county groups, developed counties exhibit a high degree of synchronization between economic development and road construction, fostering a positive interaction between the two.

3.3 Coupling Coordination Degrees Between Roads and Economy

Formula (2) and formula (3), when employed in the assessment, comprehensively consider both the interactions between variables within the system and their respective levels[6]. The calculated values of coordination degree based on this formula are presented in Table 5.

Table 5. Average coupling coordination degrees of various county groups from 2017 to 2019.

County Groups Years	2017	2018	2019
2019 Affluent Counties	0.58	0.59	0.60
2019 Poverty-Alleviated Counties	0.21	0.21	0.21
2018 Poverty-Alleviated Counties	0.21	0.21	0.22
2017 Poverty-Alleviated Counties	0.22	0.22	0.23

The results of coupling coordination degrees reveals that the average coordination degree in all counties remains stable or gradually increases, indicative of a steady development trend at the road-economy system. Notably, the coordination degree

values for both affluent and poverty-alleviated counties groups are lower than their coupling values. This characteristic data indicates that the level of interaction within the road-economy system is higher than the independent levels of the two variables. According to the classification standards (Table 2), affluent counties consistently maintain an average coordination degree within the range of 0.5 to 0.6, indicating a good coordination stage. In contrast, poverty-alleviated counties consistently have an average coordination degree below 0.3, falling into the low coordination stage.

3.4 Relative Superiority Degrees Between Roads and Economy

It is observed that affluent counties exhibit a lower correlation coefficient but a higher coupling degree, while the opposite is true for poverty-alleviated counties. This phenomenon can be explained by the different principles of the Spearman coefficient analysis and coupling degree analysis. The Spearman coefficient analysis emphasizes the monotonic consistency of the trends between two variables, while the coupling degree analysis highlights the proximity of the levels of the two variables. When the levels of two variables are close, regardless of their absolute values, the coupling degree is generally high. In the sample data, affluent counties have relatively higher and comparable levels of road infrastructure and economic development, leading to high coupling degrees. Conversely, while poverty-alleviated counties may have lower levels of roads and the economy, their actual coupling degrees are moderate, suggesting that one aspect of the road-economy system has surpassed the other.

To gain insights into which aspect is leading and the extent of this lead, Formula (4) is applied to calculate the relative superiority degree. As shown in Table 6, the average relative superiority degrees for all counties from 2017 to 2019 are less than 1, with affluent counties having significantly higher averages than poverty-alleviated counties. This result indicates that both developed and underdeveloped counties have road infrastructure development that is ahead of their economic development. However, the superiority in road infrastructure is more notable in underdeveloped counties due to their economic lag.

Table 6. Average relative superiority degrees of various county groups from 2017 to 2019

County Groups Years	2017	2018	2019
2019 Affluent Counties	0.69	0.65	0.62
2019 Poverty-Alleviated Counties	0.10	0.10	0.10
2018 Poverty-Alleviated Counties	0.11	0.11	0.11
2017 Poverty-Alleviated Counties	0.13	0.13	0.13

Based on the analysis results from 2019, eight counties exhibited relative superiority indices exceeding 1, all of which were affluent counties. Additionally, 47 counties had relative superiority indices surpassing 0.5, with 45 of them belonging to affluent counties group. This data underscores that only a minority of developed counties outpace the pace of their road infrastructure development, and these counties generally

possess higher economic-road relative superiority indices compared to those less economically developed. This trend indirectly reflects the advancement of China's transportation infrastructure construction.

4 Discussion

Based on the preceding results of economy and road data, this paper delves into the following four aspects for discussion.

(1) The growth of the economy in underdeveloped counties are more highly dependent on road infrastructure than that in developed counties. The Spearman correlation coefficients between economy and roads is relatively higher in underdeveloped counties, suggesting that as the road mileage increases within these counties, their GDP rankings rise correspondingly. This phenomenon underscores the significant reliance of underdeveloped county economies on road infrastructure, aligning with existing research findings that road infrastructure development in poverty-alleviated counties plays a pivotal role in achieving poverty eradication and economic revitalization[1, 3, 11]. Therefore, in current rural revitalization strategies and future planning, continuous emphasis and enhancement of road infrastructure construction should be prioritized.

In contrast, the Spearman correlation coefficient between the economy and road mileage in affluent counties is relatively low, indicating a gradual decrease in dependency on roads as regional economies mature. This can be attributed to several factors: firstly, developed counties possess sufficient funds for flexible allocation towards various infrastructure projects; secondly, their economic structures are more diversified, with industries such as the internet and finance demanding relatively less transportation; lastly, the road networks in developed counties are maturer, and economic growth is more reliant on fully exploiting and utilizing the efficiency of existing transportation[12].

(2) Underdeveloped counties have initially demonstrated a mutually adaptable trend between their economies and road construction, while developed counties have entered a stage of mutual promotion. The average coupling degrees of poverty-alleviated counties suggest that they are gradually integrating road construction with economic development after successful poverty eradication, with road construction becoming a crucial foundation for sustaining economic growth. Consequently, underdeveloped counties should fully exploit and utilize their local road infrastructure advantages to actively stimulate local industrial development vitality. Developed counties maintain a high level of average coupling degree over the years, benefiting from the high coordination between their economic development and road construction. Their economic development and road construction levels are coordinated, fostering a virtuous cycle where economic development funds road construction, which further propels economic prosperity[13].

(3) Comprehensive analysis results reveals that there is still room for improvement in the overall coordinated level of the county economy-road system, with developed counties significantly outperforming underdeveloped counties. This further under-

scores the disparities in China's regional economic development[14-16]. For underdeveloped counties, their average annual coordination degree remains at a low level, indicating that the overall efficiency of their economy-road system requires significant enhancement. Hence, intensified road construction efforts are necessary to drive economic growth, accompanied by continuous enhancement and completion of road infrastructure facilities. In contrast, developed counties have achieved a good level of annual average coordination, demonstrating their superior economic and road construction standards. Nevertheless, to pursue even higher levels of coordinated development, simultaneous advancement in both economy and roads is necessary.

(4) China's roads have been constructed rapidly, but most county economies, particularly those in underdeveloped areas, still harbor enormous growth potential. Data indicates that 98.5% of counties have an economy-road relative superiority index below 1, reflecting that in most counties, the development of road infrastructure has surpassed their economic development, due to the nation's sustained attention and proactive promotion of infrastructure construction. There are notable differences in relative superiority indices between developed and underdeveloped counties, with developed counties significantly outperforming underdeveloped counties, suggesting that underdeveloped regions have yet to fully unleash the potential efficacy of their road infrastructure in their economic layouts. This phenomenon may be associated with relatively monolithic industrial structures and intensifying population mobility in underdeveloped regions.

5 Conclusions

Employing the coupling coordination degree model to analyze county economy and road data, the following conclusions can be drawn. Firstly, underdeveloped county economies display a high degree of dependence on road infrastructure, with road construction playing a crucial role in poverty eradication and economic enhancement. While developed counties exhibit lower dependency, their economies and road construction have formed a mutually promoting virtuous cycle. Secondly, underdeveloped counties exhibit mutual adaptation with road construction, whereas developed counties have entered a stage of mutual promotion, with overall coordination levels requiring further improvement for both. Furthermore, most county economies, particularly those in underdeveloped regions, harbor immense growth potential despite road infrastructure development surpassing economic development, as economic layouts have yet to fully harness the potential efficacy of infrastructure. underdeveloped counties must intensify road construction to propel economic growth and enhance supporting facilities, while developed counties, though at a good level of coordination, still need to advance both economy and roads.

Acknowledgments

This study was financially supported by the Guangdong Province Youth Innovation Talent Project (No.2018KQNCX245) and Guangdong Educational Science Planning Project(2023ZX137).

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