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The effects of sub-central development on the economic growth of provincial capitals: A study based on the DID and PSO-RF models

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Abstract. As a core component in deepening reforms and expanding the strategy of dual circulation development, the importance of developing sub-centers for the economic growth of provincial capitals is self-evident. This paper, based on panel data from 300 prefecture-level cities in China from 1998 to 2020, constructs a progressive double-difference (DID) model to assess the impact of sub-central development on the economic growth of provincial capitals. The research reveals that the development of sub-centers at the provincial level significantly promotes the economic growth of provincial capitals. Moreover, the policies of sub-center cities have a more pronounced stimulating effect on the economic growth of provincial capitals in the central and western regions. Additionally, the more sub-center cities there are, the more apparent the effect on promoting the economic growth of provincial capitals. Subsequently, this paper employs the Particle Swarm Optimization - Random Forest (PSO-RF) model through machine learning to validate the above conclusions, confirming the validity of the findings.

Keywords: Sub-Central Development; Economic Growth of Provincial Capitals; Double-Difference Method; PSO-RF Model

1. Introduction

Over the past forty years, underdeveloped provinces and autonomous regions have continuously enhanced the primacy of their provincial capital cities, concentrating economic, transportation, educational, and other elements in the provincial capitals. However, as development reaches a certain scale, the relatively high primacy of cities reflects the various constraints of provincial economic resources, leading to the phenomenon of uneven economic development among cities within provinces. In recent years, the state has issued multiple plans to promote the formation of a multi-center development operation pattern to avoid the drawbacks of "one city dominance." Against this backdrop, the impact of developing sub-central areas on the economy of provincial capitals and its underlying mechanisms has gradually become a matter of common concern in society. This paper evaluates this issue, which not only contributes to enriching relevant research literature on "innovation-driven

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development" and the "dual circulation" development strategy but also has important reference significance for China's formulation of overall plans for the development of provincial capitals and sub-central areas.

2. Literature Review

Mark Jefferson refers to the city with the highest population within a country as the "primacy city" and defines the ratio of the population size between the primacy city and the second city as "urban primacy" [1]. The development of sub-centers can effectively divert population and industries, alleviate the pressure on the main city, and provide employment and economic opportunities for surrounding areas. The construction of sub-centers can promote spatial agglomeration in cities, leading to the formation of more dynamic and competitive urban clusters [2]. The massive concentration of resources in the primacy city intensifies its "polarization effect," adversely affecting both the economic growth within the province and the balanced development among regions. Additionally, it draws resources away from lower-tier cities at the outskirts of neighboring provinces [3].

In summary, while there is considerable richness in current research findings, some issues persist. Firstly, due to the subjective nature of the indicator system, it is challenging to avoid endogenous contradictions in the development of sub-centers and provincial capital cities. Secondly, existing research is relatively focused on the macro level, and there is a need to supplement the understanding of the role and mechanisms of sub-center construction in promoting the development of provincial capital cities.

3. Mechanism Analysis

The construction of sub-centers can ameliorate population density and alleviate traffic congestion in the main city, enhancing the quality of urban life and work efficiency. Simultaneously, it provides more employment opportunities, attracting population flow towards the sub-centers and reducing the demographic burden on the main city [4]. The establishment of sub-centers not only propels the development of provincial capital cities but also stimulates economic growth in surrounding areas. Through its ripple effect, the infrastructure and public services in the peripheral regions are expected to improve [5]. As an emerging economic hub and a highlight in urban development, sub-centers can garner media attention and public interest, elevating the visibility and reputation of provincial capital cities, thereby promoting overall economic growth for the province [6].

In summary, this paper proposes the following hypotheses: Hypothesis 1: The development of sub-centers at the provincial level has a promotive effect on the economic growth of provincial capital cities. Hypothesis 2: In comparison to eastern provincial capitals, the promotive effect of sub-center development on the economic growth of central and western provincial capital cities is more pronounced. Hypothesis 3: The more sub-center cities there are, the more apparent the effect on promoting the economic growth of provincial capital cities.

4. Research Design

4.1. Model Specification

The provincial sub-center, serving as a favorable quasi-natural experimental environment, allows for an objective measurement of urban economic development levels. The progressively double-difference model is specifically formulated as follows in Equation (1):

$$hq_{it} = c_0 + \beta_1 Did_{it} + \sum_{k=2}^{n} \beta_k Controls_{kit} + u_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Here, i represents the i-th city, t denotes the t-th year, c_0 is the constant term, β_1 is the regression coefficient for the core explanatory variable, β2-β6 are the regression coefficients for the control variables—foreign direct investment, fixed asset investment, educational capital investment,

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infrastructure, and population density, respectively. u_i denotes regional individual effects, λ_t represents the time effects for the study years, and ε_{it} is the error term.

4.2. Variable Selection

1. Dependent Variable: The paper selects per capita regional gross domestic product (pgdp) as the measure of regional economic growth.

2. Control Variables: The study employs the following variables as measures: Foreign direct investment enterprises' industrial output value of designated size (fdi) to gauge openness to foreign investment. Fixed asset investment (invest) to measure investment utility. Expenditure on education (edu) to assess human resources and human capital accumulation. Per capita urban road area (road) to evaluate urban infrastructure levels. Population density (indens) to measure population distribution and the closeness of urban development.

5. Empirical Results Analysis

5.1. Benchmark Regression Results

Using the double-difference model regression, as shown in Table 1, the coefficients for Did in regressions 1 and 2 are 0.713 and 0.093, respectively. These coefficients are significantly positive at the 1% and 5% confidence levels, indicating that the development of provincial sub-centers has a substantial promotional effect on the economy of provincial capitals under comparable conditions. From regression 2, it can be observed that the average economic growth of provincial capitals is enhanced by 9.3%. Despite a certain inhibitory effect of population density on economic growth, all other variables show a significant promotional impact. Therefore, even with different model constraints, the direction of the effect of sub-centers on provincial capital economic development remains consistent, namely, promoting economic growth. Hypothesis 1 is confirmed.

Table 1. Benchmark regression results

	Regression 1	Regression 2
Did	0.713***[0.056]	0.093**[0.043]
fdi		0.049***[0.004]
invest		0.094***[0.008]
edu		0.226***[0.009]
road		0.265***[0.009]
indens		-0.083***[0.010]
_cons	9.968***[0.006]	5.391***[0.101]
r2_within	0.025	0.455
N	6349	6349

5.2. Robustness Tests

5.2.1. Parallel Trend Test. As shown in Table 2, during the four years prior to policy implementation up to the year just before, the coefficients of the interaction terms are close to zero and not statistically significant. In the year of policy implementation, the regression coefficient is significantly positive. This suggests that before the policy implementation, the economic growth trends of provincial capitals and non-provincial capitals were similar, aligning with the assumption of homogeneity.

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Table 2. Parallel trend test results

Coefficient	Coefficient	Standard deviation
Pre4	0.131	[0.096]
Pre3	0.14	[0.096]
Pre2	0.114	[0.096]
Pre1	0.132	[0.112]
Did	0.102**	[0.043]
r2_within	0.456	

5.2.2. Placebo Test. The paper randomly shuffles provincial capitals, non-provincial capitals, and years simultaneously, simulating the experiment 500 times to generate experimental and control groups. The interaction term for sub-center city policy is constructed and regressed. As shown in Figure 1, the coefficients deviate significantly from the random mean, with P-values distributed above 0.1 in over 85% of the cases. This indicates that the establishment of sub-centers promoting economic growth in provincial capitals is not a random occurrence but is indeed caused by the policy.

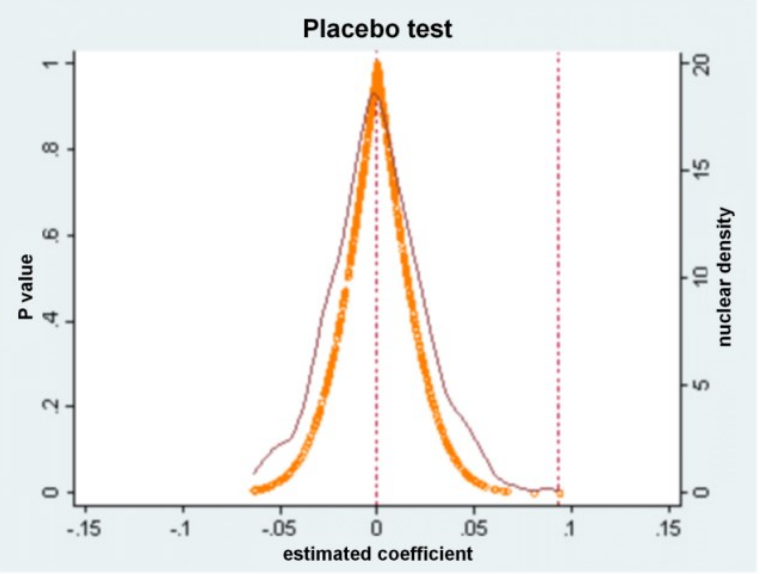

Figure 1. Placebo test results

5.2.3. PSM-DID. This paper employs Propensity Score Matching (PSM), using a Logit model to calculate propensity scores. The k-nearest neighbor matching method is used, and due to the limited sample size of provincial capital cities, a matching ratio of 1:10 with replacement is applied. After matching, balance tests have been passed, and the coefficient size, direction, and significance are consistent with the previous findings.

5.3. Heterogeneity Analysis

5.3.1. Analysis of Sub-Center Quantity Heterogeneity. In the preceding sections, the existence of sub-center policies in each province was quantified using 0 and 1. However, there are significant differences in the number of sub-center cities across provinces. This paper uses the quantity of provincial sub-centers as a moderating variable for an effect adjustment analysis. As shown in Table 3, provinces with a greater number of sub-center cities exhibit a more pronounced promotional effect on the economic growth of provincial capitals. Hypothesis 2 is confirmed.

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Table 3. Mechanism analysis results

	Regression 1	Regression 2
Did	0.105***[0.031]	0.086**[0.036]
Num2	-0.077***[0.024]	-0.081***[0.025]
Did_Num2		0.003**[0.001]
_cons	5.409***[0.103]	5.407***[0.103]
r2_within	0.456	0.456

5.3.2. Regional Heterogeneity Analysis. This paper follows the national division into eastern, central, and western regions, designating 11 provinces including Shandong, Guangdong, and Jiangsu as the eastern region, and the remaining provinces as the central and western regions. The results indicate that in the eastern group, the regression coefficient for the sub-center city policy is 0.163, but it lacks statistical significance. In the central and western regions, the regression coefficient is 0.147 and is significant at the 1% confidence level. The development of sub-center cities has a significant promotional effect on the economic growth of provincial capitals in the central and western regions, but no significant effect was observed in the eastern region. Hypothesis 3 is confirmed.

6. PSO-Based Optimization of RF Prediction Model

6.1. RF Prediction Model

The Random Forest (RF) algorithm, proposed by Breiman et al. in 2001, is a non-linear and non-parametric classifier that builds multiple decision trees in a random manner. It combines the bagging concept with the random selection of features, creating an ensemble of decision trees to achieve a more accurate and stable model. The randomness is reflected in two aspects: the random selection of features and the random sampling of data, ensuring that each tree in the forest possesses both similarities and differences.

6.2. Construction of PSO-RF Prediction Model

The Particle Swarm Optimization (PSO) algorithm, inspired by the natural hunting behavior of birds, was introduced to find optimal solutions. In this study, the PSO algorithm is employed to simultaneously optimize the five parameters of the RF model.

6.3. Experiments and Results Analysis

6.3.1. Model Training. Firstly, the data is preprocessed, and the original data is divided into a training set and a test set in a 7:3 ratio. Subsequently, the initial Random Forest (RF) model is trained using the training set data, with the mean square error chosen as the fitness function for the particle swarm. Finally, Particle Swarm Optimization (PSO) is applied to iteratively optimize the fitness function. The optimal parameters are: n_estimators=37, max_depth=16, max_features=7, min_samples_split=2, min_samples_leaf=1.

6.3.2. Evaluation Indicators and Results. As shown in Table 4, the model exhibits high accuracy and excellent generalization ability. The feature weight in Figure 2 indicates that the number of sub-centers contributes 0.007 to the Provincial Gross Domestic Product (PGDP) of provincial capitals, signifying a certain promotional effect.

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Table 4. Evaluation indicators

Model name	Indicator Name	Indicator value
PSO-RF model	score	0.9348
	OOB score	0.8148
	mean squared error	0.0178
	mean absolute error	0.1016
	R^2	0.8131

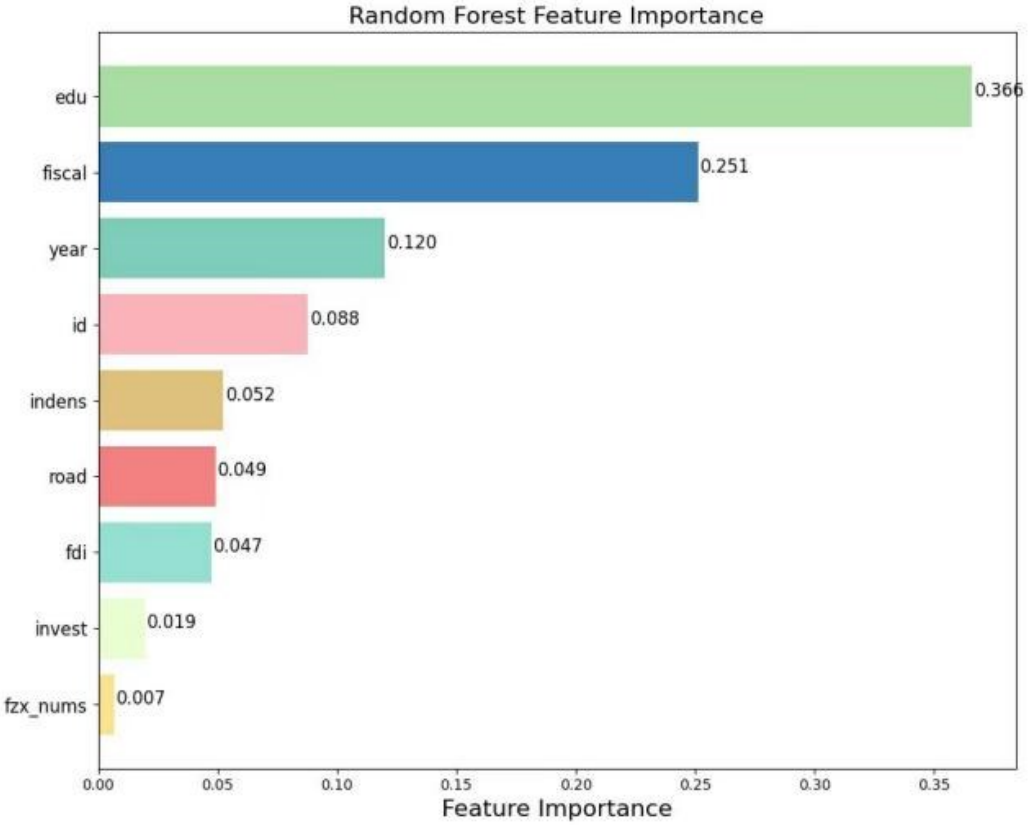

Figure 2. Feature weight

Using the PSO-RF model to predict various cities and taking the average, Figure 3 depicts a predictive graph with the number of sub-center cities as a variable. It reveals that the development of provincial sub-centers has a promotional effect on the economic growth of provincial capital cities. Additionally, the more sub-center cities there are, the more apparent the effect on promoting the economic growth of provincial capital cities.

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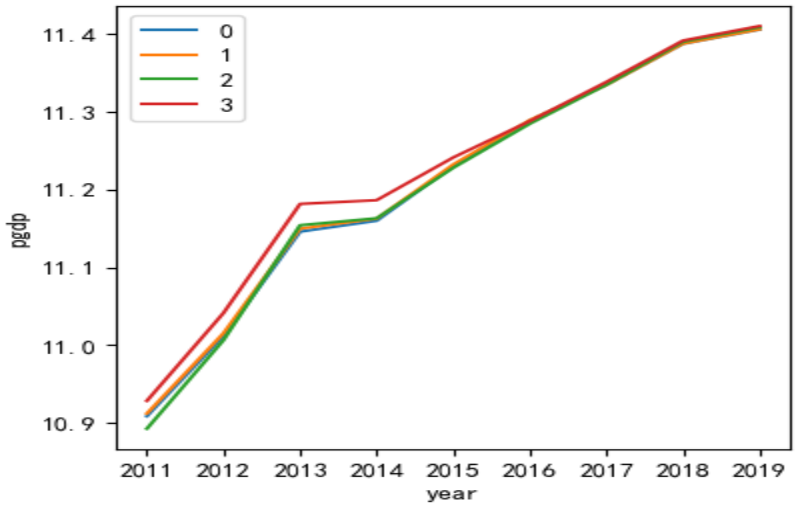

Figure 3. PSO-RF model for predicting economic growth in provincial capitals

7. Conclusion and Implications

This study has found that the development of provincial sub-centers has a promoting effect on the economic growth of provincial capital cities. In comparison to eastern provincial capitals, the promoting effect of developing sub-centers on the economic growth of central and western provincial capital cities is more pronounced. Additionally, the more sub-center cities there are, the more apparent the effect on promoting the economic growth of provincial capital cities. The above conclusions provide the following insights for the construction of the new round of provincial sub-centers in China: 1. Strengthening comprehensive awareness of accelerating development and high-quality growth strategies. 2. Scientifically formulating strategic plans for sub-center cities. 3. Continuously enhancing infrastructure construction. 4. Tailoring the development of sub-center cities to the specific conditions of different regions.

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