Effects of the Grain for Green Program on Vegetation Restoration in Shaanxi Province: A Postprint Based on PCSE-Corrected Panel Data Model

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Abstract

Based on SPOTVEG NDVI data from 1998 to 2013, this study employs the dimidiate pixel model and Panel-Corrected Standard Error (PCSE) estimation method to analyze the spatiotemporal variation characteristics of vegetation cover in Shaanxi Province and the relative contributions of natural and socioeconomic factors such as the Grain for Green Project and rainfall levels to vegetation cover changes, and to explore the driving effect of the Grain for Green Project on vegetation restoration. The results indicate: Vegetation cover in Shaanxi Province shows an overall increasing trend, with the annual average Normalized Difference Vegetation Index (NDVI) value increasing by 0.98% from 1998 to 2013, and the vegetation restoration effect is more pronounced during the implementation phase of the Grain for Green Project (1998–2009). The vegetation restoration effect in Shaanxi Province exhibits significant spatial differentiation; over the 16-year period, the magnitude of NDVI increase varies across regions, with 40.61% of areas increasing by approximately 0.1, 29.05% of areas increasing by approximately 0.2, and 23.69% of areas increasing by more than 0.25. Among these, Yan' an City, located in the Northern Shaanxi Grain for Green area, shows the most pronounced vegetation restoration effect, with an annual NDVI increase of approximately 1.12%. The Grain for Green Project has a significant impact on vegetation restoration; each 1% increase in the area of converted cropland to forest as a proportion of total land area results in a 1.97% increase in NDVI value, equivalent to a 4.29% increase in precipitation, which holds important reference significance for ecological environment construction in Shaanxi Province, where precipitation is scarce and unevenly distributed.

Full Text

2. Methods

2.1 Data Processing and Vegetation Fraction Calculation

The study utilized SPOT VEG NDVI data for Shaanxi Province from 1998 to 2013. The pixel dichotomy method was employed to calculate vegetation fraction, with the fundamental principle expressed as:

$$NDVI = NDVI_{veg} \times fc + NDVI_{soil} \times (1 - fc) \quad (1)$$

where $NDVI_{veg}$ represents the NDVI value for pure vegetation pixels, $NDVI_{soil}$ represents the NDVI value for pure soil pixels, and fc denotes the vegetation fraction.

From equation (1), the vegetation fraction can be derived as:

$$fc = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \quad (2)$$

In practice, $NDVI_{veg}$ is typically set to 1 and $NDVI_{soil}$ to 0. However, due to atmospheric conditions, sensor observation angles, and soil moisture variations, these theoretical values are rarely observed in actual NDVI data. Therefore, the maximum and minimum NDVI values are often used as proxies for pure vegetation and pure soil pixels, respectively. The vegetation fraction can then be calculated using the following simplified formula [**?**, **?**]:

$$fc = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (3)$$

2.2 Panel Corrected Standard Errors Model

To analyze the driving factors of vegetation regeneration, we employed the Panel Corrected Standard Errors (PCSE) model. This approach is particularly suitable for panel data analysis as it accounts for both heteroskedasticity and contemporaneous correlation across panels [**?**]. The model specification is as follows:

$$\ln NDVI_{it} = \beta_0 + \beta_1 \ln prec_{it} + \beta_2 \ln pop_{it} + \beta_3 \ln gdp_{it} + \beta_4 farm_{it} + \beta_5 RGPF_{it} + \mu_{it}$$

where $NDVI_{it}$ represents the NDVI value for county i in year t, $prec_{it}$ denotes precipitation, pop_{it} is population, gdp_{it} is gross domestic product, $farm_{it}$ represents farmland area, and $RGPF_{it}$ is the Grain for Green Project factor. The error term μ_{it} captures unobserved heterogeneity.

The PCSE estimation was conducted using Stata 12.0. A Hausman test was performed to determine the appropriate model specification, with results indicating that a fixed-effects model was suitable for this analysis. All variables were log-transformed to address potential non-linearity and to interpret coefficients as elasticities.

3. Results

3.1 Temporal Variation of Vegetation Cover

The analysis revealed a consistent improvement in vegetation cover across Shaanxi Province from 1998 to 2013. The annual average NDVI increased by 0.98% during this period. The implementation of the Grain for Green Project between 1998 and 2009 demonstrated particularly pronounced effects on vegetation regeneration.

The temporal trend analysis showed that NDVI values exhibited significant interannual variability. In 2000, the average NDVI was 0.439, while in 2012 it reached 0.601, representing an increase of 0.162 units. The overall trend analysis for the period 1998-2013 indicated a statistically significant upward trajectory in NDVI values at the 99% confidence level.

3.2 Spatial Distribution of Vegetation Change

The spatial analysis revealed heterogeneous patterns of vegetation change across the province. Over the 16-year study period, NDVI increased across most areas, with varying magnitudes:

- 40.61% of the region experienced an NDVI increase of 0.1
- 29.05% of the region showed an increase of 0.2
- 23.69% of the region demonstrated an increase of 0.25

The most significant vegetation regeneration effects were observed in Yan' an City, located in northern Shaanxi, where NDVI increased by 1.12%. This area represents the core implementation zone of the Grain for Green Project and exhibited the strongest positive response.

[Figure 3: see original paper]

Figure 3. Difference in NDVI values in Shaanxi Province in typical years

[Figure 4: see original paper]

Figure 4. Quantitative spatial distribution of driving factors for vegetation regeneration in Shaanxi Province

3.3 Driving Factors Analysis

The PCSE regression results, presented in Table 2, indicate that all included variables significantly influenced vegetation dynamics. Precipitation emerged as the primary natural driver, with a coefficient of 0.4594 ($p < 0.001$). The Grain for Green Project factor showed a strong positive effect with a coefficient of 1.9725 ($p < 0.01$), demonstrating the project' s significant contribution to vegetation restoration.

Table 2. Regression results of PCSE

Variable	Coefficient	Std. Error	P-value
ln(prec)	0.4594	0.0919	0.000***
ln(pop)	0.5131	0.0305	0.000***
ln(gdp)	-0.0758	0.0146	0.000***
farm	-2.7436	0.1891	0.000***
RGPF	1.9725	0.7071	0.005***

Note: ** indicates $P < 0.01$*

The results suggest that a 1% increase in Grain for Green Project implementation area yields a 1.97% increase in NDVI, an effect equivalent to a 4.29% increase in precipitation. This underscores the substantial impact of ecological restoration policies on vegetation regeneration.

Population density showed a positive correlation with NDVI (coefficient = 0.5131), likely reflecting improved management and protection in populated areas. Conversely, farmland area exhibited a strong negative relationship (coefficient = -2.7436), indicating that agricultural expansion constrains vegetation recovery. GDP showed a modest negative effect, possibly associated with urbanization and industrial development pressures.

4. Discussion

The spatial heterogeneity in vegetation regeneration effectiveness can be attributed to differential implementation intensity of the Grain for Green Project and varying baseline ecological conditions. Northern Shaanxi, particularly Yan' an region, demonstrated the most remarkable improvement, where the project was most extensively implemented. The conversion of steep slope farmland to forest and grassland in this region effectively reduced soil erosion and enhanced ecosystem stability.

The quantitative relationship between the project implementation and NDVI improvement provides valuable insights for policy evaluation. The finding that project effects are comparable to substantial precipitation increases highlights the importance of human intervention in ecological restoration, particularly in arid and semi-arid regions where water is the limiting factor.

However, the negative impact of farmland expansion on vegetation cover underscores the ongoing challenge of balancing agricultural production with ecological conservation. Sustainable land use planning that integrates food security and environmental protection objectives remains crucial for long-term vegetation regeneration success.

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Note: Figure translations are in progress. See original paper for figures.