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The Impact of the Three-North Shelter Forest Program on Rural Income

Evidence from Inner Mongolia in China

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Keywords: Three-North Shelter Forest Program, rural income, afforestation, spatial econometrics, spillover effect

JEL Codes: Q15, Q18, Q23, Q24, Q28

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1. Introduction

Deforestation and forest degradation remain major challenges to sustainable development and poverty reduction globally. A sustainable forest restoration project must achieve both ecological and economic benefits (Adams *et al.*.2004), because pursuing only ecological benefits while neglecting economic principles in resource allocation would not mobilize people's enthusiasm for production, while focusing solely on profits while violating ecological principles would lead to negative effects such as increased pests and diseases, declining groundwater levels, and the "small old trees phenomenon"[1]. However, not all of the large ecological restoration projects in the world, such as the Prairie States Forestry Project in the United States, the Green Plan in Canada, and the "Green Dam" shelterbelt project in five North African countries, have achieved both ecological and economic targets (Briain.2012; Mayer.2017; Khaouani *et al.*.2019; Howlader.2020; Li.2021; Ramzi *et al.*.2021).

China's main battlefield for sustainable forestry is composed of 11 contiguous poverty-stricken areas and 592 key development-oriented poverty-reduction counties, of which 80% are in mountainous areas, forests, and deserts (SFA.2016). These impoverished people rely heavily on natural resources for their livelihood, which puts pressure on the resources, including forests. This leads to a vicious circle of poverty and ecological deterioration (Mabogunje.2007). Whether forest restoration programs can improve both ecological conditions and the impoverished residents' income remains an open question. This paper uses a novel spatial econometric analysis to evaluate the direct and spillover effects on rural income of the Three-North Shelter Forest Program (TNSFP or "the program" hereinafter), which is the first and one of the largest forest restoration projects in China.

The Chinese government initiated the TNSFP in 1978 for ecological restoration, and has started another six major forestry projects since 1998, covering 97% of the counties in China, with a total of 1.1 billion mu[2] of afforestation and an investment of over 100 billion Chinese Yuan (CNY). While the world's forest coverage decreased by 1.935 billion mu from 1990 to 2015 (FAO.2015), this figure increased in China, by 1.12 billion mu. The total output value from the forestry industry increased from 409 billion CNY in 2001 to 5.94 trillion CNY in 2015, a 13.5-

[1] Tree planting without proper distance is one of the causes of the phenomenon of "small old trees", with the results of thin and weak trunks and crowns, scattered branches, and unhealthy leaves.

[2] Mu is a land area unit used in rural China. One mu equals one-fifteenth of a hectare.

fold increase over the 15 years, associated with 700 million farmers escaping from poverty (MacDicken *et al.*.2016).

The TNSFP consists of three stages and eight phases, beginning in 1978 and intended to run through 2050. It sets a goal of 35.6 million km^2 for afforestation, increasing forest coverage from 5.05% to 15.95% in the Three-North area (Northeast, North, and Northwest), with effective control over wind and sand damage as well as soil erosion. The program involves a total of 725 cities and counties in 13 provinces, autonomous regions, and municipalities in the Three-North areas, covering a total area of 4,069 thousand square kilometers, accounting for 42.4% of China's land. Compared to the Roosevelt Project in the United States, the Stalin Reconstruction Nature Plan in the Soviet Union, and the Green Dam Project in the five countries of North Africa, the TNSFP exceeds them in terms of both scale and duration. It has been regarded as the world's largest ecological project and is known internationally as "the Green Great Wall of China".

At the start-up stage of the program, the overall plan was to establish shelter forests that improved both ecology and the economy. However, it was difficult to achieve the dual targets. One major cause is that the program's socioeconomic assessment lagged behind. Despite the relatively large number of assessments on the TNSFP's effect on ecological benefits (Xiao.1994; Zhang and Song.2003; Cao.2008; Wang *et al.*.2010; Li *et al.*.2012; Wang *et al.*.2012; Zhu *et al.*.2016), research on socioeconomic benefits of the program has been slow (Lin *et al.*.2008).

The previous literature on the TNSFP's socioeconomic effects is limited and yields mixed findings. Some literature argues that the implementation of the program considered only the ecological benefits and neglected the need for economic growth, and therefore it had no significant effect on improvement of rural livelihoods (Zhang *et al.*.2013). As a result, human activity undermined the achievements in land reclamation and ecological restoration, resulting in environmental degradation (Cao 2012). In addition, there were problems such as lack of construction funds, difficulties in establishing forests, and a low survival rate of afforested trees (Zhang.1996). On the contrary, some other scholars and evaluation agencies argue that the TNSFP exerted a positive influence on the development of the rural economy, such as the creation of job opportunities and the increase in rural income (Chen *et al.*.1985; Three-North Shelterbelt Beraeu.2008). The contradictory findings from previous literature could result from differences in the regions studied or in analytical methods. For example, Liu and Lv (2009) estimate the effects of China's Priority Forestry Programs (PFPs) on farmers' income by a pooled OLS estimator with panel data for 31 provinces from 1997 to 2005, while Liu *et al.* (2010) apply a fixed effects model with panel data for about 2000 households from 10 counties in four provinces in China from 1995 to 2004.

To fill in the gap between practice and socioeconomic benefit assessment, this paper estimates the effect of the TNSFP on rural income, with a focus on the Inner Mongolia Autonomous Region. The Inner Mongolia Autonomous Region, which is the home of many ethnic minorities, spans the Three-North area. Historically, most of Inner Mongolia consisted of forest steppe zones. This area has suffered from severe land desertification and other ecological destruction due to population expansion and livelihood needs that unsustainably deforested the area. In turn, ecological deterioration has slowed economic growth and kept the population in poverty. In 1978, Inner Mongolia enrolled in TNSFP and carried out a plan with massive afforestation across the entire region. According to China's Eighth Forestry Resource Inventory, the forests in Inner Mongolia have increased by 18.22 million mu, reaching a total of 37.3 million mu. It is now the province with the largest forestry coverage in China. By 2015, Inner Mongolia's rural per capita net income had increased from 131 CNY in 1978 to 10776 CNY in 2015, breaking 10,000 CNY for the first time in history and almost doubling the per capita income at the end of Eleventh Five-Year Plan Period (2007-2012).From the point of rural income structure in Inner Mongolia, crop cultivation-based operating income accounts for over 50% of total rural income, and the proportion of wage income, property income and transferred income are is less than 50%, there is a downward trend in operating income, but growing trend in other else over the years (Gao *et al.*.2020).

In this paper, we use panel data from 1993 to 2015 for 101 counties in Inner Mongolia to explore how the TNSFP has affected rural income through its impacts on land use, investments, employment, and long-run forest resources. Because both afforestation area and forest stock affect rural income, and they work in different channels, we take both into account in the analysis of the impact of the TNSFP on rural income. Modeling the two sets of characteristics could yield a more comprehensive conclusion, compared to the literature that usually focuses on either of the two types of characteristics.

We distinguish direct and spillover effects of the program by considering the spatial interaction of rural income and forest resources. We choose this approach because the ecological effects produced by forest vegetation often work in accordance with ecological borders rather than administrative borders, such as county or village, which often are the basis of evaluation. Rural income is not only affected by the forest vegetation in a local administrative unit but also by that of nearby units. Ignoring this spillover effect may lead to false conclusions about the relationship of economic and ecological conditions (Lichstein.2002).

We also distinguish the effects of different afforestation methods (artificial planting of seedlings, aerial sowing of seeds, and enclosing hillsides to create protected areas) and the effects of different forest vegetation (tree, shrub, and grass). According to the overall planning scheme of the TNSFP, the implementation of this program requires an integration of agriculture, forestry, and animal husbandry, in terms of industrial structure; a combination of artificial planting, aerial sowing, and enclosed hillsides for forest reserves, in terms of afforestation; complementary trees, shrubs, and grasses, in the aspect of forest vegetation; and a mixture of multiple forest categories and seeds of trees (Three-North Shelterbelt Bureau.1993). With these distinctions, we can derive more insightful policy implications on the choice of afforestation method and forest vegetation.

Our results suggest that annual artificial afforestation of the TNSFP improved rural income significantly, and so did this afforestation from neighbors; accumulative artificial afforestation and has a negative influence on the growth of rural income, but this afforestation from neighbors exactly resulted in a reverse effect; grassland shows benefit to rural income for good ecological effect in arid and semi-arid region in Inner Mongolia. These findings provide evidence of the impact of the program on rural income and the mechanisms through which it works. Our work contributes to policy-makers' understanding of the social and economic impacts of a large-scale, national ecological project, shedding light on future plans that aim to achieve the dual targets of ecological and economic benefits.

The remainder of the paper is structured as follows. Section 2 describes the conceptual framework, including the mechanisms of the impact of the TNSFP on rural income, and presents the hypotheses. Section 3 describes the models that are used for testing the hypotheses. Section 4 introduces the data. Section 5 presents the results of the empirical analysis. Section 6 concludes with policy implications.

2. Conceptual framework

A typical forest restoration program can affect rural income by increasing local employment and investment (employment and investment effects) and improving the environment (ecological effect). The employment and investment effects depend on afforested and reforested areas as well as on forest stock, because better forest resources facilitate the development of related industries and forest tourism. Artificial afforestation involves investments, labor demand, and compensation for the ecological value of afforested trees, which could increase labor income or transfer income. In contrast, aerial sowing and enclosing land for reforestation does not have much labor demand and therefore may contribute little to local income. Ecological effects depend on forest stock, because better forest resources improve crop yield and residents' health, which could increase the income of local farmers as well as neighboring residents. The latter contributes to the spillover effect of a forest restoration program. We summarize these effects of the TNSFP on rural income in Figure 1 and elaborate on them in the following subsections.

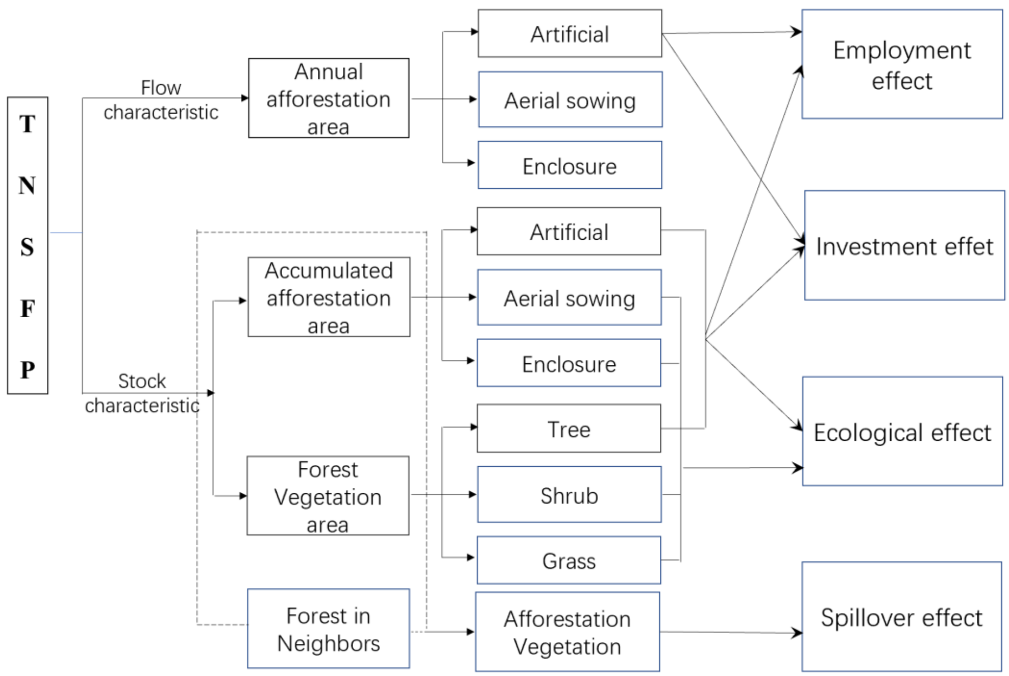


Fig 1 The Framework of the TNSFP Effects on Rural Income

2.1 Employment effect

Forest programs can create jobs through afforestation, reforestation, tree cultivation, harvesting, product processing, and forest tourism. Increased labor employment in these industries drive development in related industries, and increase rural income (Ke *et al.*.2010). Along with the development of a low-carbon economy and modern forestry, forest tourism has become an emerging industry that promotes economic growth; this also has contributed to increased rural income. Importantly, forest tourism is labor-intensive and highly linked with employment in other industries, and thus has a large capacity for employment.

In China as a whole, by the end of 2015, there were 3,234 newly constructed national forest parks, spanning 18.02 million hectares and employing 172.3 thousand people in management and services, in addition to 16.7 thousand tour guides (China's Forestry Website). The total employment in national forest tourism is estimated at 6.77 million during 2005-2020. Of the total employment of 5.121 million people during 2011-2020, 2.385 million were directly employed by the forest parks, and the remaining 2.736 million were indirectly employed (Ke *et al*., 2011). Because the Chinese government has increased its investment in forestry in response to global climate change, it is likely that forestry has great potential to continue to create jobs and increase rural income.

Moreover, in Schultz's Human Capital Investment Theory, the main reason for the low income in developing countries is not labor surplus, but low investment in human capital and education, resulting in poor labor quality (Schultz.1961). In rural China, education and training have become the core of human capital, which has a decisive effect on the increase of rural income (Guo and Chang.2007). Forestry projects contribute to this trend by educating the participants and training the employed workers for afforestation and reforestation. For example, the Global Forest Education Project initiated by the FAO aims at capacity development and knowledge sharing that could improve forestry skills.

In addition, farmers participating in the TNSFP are entitled to subsidy payments for afforestation. Recently, the central subsidy for the TNSFP has increased substantially: the per-*mu* subsidy for artificial afforestation has increased from 200 to 500 CNY. In addition, farmers who enrolled their own forestland into the TNSFP receive subsidies for maintaining an ecological forest.

Based on the analysis, we propose a hypothesis as follows:

Hypothesis 1. Annual artificial afforestation and forest stock in the TNSFP help increase rural income by providing job opportunities, work skills, and cash transfer.

2.2 Investment effect

The public investment initiated by the TNSFP promotes economic growth, and thereby increases rural income. Keynesian investment theory holds that investment correlates positively with income. The positive coefficient is regarded as the investment multiplier.

Since the implementation of the program, central fiscal policy for forestry development has increased year by year. In order to ensure effective implementation of the project, China has invested hundreds of billions of CNY in six key forestry projects. A large number of project investments are in the areas of constructing supporting infrastructure such as farmland irrigation, water conservation, and the transportation and energy sectors, which in turn promoted local economic growth and increased rural income (Queiroz and Gautam.1992; Kala *et al.*.2003).

Specifically, rural infrastructure investments can improve productive efficiency in agriculture by reducing production costs and enlarging market capacity. With increased fiscal expenditure for agriculture, rural production costs could be subsidized through transfer payments, which would incentivize more production. Meanwhile, public goods and services financed by the fiscal expenditure can reduce transaction costs and facilitate the expansion of production and market scale (Du and Huang.2006).

Meanwhile, these investments can contribute to increased rural income via enhanced resistance to natural and economic risks, as well as stabilized production and sales (Teruel and Kuroda.2005; Heerink *et al.*.2009; Mamatzakis.2015). For instance, Zhang *et al.*.2013 focus on the financial investment of the Key Forestry Sand Control Projects, which is part of the TNSFP in China, and find that the national and social investments in the TNSFP have had a significant impact on the increase of afforested land and grassland.

Based on this analysis, we propose a hypothesis as follows:

Hypothesis 2. Investments from afforestation in the TNSFP increase rural income by improving rural infrastructure and farmers' ability to be resilient to risks.

2.3 Ecological effect

Yield-improving effects -- Forestry programs improve agricultural and livestock production, raise the yield per unit area, shelter cultivated lands from sand erosion, prevent loss of water and soil, and so on. A shelter forest can directly protect farmland from wind erosion, and thereby increase grain yield; it is one of the most important forest categories the forestry program (Kort.1988). According to empirical evidence, the yield-improving effects of farmland shelterbelts are universally more than 10%, and are more than 30% in the zone with the worst sandstorm hazards. The improvement of yield increases rural income by 13%; profit in years of drought is double what it otherwise would be (Miloserdov.1989). Besides, windbreak forests can reduce wind speed by 33%; this improves the production of grass, which increases the survival rate of cattle, thus reducing losses in animal husbandry (Bird.1988).

Health effects -- Forestry programs can increase income by promoting rural health and labor productivity. Forests have the functions of reducing the frequency of sandstorms and the prevalence of dust. Sandstorms are a major health threat in the Three-North region of China. During a sandstorm, the concentration of atmospheric total suspended particulate matter (such as PM10 and PM2.5) increases significantly. Inhaling suspended particulate matter seriously harms the respiratory system (Hefflin *et al.*.1994). Afforestation and ecological restoration in forests reduce sandstorms. (Chen *et al.*.2003) use meteorological data from western Inner Mongolia to study the ecological benefits of the Three-North shelter forests system in the region and find that the Three-North shelter forests have contributed to reducing the numbers of windy days and sandy days, by weakening the meteorological factors that lead to sandstorms.

Based on the analysis, we propose a hypothesis as follows:

Hypothesis 3. Ecological improvement resulting from accumulated afforestation (artificial, aerial, and enclosure) improves rural income by increasing crop yield and livestock survival and by improving local residents' health and labor productivity.

2.4 Spillover effects

Spatially neighboring administrative regions usually interact with each other along the dimensions of economic development, culture, customs, and so on. Neighboring areas with similar cultural background are likely to spread and exchange knowledge, and areas with a similar economic level benefit from joint utilization of economic resources through increasing returns to scale (Wang.2013). The Inner inhabitants of the Mongolia Autonomous Region in China tend to have the same religious beliefs, lifestyle, and customs. Therefore, the interaction of neighboring administrative regions in Inner Mongolia should be taken into account in our estimation.

Forest vegetation also has spatial correlation, as trees both compete with each other and are interdependent with other trees growing nearby (Zhang *et al.*.2016). As mentioned above, the ecological effects of a forest function according to ecological rather than administrative boundaries. Ecological benefits such as wind prevention and sand fixation, resulting from a forest in one administrative region, usually overflow to influence the trees in surrounding areas.

For these reasons, the spatial correlations we take into account should include two parts: spatial correlations in rural income and spatial spillover effects of trees.

Based on this analysis, we propose a hypothesis as follows:

Hypothesis 4. Rural income in one region is affected not only by local forest activities and conditions but also by those of surrounding regions.

3. Empirical models

3.1 Classic econometrics model

Based on the above factors, we estimate the impact of the TNSFP on rural income. As earlier mentioned, there are three types of afforestation projects in the Inner Mongolia TNSFP region — artificial afforestation (planting seedlings), aerial seeding, and enclosing land to allow forests to increase, as in a protected area. Artificial afforestation is the most widely used afforestation method with the highest survival rate in the Three-North region of China in the early years (Zhu *et al.*.2004) Also, it is a main contributor to rural income due to increased employment for afforestation and related infrastructure construction. Accumulated artificial afforestation is beneficial to farmland protection and human health, although the effects are not noticeable on a short-term (i.e., annual) basis. While accumulated aerial sowing area and accumulated enclosed area provide ecological benefits, they do not provide much employment and do not entail investment for infrastructure construction.

On the basis of the above analysis, we estimate the effect of the TNSFP on rural income in a double logarithmic model of the Cobb-Douglas production function as follows

$$\ln Income_{it} = \alpha + \beta ln Artificial_{it} + \beta_1 ln \sum_1^{t-1} Artificial_{it} + \beta_2 ln \sum_1^{t-1} Aerial_{it} + \beta_3 ln \sum_1^{t-1} Enclosure_{it} + \theta ln Z_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where i and t represent a county in Inner Mongolia and year, respectively; $ln\, income_{it}$ represents the natural logarithm of per capita farmer income; and $lnartificial_{it}$ represents the natural logarithm of annual artificial afforestation area of the TNSFP; $ln\sum_1^{t-1} Artificial_{it}$, $ln\sum_1^{t-1} Aerial_{it}$ and $ln\sum_1^{t-1} Enclosure_{it}$ are the natural logarithm of the accumulated artificial afforestation area, accumulated aerial sowing area and accumulated enclosing area, respectively. We use accumulated area $\sum_1^{t-1} X$ rather than $\sum_1^{t} X$ is because the trees planted don't produce a measurable quantity of environmental effects in the first year (Zhong and Wang.2001). lnZ_{it} represents the natural logarithm of all the explanatory variables, including fiscal expenditure, the number of students in high school (representing the overall education level), meteorological patterns, and afforestation methods in one of the eight other ecological forestry programs[3] implemented in Inner Mongolia; α is the interception; μ_i and λ_t are county and time fixed effects, respectively; and ε_{it} is random error. These definitions of variables apply in the equations that follow as well.

β captures the employment and investment effects of the artificial forestation in the TNSFP. Artificial afforestation is the dominant afforestation method in the program, and it requires a great deal of labor from local farmers, as described in Hypothesis 1. In this way, people participating in afforestation work increased income. Meanwhile, the afforestation supplies such as tree seedings, chemical fertilizer, pesticides and so on can be drivers of the local economy, and thereby promote the growth of rural income, as described in hypothesis 2.

β_1, β_2 and β_3 capture the effects of forest stock on rural income. The three parameters distinguish the effects of forest stock afforested with different methods: artificial, aerial sowing, and enclosure. The accumulated afforestation areas of three afforestation methods can drive a low-carbon economy and modern forestry through, for example, the forest tourism industry, which helps provide employment for farmers (as described in hypothesis 1). Moreover, with the accumulation of the afforestation, the investment in the infrastructure in rural areas can form a long-term mechanism for the development of the local economy, promoting continuous improvement of livelihoods (as described in hypothesis 2). Last, but the most important, the forest

[3] The other programs are the Sand Control Program, Plain Greening Program, National Key Environmental Protection Program, Shelter Forest Program in the Upper and Middle Reaches of the Yellow River, Shelter Forest Program of Liao River Basin, Natural Forest Protection Program, Grain for Green Program, and Desertification Combating Program around Beijing and Tianjin.

stock improves the environment, which both increases crop yield and promotes human health, both of which can increase rural income (as described in hypothesis 3).

In equation (1), we used accumulated afforestation area as the measurement of forest stock. Another measurement could be forest land area. Therefore, in equation (2), we substitute accumulated afforestation area with land areas of various vegetation types (i.e., trees, shrubs and grass). In this way, the effects of forests on income can be measured, and pertinent policy implications can be proposed, for different programs within TNSFP and with different structures of forest vegetation. In addition, the different types of forest stock can be treated as robustness tests for each other. The econometric model is as follows:

$$\ln Income_{it} = \alpha + \beta lnArtificial_{it} + \beta_1 lnTree_{it} + \beta_2 lnShrub_{it} + \beta_3 lnGrassland_{it} + \theta lnZ_{it} + \mu_i + \lambda_t + \varepsilon_{it}, \quad (2)$$

where β is the same as the one in equation (1). β_1 measures the impact of trees and approximates that in (1), which measures the impact of accumulated artificial afforestation, because arboreal forest was made up of artificial pure forest in the early stages of the TNSFP (Zhou.2001). β_2 and β_3 measure the impacts of shrub and grassland; they are expected to be positive, according Hypothesis 3.

As discussed below, our data include remote sensing data, which can't distinguish among the different types of vegetation land areas that are associated with different forestry programs. Therefore, β_1, β_2 and β_3 represent the total effect of both the TNSFP and the eight other forestry programs on rural income. For this reason, we exclude the eight other forestry programs from the explanatory variable vector Z_{it}.

3.2 Spatial econometrics model

The above classic econometric model does not consider the spillover effects from the contiguous spatial units, which may lead to biased estimation (Schlenker and Roberts.2009). Therefore, in this section, we test and control the spatial correlations in rural income.

Moran's I is a commonly used measure to check spatial correlation:

$$Moran's\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Y_i - \bar{Y})(Y_j - \bar{Y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \quad (3)$$

where $S^2 = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y})$, $\bar{Y} = \frac{1}{n}\sum_{i=1}^{1} Y_i$, Y_i is the net rural income of residents living in county i, n is the total number of counties, and W_{ij} is a binary adjacency spatial matrix: when county i and county j have a common boundary, $W_{ij} = 1$; otherwise $W_{ij} = 0$.

When Moran's index is positive, different spatial units are positively correlated; when Moran's I is negative, spatial units are negatively correlated; when Moran's I is zero, then no spatial correlation exists. When the Moran's I index is between -1 and 1, the larger the Moran's I index, the stronger the spatial correlation between spatial units' economic activities, and vice versa. Annual Moran’s I of each county in Inner Mongolia is summarized in Table 1. It shows that rural income has a positive spatial correlation across counties.

Table 1 Moran's I of Rural Per Capita Net Income in Inner Mongolia from 1993 to 2000

Year	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Moran'I	0.205	0.298	0.179	0.154	0.15	0.127	0.197	0.233	0.2	0.245	0.267	0.288
P-value	0.001	0	0.002	0.006	0.008	0.02	0.002	0	0.001	0	0	0
Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	
Moran'I	0.274	0.238	0.247	0.218	0.23	0.277	0.203	0.154	0.174	0.234	0.26	
P-value	0	0	0	0	0	0	0	0.001	0.001	0	0	

Therefore, we use a spatial Durbin model to capture the spatial correlation in rural income. One advantage of a spatial Durbin model is that it can obtain unbiased estimation parameters regardless of whether the real data generation process is a spatial lag model or a spatial error model. Meanwhile, the model does not impose any restrictions on the scale of potential spatial spillover effects (Elhorst.2010). In addition, a spatial Durbin model takes into account both the spatial correlation of the dependent variable and spatial spillover effects of independent variables, and thus provides an advantage in addressing an endogeneity problem resulting from omitted variables (Tian and Zhang.2013). Lastly, a spatial Durbin model adopts the approach of Maximum Likelihood Estimation (MLE) instead of OLS, which can deal with an endogeneity problem of the dependent variable to some extent (Long *et al.*.2014).

The model is as follows:

$$lnIncome_{it} = \alpha + \rho \sum_{i'} W_{i,i'} \ln Income_{it} + \beta lnArtificial_{it}$$
$$+\beta_1 ln \sum_1^{t-1} Atrificial_{it} + \beta_2 ln \sum_1^{t-1} Aerial_{it} + \beta_3 ln \sum_1^{t-1} Enclosure_{it}$$

$$+\beta_4 \sum_{i'} W_{i,i'} \ln Artificial_{it} + \beta_5 \sum_{i'} W_{i,i'} \ln Aerial_{it}$$

$$+\beta_6 \sum_{i'} W_{i,i'} \ln Enclosure_{it} + \theta lnZ_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

Compared to eq. (1), here we further include the spatial term of rural income ($\sum_{i'} W_{i,i'} \ln Income_{it}$) and the spatial terms of forest stock ($\sum_{i'} W_{i,i'} \ln Artificial_{it}$, $\sum_{i'} W_{i,i'} \ln Aerial_{it}$, and $\sum_{i'} W_{i,i'} \ln Enclosure_{it}$). $\sum_{i'} W_{i,i'}$ represents an N-by-N spatial weighted matrix where $W_{i,i'} = W_{i',i}$ and diagonal elements $W_{11} = W_{22} = \cdots = W_{nn} = 0$. ρ is the spatial correlation coefficient. β_4-β_6 capture the spillover effects of accumulated artificial afforestation, aerial sowing, and enclosed areas in surrounding counties.

Similar to eq. (2), a spatial Durbin model suitable for remote sensing data can be obtained as follows:

$$\ln Income_{it} = \alpha + \rho \sum_{i'} W_{i,i'} \ln Income_{it} + \beta lnX1_{it}$$

$$+\beta_1 lnTree_{it} + \beta_2 lnShrub_{it} + \beta_3 lnGrassland_{it}$$

$$+\beta_4 \sum_{i'} W_{i,i'} \ln Tree_{it} + \beta_5 \sum_{i'} W_{i,i'} \ln Shrub_{it}$$

$$+\beta_6 \sum_{i'} W_{i,i'} \ln Grassland_{it} + \theta lnZ_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

(5)

Eq.(5) is obtained by adding spatial lagged term of rural income and spillover effects of forests to equ.2. $W_{i,i'}$ and $\sum_{i'} W_{i,i'}$ have the same meaning with eq. (4). β, β_1-β_6 are parameters to be estimated. Compared to equ.2 and equ.3, the additional parameters β_4-β_6 represent the spillover effects, and they are expected to be positive and significant according to Hypothesis 4.

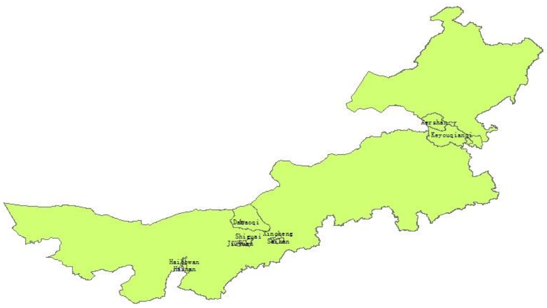
4. Data

4.1 Data source

We now describe the datasets and variables we use for the estimation of the TNSFP's impact on rural income. Firstly, we obtain the afforestation type data from the TNSFP and eight other forestry projects that were implemented in any of the 101 counties in Inner Mongolia during 1993-2015. Due to changes in administrative divisions, some counties were split and consolidated during the study period, and finally merged into a total number of 90 counties.[4] Figures 2 and 3

[4] For example, prior to 2000, data on Aershan City and other cities, which the state council approved in 1996 as a county-level

show the changes before and after the consolidation. Data include afforestation types, socioeconomics, remote sensing data, and weather data. We also collect socioeconomic data from the *Inner Mongolia Forestry Statistical Yearbook* and the *Inner Mongolia Statistical Yearbook*, remote-sensing data from the *European Space Agency*, and climate data from the *National Weather Service*.



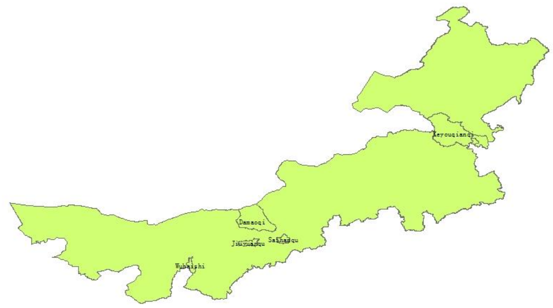


Figure 3 Counties in Inner Mongolia Before Consolidation **Figure 3 Counties in Inner Mongolia After Consolidation**

The TNSFP allocates a target for afforestation area to each county annually, and some state-owned forest enterprises have extra targets in certain years. Due to the lack of data on afforested area that could be attributed to the TNSFP and that is held by individual state-owned forest enterprises, we include the enterprises' afforestation area in the county in which they are located. Table 2 lists the names of the state-owned forest enterprises and the names of their counties.

Table 2 State-Owned Forest Enterprises (Bureaus) and Higher-Level Counties (or Cities)

Higher-level County (City)	State-owned forest enterprises	Higher-level County (City)	State-owned forest enterprises
Zhalantun city	Chaihe Forestry Bureau	Horqin Right Wing Front Banner	White-Wolf Forestry Bureau
	Nanmu Forestry Bureau		Wuchagou Forestry Bureau
Yakeshi city	Mianduhe Forestry Bureau	Dong Ujimqin Banner	Urapay Development Zone

city, is often combined with other larger cities. The new urban area, Huimin District and Yuquan District of Hohhot, were merged into the Saihan District; the Qingshan District, Kundulun District, Donghe District and Shiguai District of Baotou City were merged into the Jiuyuan District; and the Baiyun Ebo Mining Area of Baotou City was added to the Dalhan Maomingan United Flag for statistical purposes. Wuhai City has jurisdiction over three districts, but the data of these three districts are combined and represented as data from Wuhai City before 2000.

	Wunuer Forestry Bureau	Dalad Banner	Ordos Afforestation Center
	Balin Forestry Bureau	Linhe District	Farm Administration
Ewenki Autonomous Banner	Honghuaerji Forestry Bureau		Forestry Bureau directly under Bayan Nur city
Oroqen Autonomous Banner	Dayangshu Farm Bureau	Alxa Left Banner	Forestry Bureau directly under Alxa League
Hailar city	Hailar Farm Brueau		Alxa Economic Development Zone
Ulan Hot city	Farm & pasture Administration		Alxa Ecological Demonstration Area

4.2 Summary statistics

Figure 4 shows the accumulated afforestation area by afforestation type. Afforestation increased slowly in the areas with aerial seeding and enclosures, while there was a substantial increase in the area with artificial afforestation.

Figure 5 depicts the rural per capita net income change (excluding factors such as price change) in Inner Mongolia. The two endpoints on each vertical line represent the minimum and maximum incomes, respectively; the curve represents the average rural income. By comparing Figures 4 and 5, we see that farmers in this region experienced increases in income and afforested area. Whether the increases in income can be attributed to the implementation of the TNSFP is our question of interest.

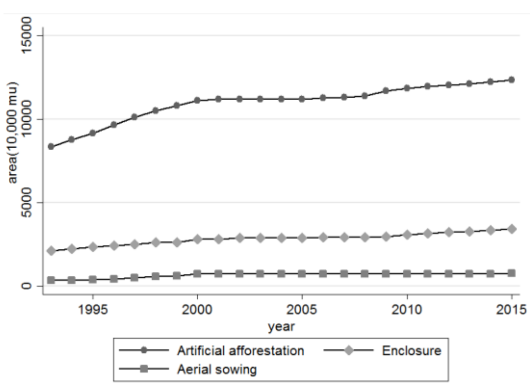


Figure 4 Accumulated Afforestation Area of th TNSFP in Inner Mongolia

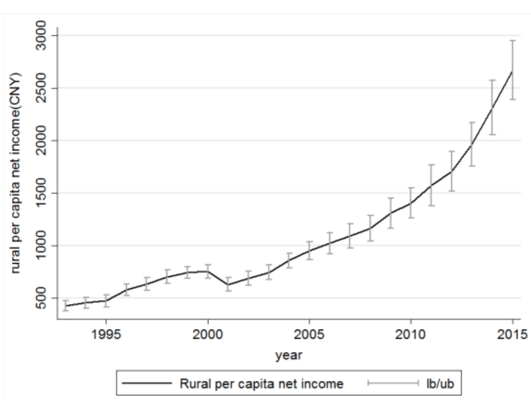
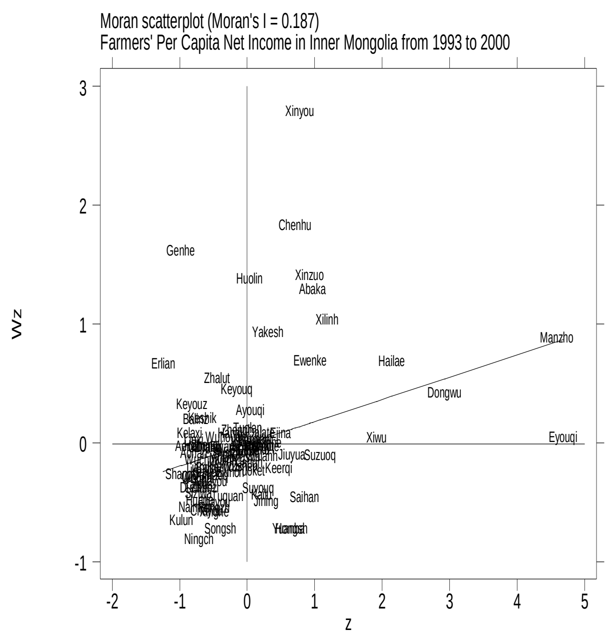


Figure 5 Rural Per Capita Net Income in Inner Mongolia

To show the spatial correlations of units in Inner Mongolia, we draw the spatial correlations between a unit and its neighbors in four scatter plots, each for a five-year plantation stage: 1993-

2000 (Fig.6(a)), 2001-2005 (Fig.6(b)), 2006-2010 (Fig.6(c)), and 2011-2015 (Fig.6(d)). The horizontal axis is rural income, and the vertical axis is the spatial lag term of the income. Each plot in Figure 6 can be divided into four quadrants: high-income counties encircling each other (in Quadrant I), high-income counties surrounded by low-income counties (Quadrant II), low-income counties surrounded by other low-income counties (Quadrant III), and low-income counties surrounded by high-income counties (Quadrant IV). The units in Quadrants I and III represent positive spatial correlation. The units in Quadrants II and IV represent negative correlation. The evenly distributed units imply no spatial correlations. These figures show that most counties lie in Quadrants I and III, suggesting that spatial correlation exists within the counties in Inner Mongolia.



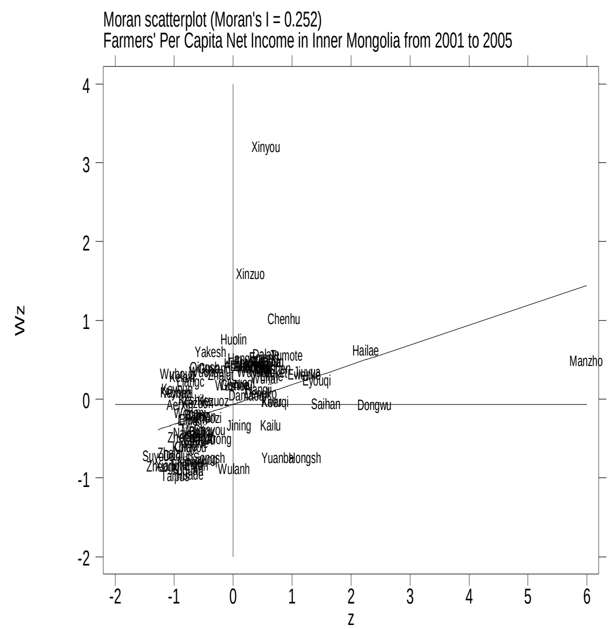
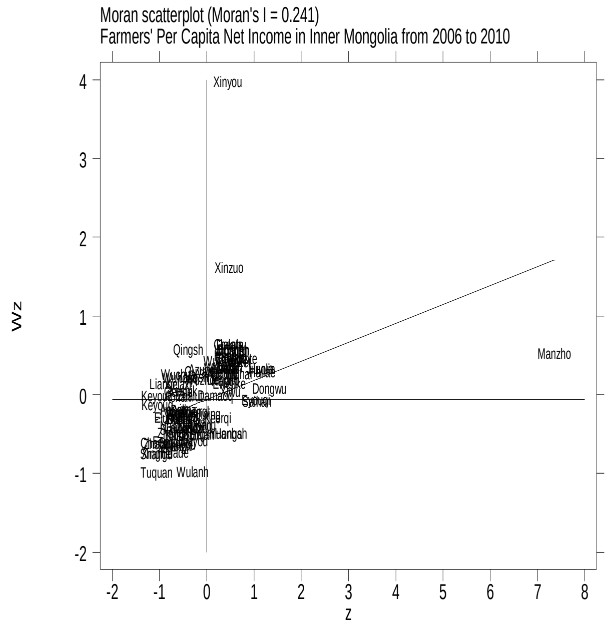


Figure 6(a)   Moran Scatter plot from 1993 to 200   **Figure 6(b)   Moran Scatter plot from 2001 to 2005**



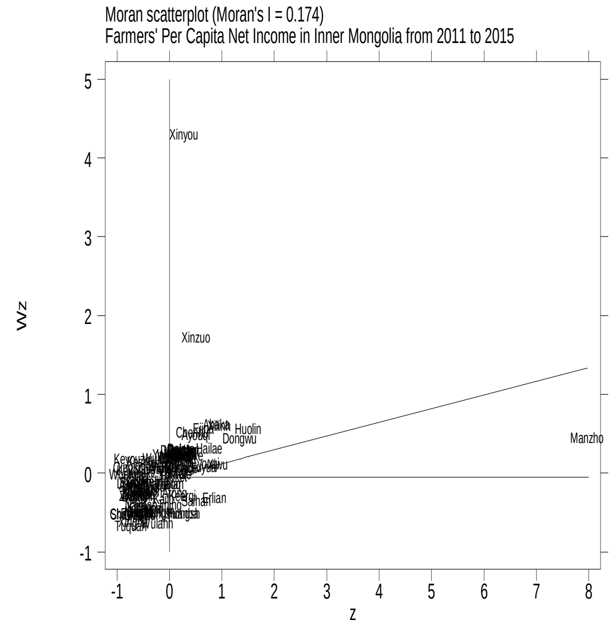


Figure 6(c) Moran Scatter plot from 1993 to 200 **Figure 6(d) Moran Scatter plot from 2001 to 2005**

The annual artificial afforestation area, and the accumulated artificial, aerial, and enclosed afforestation areas of the TNSFP, are the main independent variables. Other relevant socioeconomic variables and climate variables are control variables. In addition to the afforestation area data from the yearbook, remote sensing data describing actual forest area (with an accuracy of 300m) is also used, in which areas of trees[5], shrubs and grassland are independent variables. The statistical description of the variables is shown in Table 3.

Table 3 Summary Statistics

Variable	Unit	Obs	Mean	S.D.	Min	Max
Rural per capita net income	CNY	2,070	1083.01	862.09	96.42	12288.48
Artificial afforestation area by TNSFP, annual	Ha	2,070	1434.46	2549.97	0	18273.33
Artificial afforestation area by TNSFP, accumulated	Ha	2,070	81378.19	83932.11	49.45	372511.9
Aerial afforestation area by TNSFP, accumulated	Ha	2,070	4653.59	8782.56	0	53511.8
Enclosing afforestation area by TNSFP, accumulated	Ha	2,070	12978.07	18214.34	0	115081.5
Artificial afforestation area by other projects, annual	Ha	2,070	1714.64	3517.15	0	29058

[4]Trees are the total of the followings : Mosaic cropland (>50%)/natural vegetation (tree, shrub, herbaceous cover) (<50%); Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%)/cropland(<50%); Tree cover, broadleaved, evergreen closed to open (>15%); Tree cover broadleaved, deciduous, closed to open (>15%); tree cover, needleleaved, evergreen, closed to open (>15%); tree cover, needleleaved, deciduous, closed to open (>15%);Tree cover, mixed leaf type (broadleaved and needleleaved); Mosaic tree and shrub (>50%)/herbaceous cover (<50%); Mosaic herbaceous cover (>50%)/tree and shrub (<50%); Shrub; Grassland.

Artificial afforestation area by other projects, accumulated	Ha	2,070	20923.43	27627.38	0	147976.9
Aerial afforestation area by other projects, accumulated	Ha	2,070	9077.64	20353.45	0	148094.6
Enclosing afforestation area by other projects, accumulated	Ha	2,070	20941.28	30398.8	0	164249.1
No. of students in secondary school	Person	2,070	14400.81	15799.77	582	138980
Fiscal expenditure	CNY	2,070	852	1352.83	3.82	13674.23
Annual rainfall	cm	2,070	32.64	13.86	0.92	111.15
Annual average temperature	°F	2,070	31.27	6.07	8.32	41.93
Arbor forestland	Ha	2,070	2930	7440	2315	54600
Shrubs	Ha	2,070	15.95	50.6	0	357.56
Grassland	Ha	2,070	5021.62	5129.58	24.38	22334.49

5. Estimation results

5.1 Estimation of the classic and spatial econometric models

Table 4 reports the estimation results for the classic and spatial econometric models. Cols. (1) and (2) are the results of the fixed effects model (equation 2) and the spatial Durbin model (equation 4), which use accumulated afforestation area to measure forest stock. Cols. (3) and (4) are the results of equations 3 and 5 respectively, which use vegetation area to measure forest stock.

We perform Hausman tests to justify the choice of a fixed effects model over a random effects model. Test results show that χ^2 = 89.31 in the classic model, and χ^2 = 141.49 in the spatial model, rejecting the null hypothesis at a significance level of 1% in both models. Therefore, a fixed effects model is preferred to a random effects model.

To check whether or not the spatial Durbin model can be simplified to a space lag model or space error model, we perform likelihood ratio (LR) tests. The test results show that the LR statistic χ^2 = 70.24, rejecting the null hypothesis of simplifying to a spatial lag model, at a significance level of 1%; the LR statistic χ^2 = 66.34, rejecting the null hypothesis of simplifying to a spatial error model, at a significance level of 1%.

Table 4 Empirical Analytical Results

Independent Variable	Dependent Variable：ln(rural per capita net income）		Independent Variable		
	(1) Fixed Effects	**(2) Spatial Durbin**		**(3) Fixed Effects**	**(4) Spatial Durbin**
ln(TNSFP artificial)	0.005***	0.004***	ln(TNSFP artificial)	0.003***	0.004***
	(4.262)	(4.064)		(3.181)	(3.777)
ln(TNSFP artificial, accumulated)	-0.05***	-0.076***	ln(Arbor forestland)	-0.068*	-0.131***

	(-2.798)	(-3.429)		(-1.945)	(-4.104)
ln((TNSFP aerial, accumulated)	-0.01***	-0.006***	ln(Shrub)	0.004	0
	(-3.972)	(-3.383)		(0.651)	(0.024)
ln(TNSFP enclosed, accumulated)	0.007***	0.006***	ln(Grassland)	0.322***	0.442***
	(2.779)	(2.619)		(4.043)	(5.635)
ln(TNSFP artificial, accumulated) ×W		0.0793***	ln(Arbor forest)×W		0.258***
		(2.673)			(4.175)
ln(TNSFP aerial, accumulated)×W		-0.0002	ln(Shrubs)×W		0.011
		(-0.056)			(1.393)
ln(TNSFP enclosing, accumulated) ×W		-0.005	ln(Grassland)×W		-0.365**
		(-0.100)			(-2.517)
ln(Financial expenditure)	0.227***	0.183***	ln(Financial expenditure)	0.223***	0.186***
	(12.01)	(10.54)		(11.854)	(10.686)
ln(Student no.)	0.142***	0.139***	ln(Student no)	0.161***	0.136***
	(7.879)	(8.476)		(8.818	(8.119)
ln(Rainfall)	0.018	0.088	ln(Rainfall)	0.015	0.001
	(1.014)	(0.616)		(0.928)	(0.075)
ln(Temperature)	0.168	0.087	ln(Temperature)	0.192*	0.076
	(1.616)	(0.91)		(1.838)	(0.806)
Constant	2.617***		Constant	-0.171	
	(5.798)			(-0.195)	
ρ		0.334***	ρ		0.350***
		(14.48)			(15.233)
σ2		0.023***	σ2		0.024***
		(31.86)			(31.87)
Year FEs	yes	yes	Year FEs	yes	yes
Obs	2070	2070	Obs	2070	2070
Goodness of fit	0.906	0.437	Goodness of fit	0.905	0.156

Notes: The dependent variable is the natural logarithm of the county average per capita net income of farmers. For parsimoniousness, Table 4 does not report the coefficients of the non-TNSFP forestry projects, and the results are available upon request. *** p<0.01, ** p<0.05, * p<0.1.

From Cols. (1)-(4), the coefficients of artificial afforestation consistently suggest a significant positive impact of the TNSFP on rural income. This agrees with the results of the model that considers the actual accumulated forest areas. Compared to the afforestation area recorded in the Inner Mongolia Forestry Statistical Yearbooks (Cols. 1-2), remote sensing data reflects the actual success of afforestation activities (Cols. 3-4).

We check the robustness of these findings due to the concern that the simple afforestation areas disregard the survival rate of newly planted trees. We find the estimates of artificial TNSFP in Cols. (3)-(4) are slightly smaller than Cols. (1)-(2) but remain highly consistent in statistical significance. We thus believe the estimates using the afforestation areas from the forestry yearbooks. Furthermore, we can rely on the remote sensing data for the estimation of heterogeneous effects by forest type — arboreal trees, shrubs, and grassland — on rural income.

5.2 Calculation of the direct and spillover effects

Given that the spatial Durbin model is not linear in parameters, the estimated coefficients do not equal the marginal effects. Therefore, in this section, we calculate the direct effect (including employment effect, investment effect, and ecological effect, as described in hypotheses 1 through 3) and the spatial spillover effect (as described in hypothesis 4), based on the estimation results. Following LeSage and Pace (2009) and Elhorst (2010),we rewrite the spatial Durbin model and perform partial differential processing in eq. (6):

$$Y = (I - \rho W)^{-1}\alpha l_N + (I - \rho W)^{-1}(X\beta + WX\theta) + (I - \rho W)^{-1}\varepsilon, \tag{6}$$

where I is a unit vector, l_N is a $\mathrm{N} \times 1$ unit vector, and ε is a spatial and time special effect. Eq.(7) writes the partial differential matrix of Y with respect to the k-th partial variable of the vector X of independent variables:

$$\begin{bmatrix} \frac{\partial Y_1}{\partial X_{1k}} & \cdots & \frac{\partial Y_1}{\partial X_{Nk}} \\ \vdots & \ddots & \vdots \\ \frac{\partial Y_N}{\partial X_{1k}} & \cdots & \frac{\partial Y_N}{\partial X_{Nk}} \end{bmatrix} = (I - \delta W)^{-1} \begin{bmatrix} \beta_k & W_{12}\theta_k \cdots & W_{1N}\theta_k \\ W_{1N}\theta_k & \beta_k \quad \cdots & W_{2N}\theta_k \\ & \vdots & \\ W_{N1}\theta_k & W_{N2}\theta_k \cdots & \beta_k \end{bmatrix}, \tag{7}$$

In eq. (7), β_k represents the spillover effect of the variables X_k on Y, i.e., the mean value of the diagonal elements of the right-hand-side matrix. The spillover impacts are defined as the overall (combined) impacts of the independent variable (e.g., X_k) of all the neighbors on the dependent variable (Y), also known as the spatial spillover effect, equal to the mean of the non-diagonal elements in each column or the row of the right-hand-side matrix $\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}\theta_k / N(i \neq j)$. For example, by means of this spatial matrix weighted by distances, we can estimate the spillover impact of the TNSFP implementation in the neighboring counties on the average rural income in a specific county. The total effect of the TNSFP is the sum of the direct and spillover impacts.

We calculate and summarize the direct effect, the spillover effect, and the total effect of each type of afforestation (Table 5, Panel A) and of each forest land cover type (Table 5, Panel B).

Generally, we find that the yearly artificial afforestation, in addition to the cumulative enclosed afforestation and grassland, have a significant direct impact on the increase in the per capita net rural income.

Table 5 Analytical Results of Direct, Spillover, and Total Effects

	Direct effect	Spillover effect	Total effect
panel A.			
ln(TNSFP artificial afforestation)	0.004***	0.002***	0.006***
	(3.996)	(3.742)	(3.976)
ln(TNSFP artificial afforestation, accumulated)	-0.072***	0.076**	0.004
	(-3.492)	(2.091)	(0.107)
ln(TNSFP aerial afforestation, accumulated)	-0.007***	-0.004	-0.009*
	(-3.706)	(-0.743)	(-1.719)
ln(TNSFP enclosing afforestation, accumulated)	0.006**	0.002	0.008
	(2.535)	(0.336)	(0.932)
panel B.			
ln(TNSFP artificial afforestation)	0.004***	0.002***	0.006***
	(3.714)	(3.488)	(3.682)
ln(Arbor forest)	-0.109***	0.311***	0.203**
	(-3.328)	(3.556)	(2.075)
ln(Shrubs)	-0.001	0.016	0.017
	(-0.218)	(1.43)	(1.39)
ln(Grassland)	0.428***	-0.286	0.142
	(5.688)	(-1.377)	(0.649)

Notes: The dependent variable is the natural logarithm of the county average per capita net rural income.
Significance is denoted: *** p<0.01, ** p<0.05, * p<0.1.

Table 5 shows that a one-percent increase in annual artificial afforestation promoted income by 0.004% directly and received a 0.002% spillover effect from neighboring counties, with a total impact of 0.006%. These estimates are all statistically significant at the 1% level. Therefore, the artificial afforestation activities have effectively promoted the growth of rural income in Inner Mongolia, and the effect is attributable to the TNSFP. This finding supports our conjecture that artificial afforestation, as the dominant method of tree planting by the program, has created a lot of employment opportunities and increased the wage income of farmers, together with the construction of infrastructure related to afforestation activities, which has facilitated local economic development and thereby increased rural income too.

Interestingly, the accumulated artificial afforestation has a negative impact (of 0.072%, significant at 1%) on rural income locally, but accumulated artificial afforestation from neighboring counties does the opposite effect of local forest (of 0.076%, significant at 5%), and the total effect is not significant. This is inconsistent with hypotheses 3 but consistent with hypothesis 4. A plausible explanation is that most areas in Inner Mongolia are arid or semi-arid areas, with total annual precipitation of 50-450 mm, and high evaporation (above 1200 mm). Afforestation in arid areas has limited potential to prevent soil erosion, and may even aggravate the problems of water shortage and ecological destruction (Jiang.2005). As a result, ecological deterioration is likely to prejudice the growth of rural income. Here we can deduce that the employment from accumulated forests is affected by poor-quality forest. It's hard for us to identify how the impact of investment worked on rural income, because there is no indication of the investment effect in a comprehensive outcome made up of three effects. Some research finds that investment from the TNSFP promoted the regional economy (Zhi *et al.*.2007; Liu *et al.*.2009). Other scholars have noted problems in the use and management of the TNSFP's investment, such as lack of supervision, irregular management, inefficient utilization, and so on, which are liable to lead to low quality and redundant construction, corruption, and a shoddy program (Li.2008; Sun.2009). However, even though large-scale planting activities have caused excessive consumption of local groundwater, the shelter forests have achieved the objectives of wind-breaking and fixing sand, conserving water and soil, improving the micro-climate of the protected area, and increasing crop yields and other ecological benefits (Shen.2001; Torita and Satou.2007). These benefits are more likely to be experienced by the neighboring counties, where the plantation will not place pressure on local groundwater, rather than by the local county.

The estimated impact of cumulative aerial seeding on rural income contradicts hypothesis 3, with a negative direct impact of 0.007% on rural income (significant at the 1% level), and an overall negative impact of 0.01% (significant at the 10% level). This could be due to the large economic share of the animal husbandry sector and the fact that aerial afforestation was mostly done in agricultural and pastoral areas. Specifically, the aerial afforested areas required a prohibition of grazing for three to five years, which is not conducive to animal husbandry and thus decreases rural income (Qi and Guo.1998).

Afforestation by enclosure has a direct positive impact of 0.006% on rural income and is statistically significant at the 5% level, consistent with hypothesis 3. But we do not find a significant effect of the spillover effect, nor the overall impact. The afforestation by enclosing or closing off access to the hills, compared to artificial afforestation and aerial seeding, is effective in conserving forest vegetation in a near-natural way for restoration (Jiang.2008). This ecological improvement appears to be more significant locally – such as by hiring people to perform the tasks – and hence contributes to the increase in rural income, but may not affect the people in other counties.

Panel B of Table 5 show that the artificial afforestation by the TNSFP increases rural income, and different land cover types have different impacts on rural income. We find that a 1% increase in arbor forest area will lead to a 0.1% decrease in rural income. But the impact from neighboring counties is estimated to be positive (by 0.3%) and thus the overall impact is positive (by 0.2%). All estimates are statistically significant at the 5% level or higher. This could be attributed to the low precipitation in the Three-North region, together with the fact that arbor forests consume a large amount of groundwater, which exacerbates the existing water shortage problem. In addition, exotic tree species such as poplar, one of the main tree species for planting, compete with local native vegetation for nutrients and space, leading to the degradation of the local ecology, in addition to the fact that few of these imported trees have survived. More importantly, a forest with a simple structure – such as large-scale artificial afforestation with a single tree species with individuals of similar age – usually is very vulnerable to pests and diseases (Ma.2016).

Shrubs do not have a significant impact on rural income. Although shrubs and grass are both important components of vegetation in the TNSFP, shrubs were not seen to be as important as trees in the beginning of plantation in the north of China (Ma.2016). Therefore, the limited planting of shrubs failed to improve rural livelihoods.

Grasslands have a positive and significant effect on rural income. The estimation results show that a 1% increase in grassland would lead to a rural income increase of 0.4% (significant at 1%), mainly through direct effects. This, again, can be attributed to the fact that the arid and semi-arid climate, with sand erosion and land desertification as the main natural disasters, are more conducive for herbaceous plants to survive and for sand-fixing, compared to arbor trees. In the meantime, grassland provides forage for pastoral production, thereby increasing rural income in animal husbandry.

6. Conclusion and policy implications

In this paper, we estimate the impact of the Three-North Shelter Forest Program on rural income, using panel data for 101 counties in Inner Mongolia from 1993 to 2015. Using a spatial Durbin model, we discern both direct and spillover effects of the TNSFP. We find that the implementation of the TNSFP has a significant positive effect on rural income, through increasing employment opportunities and investment in public infrastructure. We also find that the implementation of the TNSFP resulted in local environmental degradation through excessive depletion of groundwater and competition for nutrients and living spaces with native shrub or grass. On the other hand, the accumulation of artificial forests provides benefits. In particular, the shelterbelts of the TNSFP help block wind and fix sand in place, which contributes to the growth of rural income by preventing soil erosion and protecting the health of the labor force. We further find that, compared to artificial afforestation, a grazing prohibition for a certain period (caused by aerial sowing afforestation) has an adverse impact on rural income, while enclosure helps increase rural income through natural ecological improvement. In terms of the type of forest vegetation, trees improve rural livelihood, while shrubs do little to increase rural income, and the benefit from grassland is limited to a direct local effect of improved grazing. In general, the impacts of the TNSFP include both direct and spillover effects; the impacts vary with different afforestation methods and different vegetation.

Although we find that the implementation of the TNSFP has had a statistically significant impact on the growth of rural income in Inner Mongolia, it has been a modest increase, and still has a certain distance to reach the target of "strengthening forestry and enriching farmers". Therefore, the government should attach more attention to the socioeconomic effects, and take increasing rural income as the development goal of the TNSFP. Only by continuously improving rural livelihoods can the enthusiasm of farmers be maintained to support ecological goals.

Besides jobs that are directly related to afforestation, a wider employment channel for farmers is needed, such as the development of the wood processing industry, fruit industry, forest tourism, leisure services industry, and forestry cooperative organizations. It is also important to increase investment for forestry infrastructure, expand financing channels, and promote development through investment. We recommend increasing subsidies for afforestation, and ensuring that payments for labor are received in full and on time. In the case of no increase in total investment, afforestation obligations should be reduced so that rural profit is guaranteed. We recommend implementing and consolidating the reform of the collective forest tenure system, with the expectation that this will strengthen the confidence and determination of farmers to invest in afforestation projects.

Our findings suggest that artificial afforestation has been the most important method so far in terms of high survival rate and increased wage income to farmers. However, the areas of enclosure could be expanded according to the principle of suitability. Because the “three-north” is arid or semi-arid region where the space suitable for closing the land for reforestation is large, and enclosure is close-natural way of afforestation, ecosystem gets more stable after conserving forests with the advantages of low cost, quick returns, etc.

Our findings also suggest the importance of the choice of forest categories and species. Ecological forests should be managed with priority attention to ecosystem services, and economic forestry is also needed for rural residents’ income from harvesting. Regarding the choice of forest species, the fast-growing and high-yield plantation priority to the poplar deserve expansion in the northeast of China, where has abundant rainfall. In contrast, shrubs and grass with good drought tolerance and sand control effect are expected to play a key role in ecological restoration in areas that have insufficient rainfall. Native and regionally-adapted vegetation species should be planted as much as possible due to their adaptability and survival rates. Also, the spatial disposition of tree species should avoid competition for nutrition or living space. The survival rate of tree species is an especially important consideration.

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