Economic and Ecological Impacts of a Regional Payments for Ecosystem Service Program

Peibin Hou, Huanguang Qiu, Jialing Yu
School of Agricultural Economics and Rural Development, Renmin University of China
Email: jialing.yu@ruc.edu.cn

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Economic and Ecological Impacts of a Regional Payments for Ecosystem Service Program

Peibin Hou, Huanguang Qiu, Jialing Yu [1] *†

[1]School of Agricultural Economics and Rural Development,
Renmin University of China, Beijing 100872, China
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Abstract

The study focuses on the PLDL ("Paddy Land-to-Dry Land") policy implemented in the upstream area of the Chaobai River, near the Miyun Reservoir in Beijing. Using remote sensing data on land-use types, the research identifies a conversion of paddy fields into dryland and other land-use types. By constructing a grid-level panel dataset and employing a difference-in-differences econometric approach, the paper creates a counterfactual scenario to estimate the net economic and ecological impacts of the PLDL policy using a double fixed-effects estimation method.The findings of this study reveal that the policy has positive ecological impacts in the surrounding areas, as NDVI significantly increased by 1.1%. However, it also generates negative economic impacts, as the nighttime light index significantly decreased. Subsequently, the paper examines the mechanisms of factor reallocation, specifically water resources and labor. The study observes a significant reduction of 15.8% in agricultural irrigation water, indicating water-saving effects consistent with existing conclusions about the policy. The policy also releases labor from agricultural production, leading to a substantial decrease in population density by 6.4%. Furthermore, labor mobility occurs between the agricultural and non-agricultural sectors, resulting in a significant increase in the share of existing non-agricultural firms by 11.4% and established firms by 15.0%. Overall, the ecological compensation policy has positive effects on the ecological environment. However, when designing specific compensation policies, it is essential to consider the economic balanced development among different regions.

*Authors make contributions equally, and are listed in alphabetical order
†Corresponding auther. Email: jialing.yu@ruc.edu.cn

1 Introduction

Conservation programs are widely used in various contexts, and payments for ecosystem services (PES) is one of the major vehicles for conservation[7]. Researchers have put efforts to explore various aspects of the program, such as, the policy designs, spillover effects, impact assessment etc. Impact assessment studies mainly focus on the impacts of the program, with estimates of baseline counterfactuals using identification methods e.g., [1, 9].Articles on spillovers explores the channels of how the program affect the regions outside of the program boundaries e.g., [5, 7]This article asseses the economic and ecological impacts a regional PES program in Northern China around Beijing, and also explore the spillover effects on factor reallocation in the region.

The PES program, Paddy land-to-Dry land (PLDL) program initiated in 2006 in Chaobai River Basin for water conservation. The goal is to relieve the municipal water use stress of Beijing in the downstream. Miyun Reservoir, the largest man-made lake in Asia located in Chaobai River Basin provided about a half of the municipal water use for Beijing before the program. To increase water reserve in Miyun Reservoir, Beijing government paid farmers in upstream in Hebei province to convert paddyland to dryland. Since rice cultivation was the main source of household income for upstream farmers, payment of RMB 550/mu is paid to the farmers to alleviate their income loss due to crop conversion. The program last for nearly two decades. The increase in water yield is 55% of the average runoff in Miyun Reservoir during the program in the first decade[12]. In 2022, the program is relaunch for another round and to include larger regions. It is essential to understand how the program affect the region and provide implications for policy improvements.

Unlike most conservation programs targeting relatively remote areas, PLDL policy is implemented in a region close to Beijing, which is one of the mostly developed metropolitan areas in China. And Beijing has long been given priorities due to its historical, political and economic status. In the case of PLDL, the question is whether the surrounding areas are well compensated and what the impacts of the program are. And in this study we examine the economic and ecological outcomes of the policy. Furthermore, we explore the spillover channels of the conservation policy. The main machanism of the program is converting paddy land to dry land. The rice cultivation is intensive in water use and labor, and converting land use releases agricultural water use and labor from rice cultivation. Water resource is directed to municipal use and may also have ecology benefits in the region. The labor may be reallocate to non-agricultural activities in or out of the region. In the spillover channels, we examine reallocations of water and labor resources, and how the spillover affects the economic activities in the region.

Satellite data has been widely used in the assessment of PES programs [8]. We compile a gridded dataset in a finer resolution from different sources of the satellite data and administrative data. The NDVI and night-time light index(NTLI) can be extracted from satellite data to represent the economic and ecological outcomes of the policy. Furthermore, agricultural and non-agricultural economic activities, as well as irrigation water consumption are matched with the satellite dataset. Other control variables, such as the weather variables are also collected. And county-level administrative data of agricultural production is also included. A panel dataset of over 23,000 grids from 2000 to 2015 is constructed to cover years before and after the policy implementation.

We estimate a set of reduced-form difference models to identify economic and ecological impacts of the PDLD policy. Grid-level fixed effects is used to control time-invariant confounding factors, and county specific time trend fixed effects can further control county-level variations across regions and year. Furthermore, difference-in-difference method is performed to address potential selections existed in treated areas. The control region is Guanting Reservoir Watershed in nearby Yongding Basin which has similar climate and socioeconomic characteristics.I find that the PLDL policy has a significant negative impact on economic growth. After the implementation of the policy, the night-time light index in the Miyun Reservoir basin significantly decreases. However, it has a significant positive impact on the ecology, as indicated by a significant increase of 0.007 in NDVI. Additionally, this study tests the reallocation of factors in the results and observes that the PLDL policy saves agricultural water resources, leading to a significant irrigation consumption reduction of 15.8%. Furthermore, there is a shift from labor-intensive crops to capital-intensive crops, resulting in a decrease of 6.4% in population density in the area, with labor outflow to other regions. These findings suggest that this ecological compensation policy provides a potential transmission link from reducing population density to slower economic growth, saving water resources, and improving the ecological environment through the reallocation of factors. By using remote sensing data of economic activities and constructing a dataset of firm within the buffer zone, I also find that the policy promotes changes in industrial structure, with a significant increase in the number and proportion of non-agricultural sector enterprises, while agricultural enterprises show a declining trend.

In the following, a brief introduction of the background and policy is provided in Section 2. It follows sections of data and empirical models. Section 5 presents results of economic and ecological impacts, evidence on reallocation of labor the water resources, and further discussions on impacts of economic activities. Section 6 concludes.

2 Background

Beijing is located in the northern part of the North China Plain and belongs to a semi-arid climate zone. The total amount of water resources is insufficient, and the distribution of surface water, groundwater, and rainwater resources is unbalanced, which results in scarce resources. As the capital of China with a huge population, water supply has become one of the important bottlenecks restricting the social and economic development of Beijing, especially in dry seasons or drought years, which makes the contradiction between water supply and demand more prominent. In order to alleviate the "water shortage" problem in Beijing, construction of the Miyun Reservoir began on September 1, 1958 to supply water to the Beijing-Tianjin-Hebei region. However, in the early 1980s, as Beijing's water consumption increased, the reservoir stopped supplying water to Tianjin and Hebei and only provided water to Beijing. Through the construction of water pipelines and water treatment plants, the reservoir's water resources were brought into the city's water supply system to meet the city's water demand. During the implementation of the project, China's social and economic conditions were relatively difficult, and the government's fiscal revenue was also limited, making it difficult to provide large economic compensation to the surrounding areas. However, the economic development of Beijing had limited spillover effects on the surrounding areas. Subsequently, payment for environment service projects began to be implemented to compensate the surrounding areas for their guarantee of Beijing's water supply. The PLDL project is one of them, and this article aims to explore whether it has had an impact on the economy and ecology of the surrounding areas. Is this impact positive or negative?

Nowdays, Miyun Reservoir is the only surface water source for domestic water supply in Beijing, located in the northeastern part of the city, and it plays an important role in supplying water to Beijing. The upstream basin refers to the part of the Chaobai River basin controlled by the Miyun Reservoir, with a drainage area of 15,788 km^2, of which the area within Beijing is approximately 3,476.7 km^2, distributed in three districts of Miyun, Huairou, and Yanqing. The area within Hebei Province is approximately 11,892 km^2, distributed in six counties, including six Counties. Changes in the water volume and water quality trends in the basin have an important impact on the water quantity and quality of Miyun Reservoir, thus affecting the domestic water supply in Beijing.

At the same time, the excellent geographical conditions in the Miyun Reservoir provide high-quality water and irrigation support for the people on both sides of the river. Upstream farmers mainly relied on planting rice as their main source of household income. However, investigations have shown that the amount of water consumed during the rice planting process is extremely high, with an annual consumption of about 1,200 cubic meters per mu [2]. The water consumption of dryland crops is only one-third of that of rice. At the same time, planting rice requires the use of a large amount of fertilizer, which has led to water source pollution and serious negative impacts on water quality. In order to ensure the daily water supply for Beijing, the Beijing Municipal Government and the Hebei Provincial Government signed a memorandum of understanding on strengthening economic and social development cooperation, and signed the PLDL project agreement with Chicheng County in Chengde City and Zhangjiakou City in the Chaobai River Basin. PLDL encourages upstream rice farmers to switch to more water-saving crops such as corn and provides a certain amount of financial compensation to participating farmers. For participating farmers, the government adopts a "funds subsidy mode in which the Beijing Municipal Government provides funds to the upstream government, which then distributes them to farmers".

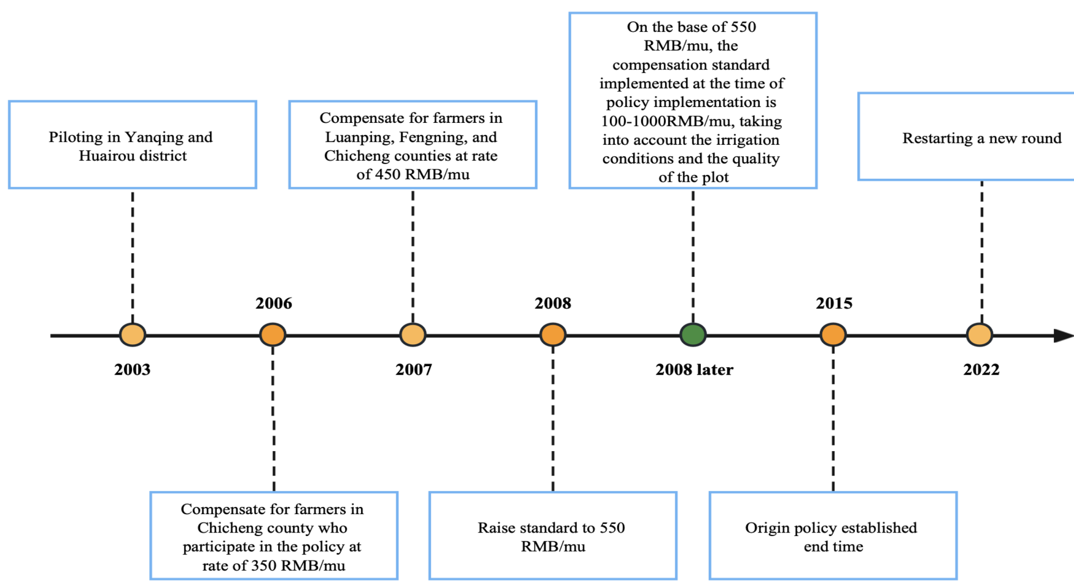


Figure 1: PLDL Policy Compensation Timeline

As the timeline 1 shows, the PLDL policy went through a process of pilot testing within Beijing and then extended to areas outside of the city, eventually covering the entire upstream area of the Miyun Reservoir. The policy was first piloted in 2003 in Yanqing and Huairou districts, where a total of 2,300 mu of rice fields were converted to corn fields. In 2006, the Beijing Municipal Government and the Hebei Provincial Government signed a lateral compensation agreement to implement the water-to-dry land project in two stages in Chicheng

County and Chengde City. Using land use remote sensing data with a resolution of 1 km, the "PLDL" effect of the policy was tested in five regions (Yanqing District, Huairou District, and Fengning Manchu Autonomous County, Luanping County, and Chicheng County in Hebei Province) from 2005 to 2015. The changes in paddy fields in the above five counties are shown in Figure 2. It can be seen from the figure that by 2015, the area of paddy fields disappeared, which is close to the "PLDL" coverage of 68.7 square kilometer mentioned in previous studies[11] (considering errors caused by the resolution of remote sensing data, etc.).Most of the paddy fields have been converted to other dry crops, saving water resources. At the same time, since rice is a labor-intensive crop, it also saves some agricultural labor. Some paddy fields have been converted to forests, increasing NDVI directly. Some paddy fields have also been converted to impervious land, releasing labor from the agricultural sector. Whether the outflow of this labor will promote the development of other non-agricultural sectors is the focus of this article. PLDL policy compensation policy scheme is subject to change every year, with the final subsidy standard determined to be 550 yuan per mu, and additional subsidies are provided based on irrigation conditions and plot quality.

3 Data

This section describes the different data sources used in this paper. This information is also summarized in Appendix Table A 1. For the objectivity and accuracy of the study, We focus on the grid-level economic and ecological impact that PLDL brought. In order to conduct this analysis, we construct a "grid (1km $\times$ 1km) by year (2000 to 2015)" panel dataset by merging the NDVI and economic activities of each grid with the annual climatic characteristics attached to each grid, and administrative data. As for the ecological impact, We use NDVI as ecological impact indicators, where NDVI is a sensitive factor in the environment change and an important indicator of regional ecosystem ecological changes, While irrigation water use serves as an indicator for factor reallocation. The NDVI index is the most clas-

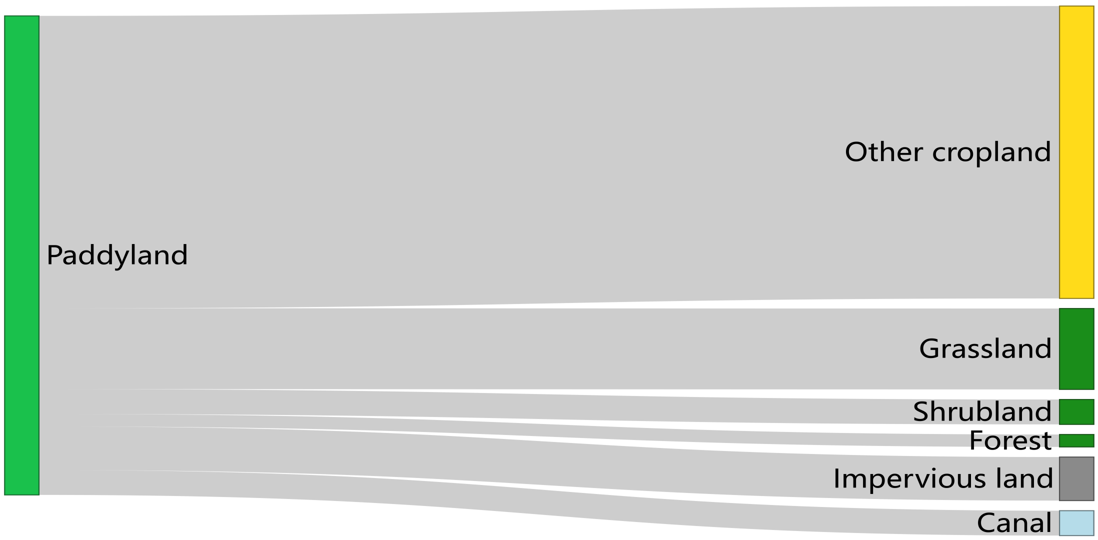


Figure 2: Sankey diagram of water paddy field land-use type transformation

sic vegetation index used for monitoring vegetation changes. In terms of economic impact, we use GDP, population, number of existing enterprises and number of newly established enterprises within a kilometer radius as as measuring indicators The main datasets include normalized difference vegetation index (NDVI), irrigation water consumption, Night-time lights (NTL), gross domestic product (GDP), population and economic activities. Other datasets measuring climate like temperature and Precipitation are used for control variable.

3.1 Study area

This paper utilizes panel variation in the quasi-random timing of the implementation of the Paddy Land-to-Dry Land (PLDL) policy between the Chaobai, Beiyun, Jiyun River systems of the Miyun Reservoir and the Yongding River system of the Guanting Reservoir, which serves as the control group, to identify the impacts of the PLDL policy on the local economy and ecology.

Miyun Reservoir and Guanting Reservoir are both significant reservoirs situated in the northern region of Beijing, exhibiting analogous geographical and climatic conditions. Both reservoirs have a continental monsoon climate, with an average annual temperature ranging between 6-10℃, and average annual precipitation ranging between 500-700mm. Furthermore, both reservoirs possess a comparable topography, with high mountains, steep slopes, and intricate terrain, making them susceptible to soil erosion.

As essential reservoirs in Beijing, Guanting Reservoir and Miyun Reservoir are responsible for providing drinking water and industrial water to the city's residents and industry, and irrigation water for agriculture. They also serve as crucial facilities for flood control, water regulation, and maintenance of the ecological environment. Therefore, both reservoirs have undergone long-term soil and water conservation, and ecological environment construction projects, for the sustainable development and protection of water resources and to ensure ecological safety.Therefore, long-term soil and water conservation and ecological environment construction projects have been implemented in the Chaobai, Beiyun, Jiyun canals, and Yongding River basins where the two reservoirs are located. Among them, two large-scale ecological construction projects were implemented, namely the Beijing-Tianjin-Hebei Grain for Green Project and the South-to-North Water Diversion Project. The implementation period of the Beijing-Tianjin-Hebei Grain for Green Project was from 2000 to 2010, covering both basins. Both basins are also part of the central line project of the South-to-North Water Diversion Project. However, the first phase of the central line project officially started water diversion on December 12, 2014, which does not overlap with the research period of this paper. The experimental and control groups in the study area are shown in Figure 3 below. The watershed boundaries of the treatment group and the control group are obtained by extracting the watershed areas from the DEM data. Although both reservoirs are located in the Haihe River Basin, they belong to different water systems, indicating that the PLDL policy implemented in the upstream area of Miyun Reservoir will not affect Guanting Reservoir and its downstream areas, which meets the requirement of the independence of the control and treatment groups.

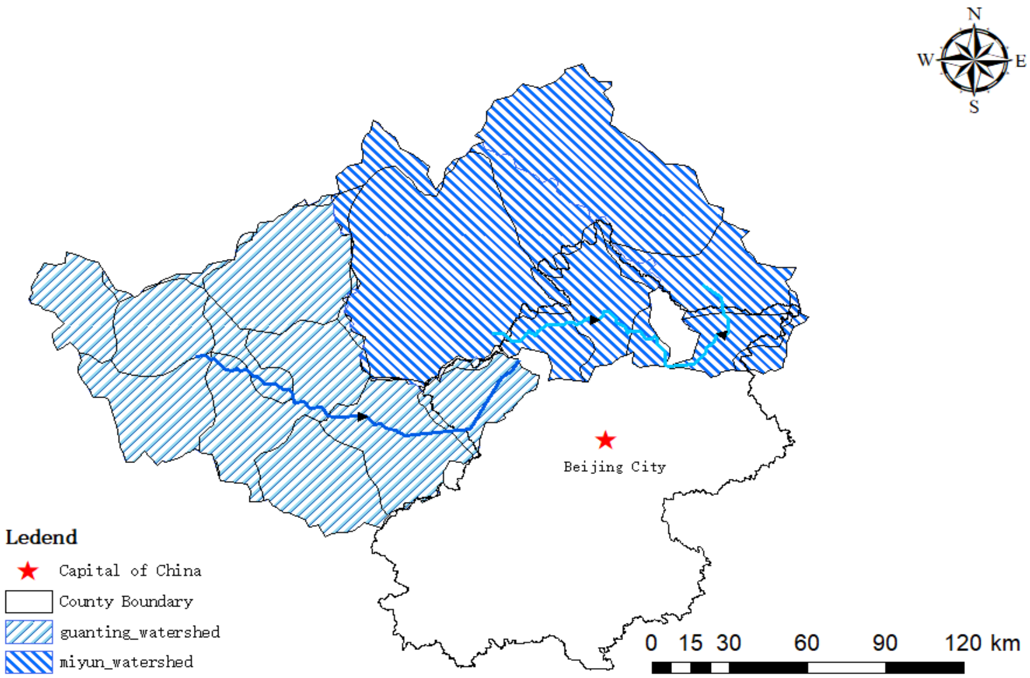


Figure 3: Study Area

3.2 Data sources

3.2.1 NDVI

Vegetation changes are usually closely related to the ecological environment quality, such as hydro-ecological fluxes and so on. The most commonly used Normalized Difference Vegetation Index (referred to as NDVI in the following text) was employed in this study to estimate vegetation coverage, which is calculated using the formula shown in equation. In ecological environment research using remote sensing data, the NDVI has been widely applied. It can accurately reflect the growth status of plants, vegetation health and density using plant reflectance characteristics recorded by satellite imagery [6].

$$\text{NDVI} = \frac{\text{NIR-R}}{\text{NIR+R}} \tag{1}$$

The NDVI data used in this study is based on a continuous time series of SPOT/VEGETATION NDVI satellite remote sensing data. The maximum value composite method was employed to generate an annual vegetation index dataset spanning the time period from 2000 to 2015 with a resolution of 1 km. A total of 23,692 gridcells were included in the control and experimental groups. The descriptive statistics of the data will be presented in section 4.3.

3.2.2 Night-time light

The night-time light index (NTL) used in this article is based on DMSP/OLS and NPP-VIIRS satellite nighttime light remote sensing image data, processed to generate annual nighttime light brightness data from 2000 to 2015, with a resolution of 0.004 degrees.

DMSP/OLS was captured by the Operational Linescan System (OLS) on board the Defense Meteorological Satellite Program (DMSP) between 1992 and 2013, while NPP-VIIRS was captured by the Visible Infrared Imaging Radiometer Suite (VIIRS) on board the Suomi National Polar-Orbiting Partnership (NPP) satellite since 2012. The most significant difference between the two is that the DMSP/OLS data exhibits a clear "ceiling effect," which mainly refers to the fact that some pixels with actual grayscale values larger than 63 can only be represented by 63. Descriptive statistics show that NTL in the study area did not reach 63 in most years before 2012. Therefore, this study combined the data from 2000 to 2012 with the data from 2012 to 2015.

Typically, satellite sensors mainly capture the solar radiation reflected from the Earth's surface. However, nighttime satellite sensors are unique in that they collect radiation signals generated by nighttime lights, fires, and other sources of illumination. These sensors work at night and can detect low-intensity lights emitted by city lights, small-scale residential areas, and traffic, distinguishing them from the dark rural background. Therefore, nighttime light images can be used as a representation of human activity and have become a valuable data source for monitoring human activity.

There are two main advantages to using nighttime light remote sensing data. First, it does not depend on high spatial resolution, and the image resolution is typically around 1-10 km, making the image data volume very small, even less than 1% of TM data, making it easier to process. Second, nighttime light images can reflect comprehensive information, covering information closely related to the distribution of factors such as population and cities, including transportation and residential areas. Therefore, when using light data, it is unnecessary to consider these factors separately.

The contrast between bright and dark areas on light images makes it a powerful tool for studying intensive human activity and its impact. Clearly, there is a positive correlation between light intensity and socio-economic factors, which can be used to estimate the level of economic development quantitatively.

3.2.3 Economic Activities

The data used in this paper comes from scientific data, obtaining a dataset of business operations with a resolution of 0.01°by 0.01°for the years 2005-2015. This dataset uses registration records from approximately 25.5 million companies to construct a geographically based dataset - the Gridded Establishment Dataset (GED) - which records the economic activities of mainland China, which is the first geocoded establishment dataset in China[4]. An important advantage of this dataset is that it provides high spatial resolution at approximately 1.1 km x 1.1 km at the equator.

The economic activities data includes centroid longitude and latitude, record year, total number of establishments, number of establishments in different operational statuses, and number of establishments in different industries. In GIS software, the dataset can be imported as a vector layer. To match with other geographical datasets, we can use the spatial join function in GIS software to merge the attributes of GED with other data based on their spatial relationship. In this study, we draw buffers with radii of 1, 3, 5, and 10 kilometers for each observation point, and then extract the grid cells and corresponding establishments that fall within these buffers. The total number of new and existing establishments for each of the three industries within the watershed area of each observation point can be obtained by summing these establishments.

3.2.4 Other dataset

changes in crop planting structure first affect water factor reallocation in the agricultural sector, and agricultural water usage is mainly for irrigation. The data we used for measuring irrigation come from Institute of Tibetan Plateau Research Chinese Academy of Sciences. The original data for this dataset is sourced from the JGCRI paper dataset. After performing temporal linear interpolation, extracting the China regional mask, and converting the coordinate system, we obtained the China irrigation water withdrawal data with a normalized historical time span of 1990-2015.Due to the fact that the study focuses on grids with a resolution of 1 square kilometer, the original irrigation water dataset was resampled, which resolution is $0.25° \times 0.25°$.The three commonly used resampling methods are nearest neighbor, bilinear interpolation, and cubic convolution. Nearest neighbor resampling assigns the value of the closest cell in the source raster to the target cell during resampling. This method is simple and fast, and is more suitable for discrete data such as classification data. However, the disadvantage of nearest neighbor resampling is that the processed data has sharp edges and diagonal features, which are not smooth and may introduce artificial errors. Bilinear interpolation and cubic convolution can generate smoother data, which are suitable for continuous variables. Due to the large amount of data in this article, bilinear interpolation is selected as the resampling method.

The temperature and precipitation data are from the annual spatial interpolation dataset of Chinese meteorological elements provided by the Resource and Environment Science and Data Center. Based on the daily observation data of meteorological element stations at more than 2,400 sites across the country, the Anuspl interpolation software was used to generate the spatial interpolation data of annual precipitation and temperature from 1960 to 2021, based on the calculation of the annual values of each meteorological element. Like the NDVI data, the resolution of these data is 1km * 1km. The dataset uses an equal-area cut cone projection. The national uniform central meridian and double-standard parallel lines were used, with the central meridian at 105° east longitude and the double-standard parallel lines at 25° north latitude and 47° north latitude, and the Krasovsky ellipsoid was used. Note that the raster dataset in this paper has been unified to GCS_WGS_1984 geographic coordinates and $WGS_1984_UTM_Zone_49N$ projection coordinates. The population data comes from the WorldPop datasets, including population density data with a resolution of 1km × 1km between 2000 and 2015. The top-down modeling method of WorldPop uses a global database based on population census and predicted counts by administrative units from 2000 to 2020, and decomposes it into 1x1km grid cells using a set of detailed geographic spatial datasets, with the advantage of consistent and complete estimates for each country from 2000 to 2020 each year [10]. However, the disadvantage is that for countries that have not conducted a population census for a long time or have significant sub-national differences in migration, fertility, and mortality rates, the input "official" population counts and predictions for these countries may be highly uncertain, but this is not the case in China, so the dataset can be used with confidence. The administrative boundaries are from the Resource and Environment Science and Data Center. The watershed boundaries of the treatment group and the control group are obtained by extracting the watershed areas from the DEM data.

3.3 Summary Statistic

This subsection mainly provides a descriptive analysis of the data used in the previous section, focusing on the final (year 2015) period. The summary statistics of the data are presented in Table 1.

The Normalized Difference Vegetation Index (NDVI) increased by 0.086 in 2015 compared to the base year of 2000. This indicates an improvement in the ecological environment of the study area over the 16-year period from 2000 to 2015. The Nighttime Light Index (NTLI) also

Table 1: Summary of Statistics

	Mean	Std. Dev	Descrption
	year=2015		
NDVI	0.75	0.14	Normalized Difference Vegetation Index
Night-time Light Index	345.26	702.84	Annual average nighttime light intensity
Irrgation Water Consumption	0.07	0.05	Annual agricultural Sector Irrigation Wateruse
Population	128.82	657.28	Population density within 1 square kilometer
Economic Activities			
Existence Total	0.42	11.54	Number of existing firms
Existence Agri	0.05	0.38	Number of existing firms in agri sector
Existence Nonagri	0.37	11.49	Number of existing firms in nonagri sector
Establish Total	0.48	12.79	Total number of establishments
Establish Agri	0.05	0.42	Number of newly established firms in agri sector
Establish Nonagri	0.43	12.72	Number of newly established firms in nonagri sector
Temperature	7.74	12.72	Annual average temperature
Precipitation	535.33	37.02	Annual precipitation
Note: The observation is 23,692, and the economic activities data represents the number of firms within a 3 km buffer zone around the observation point.			

experienced a significant increase, suggesting a rapid overall improvement in the economic development level of the region. The agricultural sector's water consumption for irrigation has decreased, contributing to a reduction in the consumption of water resources.

Between 2005 and 2015, the number of existing enterprises in both the agricultural and non-agricultural sectors increased. Additionally, a higher proportion of non-agricultural enterprises suggests a gradual increase in the proportion of the second and tertiary industries. This trend aligns with the reported non-agricultural main business income of 31,705.46 and 1,277,804 billion yuan for Beijing and Hebei provinces in 2005 and 2015, respectively, by the National Bureau of Statistics. The number of newly added enterprises in both agricultural and non-agricultural sectors also increased, consistent with the overall trend of economic development.

Regarding Climate data, the average temperature in the study area was around 7 degrees Celsius, and the average precipitation was around 500mm, consistent with the official statistical data reported by the government.

4 Empirical Models

In policy impact evaluation research, a common issue is the counterfactual problem. The purpose of this study is to explore the economic and ecological impacts of the PLDL policy. Factors such as local economic development, climate conditions, and resource endowment also affect the ecological environment. Based on this analysis, it is not possible to accurately identify the net impact of the PLDL policy by directly comparing the NDVI and nighttime light index (referred to as NTLI in the following text) between areas where the policy has been implemented and those where it has not. Therefore, to identify the net economic and ecological impacts of the PLDL policy, it is necessary to compare the ecological differences in the Miyun Reservoir Basin with and without the implementation of the policy. However, since the policy has already been implemented in the upstream areas of the Miyun Reservoir, we cannot obtain the economic and ecological levels before the policy was implemented. The Difference-in-Differences (DID) Method can effectively solve the above problem: first, this study finds control areas that are most similar to the Chaobai, Beiyun, and Jiyun water basin before the implementation of the PLDL policy, and used the conditions in these areas as the counterfactual scenario where the policy was not implemented. Therefore, we use the situation in these areas where the policy was not implemented to simulate the counterfactual scenario, that is, the Chaobai, Beiyun, and Jiyun water systems did not implement the policy. Finally, the economic and ecological impacts of the PLDL policy are analyzed using DID regression, to identify the net economic and ecological impacts of the PLDL policy.

The data used in this study is annual panel data at the raster level. To minimize endogeneity issues caused by omitted variables, a two-way fixed effects (FE) model is used for estimation. $_t$ represents time fixed effects, controlling for all factors affecting the ecological environment of each raster that vary over time, such as carbon dioxide content and air pollution concentration. d_i represents individual fixed effects, controlling for the characteristics of each raster that remain constant over time, such as topography, elevation, and slope.As the grassroots unit for land resource management in China, counties are the foundation of

China's economic development and are responsible for formulating and implementing local economic development plans. Therefore, each county has its own time trend. By incorporating the time-varying factors of county-level areas into the model, it is possible to capture the unique time trend of each county and more accurately estimate the effects of policies or other variables. Therefore, this paper adds county-specific time trends to the fixed effects model. Due to the cyclical nature of economic development and the seasonal variation of NDVI, this study employs a second-order differencing method to process the dependent variable, transforming the time series into a more stable residual series, thus eliminating the influence of trend and seasonality on the time series, in order to better study its remaining part. Finally, in order to mitigate the influence of extreme values on the regression results, this study takes the natural logarithm of the dependent variable NTL for regression analysis, while NDVI is a variable with values between 0 and 1, so only second-order differencing is performed.

The main empirical strategy is based on the exogeneity of PLDL policy with respect to the ecological environment and economic activities. The main equation estimated is as follows,the equation (2) estimates the economic and ecological impact of PLDL.

$$\Delta Y_{ict} = \alpha_0 + \alpha_1 treat_{ic} \times post_t + \alpha_2 X_{ict} + \sigma_{ic} + \mu_t + \phi_{ct} + \epsilon_{ict} \tag{2}$$

In the above formula(2), i denotes the grid cell, t denotes the year, and c denotes the county where the grid cell is located.In the evaluation of economic impacts, this paper uses the second-order difference of the logarithm of the nighttime light index (NTL) as the dependent variable Y, denoted as $\Delta \ln(NTL_{ict})$. In the assessment of ecological impacts, we use the second-order difference of NDVI as the dependent variable Y, denoted as $\Delta NDVI$. $treat_{ic}$ is a dummy variable indicating whether the watershed to which the grid cell belongs participates in the PLDL policy (the treatment group variable). Its value is 1 if the watershed participates in the PLDL policy and 0 otherwise. $post_t$ is a time dummy variable indicating whether the observation is after the implementation of the policy, with $post_t = 0$ and $post_t = 1$ indicating before and after 2006, respectively. $treat_{ic} \times post_t$ is the interaction term between $treat_{ic}$ and $post_t$, which reflects the average change in the dependent variable of the treatment group relative to the control group under the policy. X_{ic} is a vector of control variables, including average annual temperature (in Celsius), annual average precipitation and its quadratic term. ϕ_{ct} is the time trend specific to the county, μ_t is the year fixed effect, and σ_i is the fixed effect of the grid cell, ϵ_{ict} is the random error term.

5 Result

This section is split into four subsections. In Section 5.1 we present the main results from estimating equation (2) for different dependent variables(NDVI and NTLI) and specifications. Section 6.2 reported the mechanism behind the economic and ecological impacts of the PLDL policy in the previous section, including population migration and reduction in irrigation water use. Section 6.3 further discusses the economic impacts of PLDL from the perspective of economic activities, and examines its effects on both agricultural and non-agricultural sectors. Section 6.4 presents balance test and robustness checks.

5.1 Main results

Using remote sensing data at the grid level and applying the double difference method to estimate the equation, it was found that the policy had a positive impact on the ecological environment but slowed down the economic development level in the area. Table 2 presents the empirical results of different functional forms of the estimation equation for NDVI. Columns (1) to (4) represent no control variables, control variables, double fixed effects, and additional county-specific time trend fixed effects, respectively. When there are no fixed effects, the impact of PLDL on NDVI is significantly negative, but using the fixed effects model, its impact on NDVI is significant. This indicates that the estimation effect of fixed effects is better, and there are endogeneity problems such as omitted variables when fixed effects are not used. From the regression results, it can be seen that the implementation of the PLDL policy significantly increased the NDVI level around the Miyun Reservoir by 0.007, to a certain extent, improving the local ecological environment. Consistent with other literature reports, precipitation and temperature have a nonlinear impact on NDVI.

Similarly, Table 3 presents the results when the dependent variable is changed to the logarithmic difference of NTLI. All four models report that the implementation of the PLDL policy has a negative impact on the economic development around the Miyun Reservoir. When using double fixed effects, this policy has a negative impact of 73.6% on the nighttime light index, and when considering county-specific time trends, this negative impact reaches 101.2%. Similarly, temperature and precipitation have a nonlinear relationship with economic development, and as temperature rises and precipitation increases, the nighttime light index experiences a trend of first increasing and then decreasing.

5.2 Factor reallocation

To better understand the relationship between PLDL and the NTLI and NDVI , I conducted two tests and additional analyses. First, to explore the potential mechanism through which PLDL affects the economic level by releasing labor, I extracted remote sensing data on population density (number of people per square kilometer) in the study area and replaced the dependent variable in equation (2) with population density for analysis. Second, I hypothesized that PLDL increased NDVI by redistributing water resources through reduced agricultural irrigation water use, thus improving the ecological environment. Similarly, I replaced the extracted remote sensing data on agricultural irrigation water (cubic kilometers per year) in the study area with the dependent variable in equation (2) for analysis. Under the double fixed effects model, after controlling for county-specific time trends, the PLDL policy indeed caused labor migration, and the population density around the Miyun Reservoir area significantly decreased by 6.4%. This verifies the hypothesis of this study: the

Table 2: Impact of PLDL on NDVI

Variables	(1) ΔNDVI	(2) ΔNDVI	(3) ΔNDVI	(4) ΔNDVI
PLDL	-0.007^{***} (-40.49)	-0.015^{***} (-78.90)	0.002^{***} (5.33)	0.007^{***} (8.19)
Temperature		0.031^{***} (13.94)	0.141^{***} (8.82)	0.197^{***} (7.59)
Precipitation		0.011^{***} (72.69)	0.004^{***} (17.26)	0.009^{***} (24.47)
Temp^2		-0.012^{***} (-7.10)	-0.114^{***} (-26.54)	0.060^{***} (10.36)
Prep^2		$-8.85e-5^{***}$ (-65.60)	$-2.79e-5^{***}$ (-16.00)	$-5.44e-5^{***}$ (-19.76)
Constant	0.015^{***} (129.95)	-0.317^{***} (-73.90)	-0.141^{***} (-10.01)	-0.473^{***} (-23.15)
Year FE	NO	NO	YES	YES
Gridcell FE	NO	NO	YES	YES
County specific trend	NO	NO	NO	YES
Observations	165,844	165,844	165,844	165,844
R-squared	0.003	0.057	0.447	0.606

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

structural adjustment of planting crops from labor-intensive to less labor-intensive ones will reclassify labor resources, release some labor force, and thus lead to labor migration to other areas. The nighttime light index refers to the brightness of artificial light observed at night. Higher population density is usually accompanied by higher nighttime light index because more population requires more lighting and other forms of energy use. Conversely, lower population density may be accompanied by lower nighttime light index because relatively fewer people require less lighting and other forms of energy use.

Similarly, the PLDL policy significantly reduced irrigation water usage in the agricultural sector by 15.8%, consistent with the hypothesis of this study. There is a U-shaped relationship between temperature and irrigation water usage, which first decreases and then increases significantly with the increase in temperature. Precipitation has an inverted U-shaped relationship with irrigation water usage, which is consistent with the actual situation.

Table 3: Impact of PLDL on Night-time Light Index

Variables	(1) $\Delta \ln(light)$	(2) $\Delta \ln(light)$	(3) $\Delta \ln(light)$	(4) $\Delta \ln(light)$
PLDL	-1.536^{***}	-1.235^{***}	-0.736^{***}	-1.012^{***}
	(-75.59)	(-49.01)	(-17.20)	(-8.12)
Temperature		1.534^{***}	-11.014^{***}	33.354^{***}
		(6.69)	(-3.75)	(6.29)
Precipitation		-0.010	0.455^{***}	0.490^{***}
		(-0.64)	(17.21)	(10.54)
Temp^2		-1.759^{***}	-3.909^{***}	-3.350^{***}
		(-10.47)	(-5.28)	(-2.85)
Prep^2		$-3.678e-4^{***}$	-0.003^{***}	-0.005^{***}
		(-2.42)	(-12.33)	(-13.06)
Constant	1.857^{***}	3.227^{***}	-3.940^{*}	-32.923^{***}
	(154.90)	(7.45)	(-1.74)	(-8.39)
Year FE	NO	NO	YES	YES
Gridcell FE	NO	NO	YES	YES
County specific trend	NO	NO	NO	YES
Observations	165,844	165,844	165,844	165,844
R-squared	0.013	0.017	0.187	0.210

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5.3 Further discussions on economic activities

In this subsection, the article further discusses about the economic activities in the region, constructs buffers around the observation points, and sums up the number of agricultural and non-agricultural enterprises within the buffer zone, trying to explore whether the released labor force by the PLDL policy in Section 6.2 can promote changes in the local industrial structure. The areas around the Miyun Reservoir are located in mountainous or remote areas with inconvenient transportation and a lack of natural and economic resources, such as mineral resources and human resources. The geographical location and resource endowment of the region may limit the development of enterprises and the economy, resulting in weaker economic activities and fewer enterprises. Therefore, the discussion of economic activities is

Table 4: Impact of PLDL on factor reallocation

Variables	(1) $\Delta\ln(pop)$	(2) $\Delta\ln(wateruse)$
PLDL	-0.064^{***}	-0.158^{***}
	(-4.09)	(-5.46)
Temperature	3.754^{***}	-14.426^{***}
	(16.17)	(-8.17)
Precipitation	-0.023	0.103
	(-11.74)	(4.84)
Temp^2	-1.540^{***}	20.409^{***}
	(-24.94)	(38.87)
Prep^2	$1.134e-4^{***}$	-0.002^{***}
	(7.57)	(-9.85)
Constant	2.595^{***}	-2.431^{*}
	(18.57)	(-1.74)
Year FE	YES	YES
Gridcell FE	YES	YES
County specific trend	YES	YES
Observations	165,844	165,844
R-squared	0.963	0.499

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

a sub-sample of the above data, with a total sample size of 12,705.

Table 5 reports the impact of PLDL on the number of existing firms within the 3km buffer zone, with columns (1) to (4) respectively showing the impacts on the total number of existing firms, the number of existing firms in the agricultural sector, the number of existing firms in the non-agricultural sector, and the proportion of non-agricultural firms in the total number of existing firms. It can be seen that the policy had no significant impact on the number of existing firms, possibly due to the fixed effects absorbing the impact on existing firms. However, it had a significant negative impact on the number of existing firms in the agricultural sector, and a significant positive impact on the number of existing firms in the non-agricultural sector, with the proportion of non-agricultural firms in the total number of existing firms increasing significantly by 11.4%.

Next, the focus is on the impact of PLDL on the number of established firms. Table 6

Table 5: Impact of PLDL on Existing Firms

Variables	(1) Existence Total	(2) Existence Agri	(3) Existence Nonagri	(4) Percentage of Existence Nonagri
PLDL	0.315 (1.51)	-1.913^{***} (-7.05)	1.136^{***} (2.94)	0.114^{***} (4.53)
Control	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Gridcell FE	YES	YES	YES	YES
County specific trend	YES	YES	YES	YES
Observations	12,705	12,705	12,705	12,705
R-squared	0.521	0.346	0.504	0.463

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

reports the impact of PLDL on the number of established firms within the 3km buffer zone. The policy had a significant positive impact on the total number of established firms, a significant negative impact on the number of established firms in the agricultural sector, and a significant positive impact on the number of established firms in the non-agricultural sector, consistent with the results in Table 5. Moreover, column (4) shows a significant increase of 15% in the proportion of non-agricultural firms, which verifies our hypothesis that the labor force released from the agricultural sector may flow to the non-agricultural sector and promote the development of the non-agricultural sector to some extent. However, since data on operating income and other variables are lacking, the discussion can only be conducted from the perspective of the number of firms.

5.4 Balance test and Robustness check

In this section, Balance test and several robustness checks are performed.

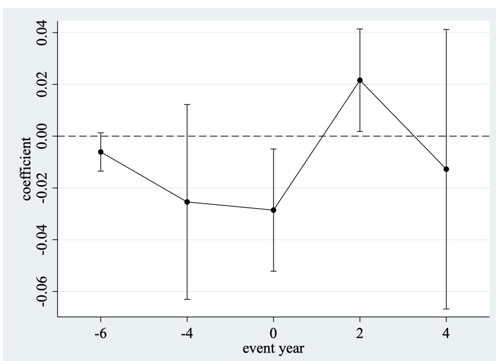
To test the assumption of parallel trends, a prerequisite for using the DID method, we apply the event study method to NDVI and NTLI, and Fig. 4 shows an event study figure

Table 6: Impact of PLDL on Established Firms

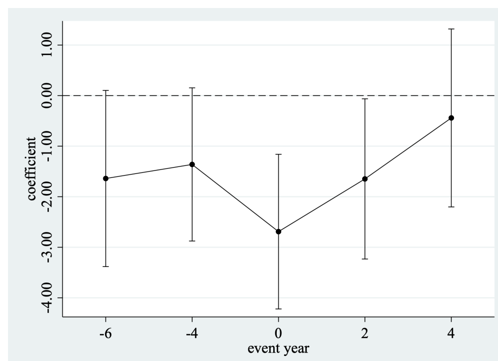
Variables	(1) Establish Total	(2) Establish Agri	(3) Establish Nonagri	(4) Percentage of Establish Nonagri
PLDL	0.837***	−1.931***	1.672***	0.150***
	(4.08)	(-7.04)	(6.25)	(8.46)
Control	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Gridcell FE	YES	YES	YES	YES
County specific trend	YES	YES	YES	YES
Observations	12,705	12,705	12,705	12,705
R-squared	0.528	0.357	0.513	0.464

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1



a Balance test for $\Delta NDVI$



b Balance test for $\Delta \ln(NTLI)$

Figure 4: Balance test. The regression equation of the model is: $\Delta Y_{ict} = \sigma_t \times$ Years After Adjudication$_{ict} + \mu_t + \phi_{ct} + \epsilon_{ict}$ The sample is restricted to data with at least 7 years of observations before and after policy implementation. The omitted factor in the regression is $t = -2$, the difference value two years before policy implementation.

where the left-hand side of the regression equation is consistent with formula (2), denoted as ΔY_{it}, and the right-hand side is a set of binary variables representing the number of periods before or after the implementation of the PLDL policy. The regression also controls for time fixed effects and individual fixed effects to eliminate the possibility of omitted variables. Fig. 4 shows that there is no significant difference between the experimental group and the control group before the policy implementation, and after the implementation, NDVI increases while NTLI continues to decrease, which is consistent with the main results in section 6.1.In addition, for the parallel trend test of economic activities data, since there is only one pre-period data in 2005, the event study method cannot be used as in the above test. Instead, following the approach of Raj Chetty et al.[3], a t-test is conducted on the pre-period data with control variables, and it is found that there is no significant difference in economic activities between the control group and the experimental group during this period, which satisfies the Balance test.

Subsequently, in order to conduct robustness checks in this study, equation (2) is re-estimated by replacing the dependent variable with the difference between the baseline and endline values of NDVI and NTLI. The regression results are presented in Table A **??** in the Appendix. Table A2 shows that the variable has a significantly negative impact on $\Delta NTLI$, which is consistent with the results in Table 3. Moreover, it has a significantly positive impact on $\Delta NDVI$, indicating that NDVI increases by 4.1%, consistent with the estimation results in Table 2, and thus proving that the estimation results of equation (2) are robust.

6 Conclusion

This article is based on one of the primary approaches to ecological conservation, the Payment for Ecosystem Services (PES) program. It focuses on the PLDL (Paddy land-to-Dry land) policy implemented by the Beijing Municipal Government in the Chaobai River Basin and examines its economic and ecological impacts. By utilizing remote sensing data to construct a gridded dataset of the study region, the study employs a difference-in-differences method to identify the improvement in the ecological environment of the treated group resulting from the PLDL policy. The findings reveal that the local NDVI has increased by 0.007. Further analysis demonstrates that agricultural irrigation water use in the region has significantly decreased by 15.8% after the implementation of the PLDL policy, leading to water resource conservation. These positive ecological impacts indicate that altering the agricultural cropping structure through this ecosystem service project can effectively alleviate the conflicts between agricultural production and the ecological environment, making it a key aspect of environmental management for the Miyun Reservoir. Considering the positive externalities for the ecological environment generated by this policy, such agricultural PES policies possess sustainability and should be implemented and promoted. For instance, in areas suffering from severe groundwater depletion and water scarcity, policies such as adjusting the cropping structure to replace high-water-demand crops with low-water-demand crops could be considered as a means of mitigation. Specifically, this policy can be extended to regions like the Sanjiang Plain in Heilongjiang Province, where groundwater over-extraction is severe and there is a prevalence of low-quality and inefficient rice cultivation.

Simultaneously, the study's results indicate that this policy has negative impacts on the local economy, as the nighttime light index has decreased by 101.2%. To investigate this, the study examines the conversion of households previously engaged in rice cultivation to dryland crop cultivation. Since dryland crops require less labor compared to rice cultivation, the policy has also resulted in the release of labor force, leading to labor outflow and a significant decrease in population density by 6.4%, which subsequently contributes to the decline in the nighttime light index. The release of labor force not only involves migration within and outside the region but also occurs between the agricultural and non-agricultural sectors. The estimations further indicate that the implementation of this policy has significantly increased the proportion of the non-agricultural sector, with a rise of 0.15 in the proportion of newly added non-agricultural enterprises and an increase of 0.114 in the proportion of existing non-agricultural enterprises. Therefore, for ecological compensation policies, it is crucial to estimate their economic impacts in addition to evaluating their ecological effects. If the economic impacts are negative, it directly affects the implementation efficiency of the policy, potentially hindering the expected resource conservation and ecological improvement outcomes. Moreover, the formulation of compensation standards should fully consider the positive and negative externalities brought about by the policy. Imbalanced compensation between ecologically vulnerable areas and economically developed areas can exacerbate the urban-rural disparity and result in regional imbalances in development. In summary, the policymakers of PES programs need to consider both economic and ecological aspects in their decision-making processes.

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1. Appendix Section

Table A 1 List of Data Sources

Data	Source	Resolution	Years Avaliable	Fields
Study Watershed	SRTM	1km×1km Raster	NA Cross Section	Define the boundary of treatment group and control group watersheds
Normalized Difference Vegetation Index	Resource and Environment Science and Data Center	1km×1km Raster	Annual 2000-2015	Annual NDVI
Water Consumption	Institute of Tibetan Plateau Research Chinese Academy of Sciences	0. 25°×0. 25° Raster	Annual 2000-2015	Annual Agricultural Sector Irrigation Wateruse
Night-time Light	Resource and Environment Science and Data Center	0.004°×0.004° Raster	Annual 2000-2015	Night-time Light
Population	WorldPop Datasets	1km×1km Raster	Annual 2000-2015	Population density within 1 square kilometer
Economic activities	Resource and Environment Science and Data Center	0.01°×0.01° Raster	Annual 2000-2015	Total number of establishments and existing firms within the cell, Number of newly established and existing firms in primary, secondary, tertiary industry
Climate Data	Resource and Environment Science and Data Center	1km×1km Raster	Annual 2000-2015	Annual Temperature, Annual Precipitation

Table A2: Impact of PLDL on NTLI and NDVI, alternative specifications

Variables	(1) $\Delta\ NTLI$	(2) $\Delta NDVI$
PLDL	-28.220^{***}	0.041^{***}
	(-6.89)	(39.42)
Temperature	-176.817^{***}	0.169^{***}
	(-4.19)	(12.87)
Precipitation	-344.275	0.057
	(-22.82)	(22.17)
Temp^2	408.286^{***}	-0.151^{***}
	(13.22)	(-16.32)
Prep^2	3.013^{***}	-0.001^{***}
	(21.65)	(-23.41)
Constant	$9,808.408^{***}$	-1.392^{*}
	(23.64)	(-20.33)
Observations	23,692	23,692
R-squared	0.189	0.156

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1