Impacts of Foreign Aid and Investment on Emerging Countries: Grid Cells of Nighttime Light Data Analysis of the Belt and Road Initiative Projects Effects in Central Asia

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Abstract:

This study investigates the direct and spillover economic impact of China's Belt and Road Initiative (BRI) in Central Asia over the period 2012-2022. Remote sensing nighttime light data are utilized due to the inaccessibility of subnational GDP data in the region. The analysis is conducted at the 0.25° (longitude) × 0.25° (latitude) grid cell level using a Spatial Durbin Model (SDM). Results show that BRI projects significantly increase nighttime light luminosity in local cells and that the positive effects persist for at least two subsequent years. Strong spatial spillover effects are also observed in the results, reflected by the increased intensity of nighttime light in adjacent cells. Government effectiveness is positively correlated with economic performance, providing evidence to explain the heterogeneity of economic growth by country. Additionally, the model controls for fixed effects and spatial lags, ensuring robustness against endogeneity. The findings support the use of nighttime light as a proxy for economic activity and highlight the role of infrastructure-driven aid in promoting regional growth in landlocked and institutionally diverse economies like those in Central Asia.

Keywords: Foreign direct investment; foreign aid; Belt and Road Initiative; nighttime light; spatial spillover effect.

1. Introduction

Covering more than three scores countries in three continents, with hundreds of billions of direct investments made annually, as unarguably the most ambitious and expensive international infrastructure investment project, Belt and Road Initiative (BRI) and its effect are widely discussed. As China's official

doctrine frames the BRI as a win-win cooperation, some people regard the BRI as a mean of "Debt Trap Diplomacy" or "white elephants" [1, 2, 3]. Of interest to many aid-giving organizations, the contentions about the effects of foreign aid and investment went far before and beyond the BRI, with concerns about aggravating corruption, widening income gap, etc [4, 5]. And what draws the most attention of the scholars is the economic effectiveness of foreign aid and investment, as in the extent to which they contribute to economic growth in underdeveloped regions. This topic is of great significance for it serves the need to evaluate whether the methods currently taken by aid-givers are the most effective for the development of the Global South. Research focusing particularly on the BRI will also provide evidence for the contentions between the officials and the press, as well as advice for future foreign aid projects. To further address the topic, this study will assess the direct and spatial spillover effects of the BRI projects on the economic development of Central Asia.

Due to the inaccessibility of sub-national GDP data in Central Asian countries, as well as the endogeneity rising from unexpected factors, this study uses nighttime light data obtained from NASA's Visible Infrared Imaging Radiometer Suite (VIIRS) to indicate the increase of economic growth in the studied area [6]. The advantages of this technique are the wide scope of region that nighttime light images can cover, the consistency of measurement compared to traditional GDP data providing by each country, the convenience of dividing regions into pixels instead of administrative regions and data coherence by time, which suit well with framing spatial spillover models. Since this study is aimed at measuring the effect of the BRI projects on Central Asian countries, Spatial Durbin Model is employed and government effectiveness is taken into account as a key control variable.

2. Literature Review

Does the economic effect outweigh the drawbacks brought by foreign direct investment? Does aid foster local economic growth? Scholars' study outcomes are divided on the extent to which foreign direct investment promotes economic development, with evidence indicating that foreign direct investment is the engine of economic growth in underdeveloped regions and that the effect hinges on government capacity, transparency, accountability, trade barriers, human capital conditions and macroeconomic stability [7, 8, 9]. There is less consensus in terms of the impact of foreign aid, for the outcome of foreign aid is highly mixed. A previous study looked into the heterogeneous effect of aid on different countries and found that foreign aid has positive impact on high income developing

countries (HIDCs) but negative outcome on low income developing countries (LIDCs), which is probably due to institutional quality of different countries [10]. Some other studies have similar claims, with proof that reveals the correlation between aid's negative impact on economic growth and governments' misallocation and mismanagement of aid [11].

Aid and investment under the framework of the BRI are mostly given in the form of infrastructure projects or substantial medicine like vaccines, making the initiative different from others with fewer concerns about misallocation and mismanagement. The direct effect and spatial spillover effect are estimated by economists with various approaches. A study focused on the impact of transport infrastructure on economic growth, finding the former facilitates the latter and that economic growth in one country has significant spatial spillover effect on adjacent countries and those that share economic, cultural and institutional proximity [12]. Empirical evidence also supports the thesis that infrastructure has both short-term and long-term impacts on the economic growth of BRI countries [13]. Using a computable general equilibrium (CGE) model, Chen and Li illustrated how transport infrastructure fosters economic growth by increasing connectivity and eliminating trade costs [14]. These studies measure economic effects with the smallest unit "country" or "region", raising concerns about endogeneity about the outcome evaluated with data of this level. That is to say, the effect of BRI projects is not very likely to be reflected in per capita GDP of a nation-level economy.

In response to the endogeneity issue, assessment of smaller scales was introduced. Bennett pointed out the applicability of nighttime light (NTL) data in political geography and deconstructing the official doctrine and criticism, for the satellite images can not only bypass the inaccessibility of local economic index, but it is also capable of revealing the use (or lack of use) of infrastructure [15]. And in fact, this technique has been used to examine the effect of aid. Xu and colleagues took China's aid in Africa as an example, parameterized the spatial spillover effect of China-built infrastructure using nighttime light data and spatial autoregression model, concluded that Chinese aid is significantly and positively associated with local economic growth [16].

3. Data

Considering the burden of large computation, Central Asia is divided into 0.25° (longitude) × 0.25° (latitude) grid cells (8118 in total) of nighttime light images and the locations of infrastructure projects are marked in the separate cells. Instead of using GDP data, the level of econom-

ic development is indicated by nighttime light luminosity in this study. Higher luminosity is generally interpreted as indicative of more intense economic activity, as is widely accepted in economic studies [17].

The nighttime light data of this study are obtained from the Visible Infrared Imaging Radiometer Suite (VIIRS) boarded by the Suomi National Polar-orbiting Partnership (NPP) satellite platform that was launched on October 28, 2011 [18]. The data cover a temporal length from 2012 till now, allowing us to analyze the change of nighttime light during the period when the BRI was launched.

As for the location and other information associated with investment projects from China to Central Asia, geocoded data provided by the AidData Center of the College of William and Mary were used to select investment projects from the period 2013–2022. As a measure taken by previous scholars, the projects which are too grand and general, such as the donation from China state-owned corporation to a country, are screened out of the data due to the object

of this research for they are unable to fit in disaggregated grid cell data [16, 19, 20]. In this study, since the BRI projects are mostly distributed in separate grid cells, the existence of BRI projects is processed as dummy variables, valued 1 if there exist projects in the cells and 0 otherwise.

Since the collapse of the Soviet Union, the five states of Central Asia have taken different paths in economic choices and political arrangement, implying that the background of development in Central Asia is heterogeneous [21]. To better explain economic growth, the level of governance effectiveness is taken into account in this study, indicated by data from World Bank [22].

In Fig. 1 shown is Central Asia divided in grid cells, where blue means the nighttime light in this cell during 2012-2022 faded, red indicates increased nighttime light and intensified economic activity. White lines and dots represent the locations of BRI projects.
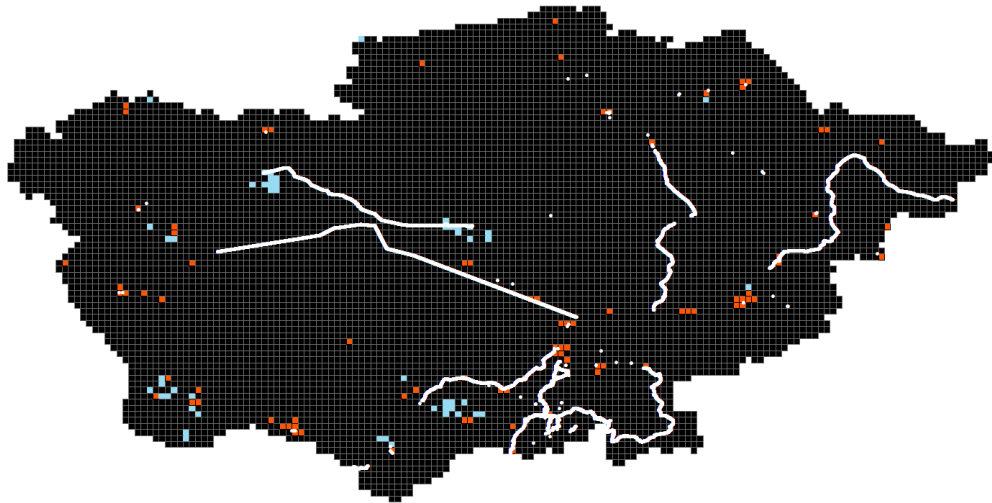

Fig. 1 Changes in Average Nighttime Light Luminosity of Grid Cells in Central Asia (2012–2022), with BRI Project Locations
(Data from: Payne Institute for Public Policy, VIIRS)

Table 1. Basic descriptives

	Observations	Mean	Std. Dev.	Min	Max
ln(light+1e-6)	89298	-7.86	4.08	-11.51	4.86
Has BRI project	89298	0.0028	0.05	0	1
L1 BRI project	89298	0.0028	0.05	0	1
L2 BRI project	89298	0.0027	0.05	0	1
Effectiveness	89298	-0.32	0.39	-1.18	0.14

4. Empirical Model and Results

The empirical model of this study is to apply the Spatial Durbin Model, which has been proven practical in analyzing both temporal and spatial lag effect, to comprehensively reflect the effects of the independent variable. The exact Equation 1 is as below:

Equation 1. Spatial Durbin Model

$ln(light_{it}+10^{-6})$ is the log form of nighttime light intensity of grid i in year t, with a small constant 10^{-6} to avoid ln0. $Wln(light_{it}+10^{-6})$ represents the spatially lagged variable, capturing the influence of the economic activity of neighbouring grids. $has\_bri_{it}, L1\_has\_bri_{it}, L2\_has\_bri_{it}$ are

dummy variables indicating the presence of BRI infrastructure projects in the current, first lag, and second lag years, respectively. Control variable *effectiveness* refers to the time-varying governance effectiveness of the country where the grid belongs. Terms $W(has\_bri_{it})$, $W(L1\_has\_bri_{it})$, $W(L2\_has\_bri_{it})$ are the spatial lagged independent variables to account for potential spatial spillover effects from neighbouring units. μi and λt are spatial and temperol fixed effects caused by unobserved factors such as the COVID-19 pandemic. ε_{it} denotes the disturbance term that captures unexplained variations across grid cells and over time. Table 1 presents the data processing results based on the empirical model.

Table 2. Spatial regression results

Dep.Var.: $ln(light_{it}+10^{-6})$	Estimate	Std. Error	t-value	Significance
has_bri	3.1411	0.2465	12.744	< 2.2e-16***
L1_has_bri	3.0409	0.248	12.262	< 2.2e-16***
L2_has_bri	3.0813	0.2499	12.329	< 2.2e-16***
year2013	-0.0578	0.0611	-0.946	0.344
year2014	-0.219	0.0756	-2.896	0.003775**
year2015	-0.2221	0.0711	-3.125	0.001780**
year2016	-0.1956	0.0693	-2.822	0.004777 **
year2017	-0.0769	0.0723	-1.064	0.2873
year2018	-0.0371	0.0732	-0.508	0.611684
year2019	-0.0107	0.079	-0.135	0.892716
year2020	0.0989	0.0819	1.207	0.227437
year2021	0.2129	0.0807	2.639	0.008324**
year2022	0.1942	0.084	2.313	0.020744*
countryKyrgyzstan	1.4381	0.0975	14.749	< 2.2e-16***
countryTajikistan	-0.2598	0.1203	-2.159	0.030820*
countryTurkmenistan	-0.5259	0.1015	-5.181	2.21e-07 ***
countryUzbekistan	1.2617	0.0716	17.611	< 2.2e-16***
effectiveness	0.2687	0.11	2.444	0.014541*
Spatial lag (λ)	0.3942	0.0047	84.448	< 2.2e-16***

Significance levels: *p<0.1, **p<0.05, ***p<0.01

The variable has_bri, indicating whether a grid has BRI projects or not, shows a significant and positive effect on nighttime light luminosity of that grid, which serves as a proxy for the local economic development. The two time-lagged variables followed also show similar results, implying that the economic effect of BRI projects persist for at least two years. The spatial lag (λ) is also strong and positive, providing evidence of spatial spillover effect, implying that the influence of BRI projects on economic growth is not simply limited to what observed locally. This outcome is consistent with the information provided

in Figure 1., in which the grids adjacent to grids with BRI located witness increased nighttime light.

Also significantly and positively associated with economic development, government effectiveness represents an important sociological factor in the model. This indictor captures a range of government performances from the perceived quality of public services to policy formulation and implementation. This is consistent with the fact that investors and aid givers take account of the quality of governance when making their decisions. Additionally, this result provides evidence to explain the heterogeneity of economic growth by country in Central Asia.

The country fixed effect data in Table 2., with Kazakhstan being the base country, indicates the contribution of each country to the nighttime light in the studied region. While Kyrgyzstan and Uzbekistan are brighter than the other counterparts, the luminosity of Tajikistan and Turkmenistan is below average.

Regarding the temporal difference of nighttime light, 2012 is set as the base year. The parameters for the subsequent years clearly show a decline in nighttime light, with economic conditions not recovering to the previous level until 2020. Considering that five Central Asian countries—apart from Turkmenistan—experienced economic growth during that period, the observed trend may be attributed to urbanization, which caused the agglomeration of population and economic activities. Let aside the temporal fixed effects added in the model that helped better reflect the effect of BRI projects, urbanization can explain why BRI projects is associated with increased economic growth when nighttime light of Central Asia is statistically fading. Understanding the path through which the economic spatial spillover effect take place is key to designing policies to promote regional growth. Previous studies have attempted to address this issue by modeling spatial weights matrix in terms of economic proximity other than geographical proximity, and their results implies that spatial spillover effects transmit through value chain [23]. Similar research can be done in Central Asia if the interregional value-added data on Level 2 or Level 3 is available.

5. Conclusion

This study overcomes the inaccessibility of economic growth data in small units by using remote sensing nighttime light data to indicate economic growth. GIS makes it possible to divide Central Asia into grid cells, and therefore, to analyze the direct and spatial spillover effect of BRI projects on local economic growth, this is can make sure the influence of the BRI would be less undervalued than it was when spillover effect is not part of the model. The result verify the significance and positive influence of BRI projects on local economic growth, and that the effect seems to persist for at least two years after the projects' completion. As predicted, in a year when the observed country scores high in government effectiveness, there comes good economic performance.

This study presents some limitations that might be addressed in future research. To start with, this research lacks the analysis on the heterogeneity of BRI projects. It would be helpful to categorize BRI projects to look into what kind of projects, be it social, economic, energy or transportation, contribute to local economic growth most significantly. Besides, as is mentioned in the previous

session, spatial weights matrix based on geographical proximity should be supplemented by counterpart that is based on economic interactions. In that case, given the appropriate data, political proximity matrix can be employed to see if like-minded regions are more beneficial to each other in terms of economic growth. Furthermore, if subnational data were available, dividing Central Asia by its subnational administrative boundaries could allow for the assignment of socioeconomic meaning to the analysis units.

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