Illuminating Dark Deals:
The Economic Impact of North Korean Arms Export to Russia

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Abstract

This study examines the regional economic impact of North Korea's arms transfers to Russia. Using monthly nighttime light data from January 2022 to December 2024, we employed a difference-in-differences approach to identify the causal effect of arms export. Results show that the nighttime light intensity in heavy-industrial regions becomes 5.9 percentage points brighter on average than in other areas after September 2022. This result implies that the GDP in these regions has increased by approximately 1.77%–2.47%. This paper highlights empirical evidence on how small states can benefit from military conflicts.

Keywords

Russia–Ukraine war; North Korea, arms export, nightlight, difference-in-differences

1. Introduction

On September 5, 2022, a senior official in the U.S. government stated that Russia was in the process of purchasing millions of rockets and artillery shells from the Democratic People's Republic of Korea (hereafter, North Korea) for use in its war against Ukraine (Barnes, 2022). The North Korean Ministry of National Defense denied this claim. However, by the fall of 2023, North Korean weapons and ammunition were reported to have reached Russian artillery units on the front lines of the Russia–Ukraine war. In February 2024, South Korea's Minister of National Defense stated that North Korea's military factories had been operating at full production capacity. Further irrefutable evidence of arms exports emerged during a United Nations Security Council panel held on June 28, 2024. They showed that missile debris recovered in Kharkiv, Ukraine, had been manufactured in North Korea in 2023 (United Nations, 2024).

The recent surge in the demand for military supplies presents a potential opportunity for North Korea's economic uplift. Although official statistics on North Korea's economy are largely unavailable, recent studies have demonstrated that economic activity can be measured using nighttime luminosity and related proxy data. Their results showed sustained economic growth during the 2000s (Lee, 2018; Kim, K., 2022). However, the overall growth slowed due to the effects of international sanctions linked to North Korea's nuclear weapons program (Kim, D., 2022; Park, 2022; Kim et al., 2023). Given the far-reaching consequences of Russia's invasion of Ukraine

(Conyon, 2025), the compelling question of how North Korea may be benefiting economically from the ongoing war has been raised.

This study quantitatively analyzes the regional economic impact of North Korea's arms transfers to Russia. Monthly nighttime light data were used to examine whether the economic activity in North Korea's heavy manufacturing industry regions has increased since the reported start of arms exports to Russia. The analysis employs a difference-in-differences (DiD) approach to identify changes in economic activity. Results show intensified economic activity in these regions in September 2022. On average, the nighttime light intensity in heavy industry regions increased to 5.9 percentage points brighter than in other areas after September 2022. This finding is qualitatively robust to alternative specifications.

This study provides evidence on two main issues: (1) the effects of North Korean arms exports to Russia using updated data and a standard causal inference framework and how small states can benefit from great power conflicts.

2. Data and empirical strategy

2.1 Data

We constructed a monthly balanced panel dataset using nighttime light data. The nighttime light data were sourced from the Visible Infrared Imaging Radiometer Suite (VIIRS) provided by the Defense Meteorological Satellite Program. Although multiple options for nighttime light data are available, Gibson et al. (2021) reported that VIIRS performs best as a proxy for GDP. As Kim et al. (2023) noted, the VIIRS collects nighttime light data at 1:30 a.m., and the light intensity variation at this hour is likely to reflect manufacturing activity.

Our dependent variable (the radiance values obtained from the VIIRS Day/Night Band) represents the intensity of nighttime lights observed at the Earth's surface and is expressed in units of nW/cm^2/sr (nanowatts per square centimeter per steradian). Following Elvidge et al.'s (2017) methodology, the raw satellite data underwent a series of filtering processes to remove contamination. The resulting composite product reflects the average monthly radiance values, which were then aggregated at the administrative unit level (e.g., counties or cities) in our analysis.

Our dataset covers the period from January 2022 to December 2024, encompassing the period before and after the commencement of arms exports. Figure A.1 in the Appendix presents sample data for February 2022 and February 2023. Data for July 2022 are excluded from the analysis because of an exceptionally low number of satellite observations caused by a satellite anomaly (see Appendix Note 1), though including these data does not qualitatively affect our findings.

2.2 Empirical strategy

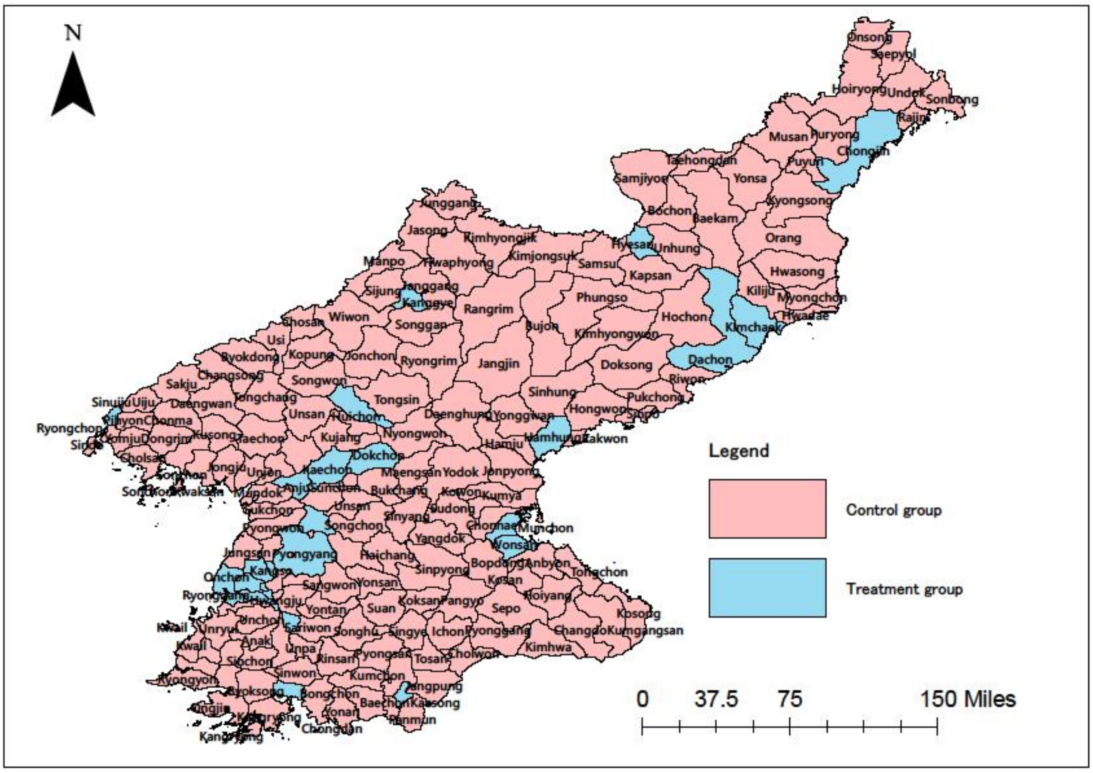
The DiD estimation model used in this study is specified as follows:

$$\operatorname{asinh}(radiance_{it}) = \alpha_0 + \alpha_1 T_t * D_i + \tau_t + \delta_i + \varepsilon_{it} \quad (1)$$

where $radiance_{it}$ represents the intensity of nighttime light in city *i* at month *t*, D_i and T_t are dummy variables indicating the treated areas and intervention period, respectively. $T_t * D_i$, ε_{it}, and α_0 are the treatment term, error term, and constant term, respectively. Following Blakeslee et al.'s (2022) approach, we used inverse hyperbolic functions (asinh function) to transform nightlight data to account for the skewed distribution and the presence of zero or near-zero observations. Alternatively, we estimated the model by using the log($radiance_{it}$) for a robustness check and interpretation.

The unit of analysis is the second-level administrative division in North Korea, comprising 186 units (see Figure 1). In the baseline specification, the intervention period dummy variable is defined using the news reports introduced earlier: months before September 2022 are coded as $T = 0$, and months from September 2022 onward are coded as $T = 1$.

Figure 1. North Korean second-level administrative unit and baseline grouping



Source: Authors' estimation.

In this study, the definition of the treatment group regions is a critical element. A key source for identifying these regions based on micro-level information is the North Korean company news database utilized by Kim et al. (2023). This database was compiled by the Korea Institute for

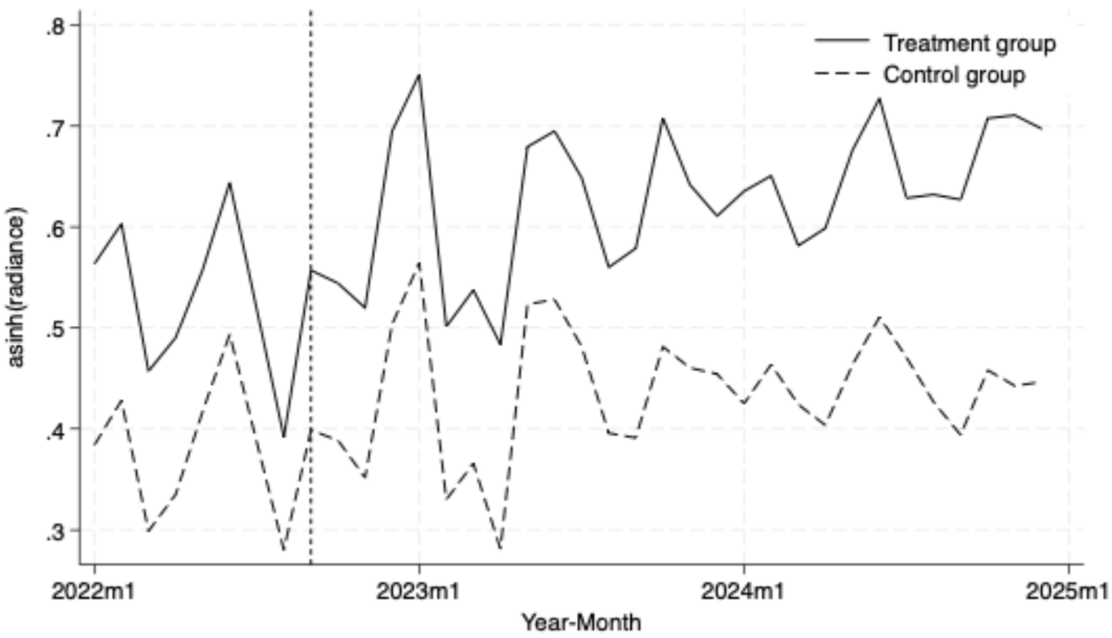
Industrial Economics & Trade (KIET) and tracks articles published between 2000 and 2019 in two major state-run North Korean newspapers, namely, *Rodong Sinmun* and *Minju Chosun*. This study uses the aforementioned database and applies two criteria: (1) extraction of companies classified under heavy industry using ISIC Rev. 3 Codes 27–35 and (2) selection of regions with at least 100 related articles. As a result, 25 regions were identified as shown in Figure 1 (see Appendix Note 2 for the list of regions). Light industrial products, such as military uniforms, may also be involved in arms-related exports, whereas heavy industry has been the most directly affected by North Korea's arms transfers to Russia since September 2022. In addition, the potential impact of the spread of COVID-19 on the estimation is addressed by including regional fixed effects and examining pre-trends (see Appendix Note 3).

3. Results

3.1 Baseline results

The trends in the nighttime light intensity for the treatment and control groups are presented in Figure 2 to verify the parallel trends assumption. No trends that would violate the parallel trend assumption were observed before the intervention event (see Figure A.2 in the Appendix for the log(*radiance*) version).

Figure 2. Trend comparison between the treatment and control groups



Source: Authors' estimation.

The DiD estimation results indicate a statistically significant increase in the nighttime light intensity of heavy industry regions (Table 1). In model (1), the coefficient on the DiD term is 0.045, with a standard error of 0.0136, and is statistically significant at the 1% level. In model (2), which uses the log(*radiance*) specification, the coefficient on the DiD term is 0.059, which is also statistically significant at the 1% level. Therefore, the treatment group (regions presumed to be involved in arms exports) experienced an increase in nighttime light intensity by 5.9 percentage points greater than the control group.

According to Henderson et al. (2012), the elasticity between nighttime light intensity and GDP in low- and middle-income countries is approximately 0.3, implying that a 1% increase in light intensity corresponds to a 0.3% increase in GDP. Therefore, the GDP in heavy industry regions increased by approximately 1.77%. Using an alternative elasticity of 0.419, the estimated GDP impact rises to 2.47%. — The alternative elasticity was estimated by Kim et al. (2023) based on regional data from northeastern China with light levels comparable to those of North Korea.

Table 1. Estimated effects of policy intervention on nighttime light intensity

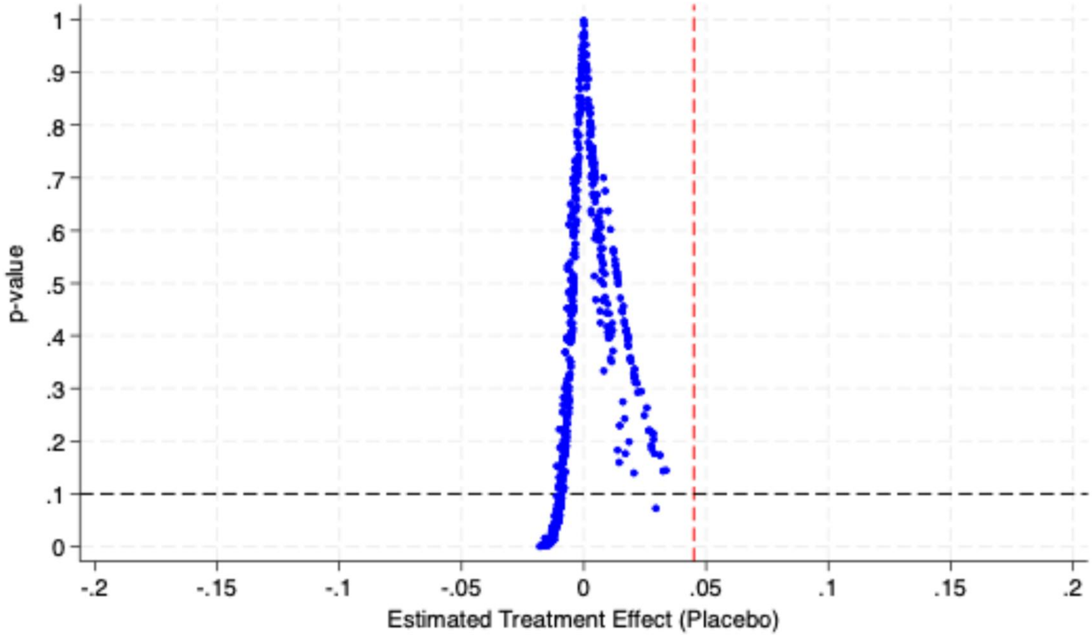
	(1) asinh(*radiance*)	(2) log(*radiance*)
Treat * Post	0.045^{***}	0.059^{**}
	(0.0136)	(0.0146)
Constant	0.443^{***}	-0.832^{***}
	(0.0014)	(0.0015)
Month FE	Y	Y
City FE	Y	Y
Adjusted R^2	0.90	0.89
Observations	6,510	6,510

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.
Source: Authors' estimation.

3.2 Robustness check and further analysis

We conducted a placebo test to assess the robustness of the estimated treatment effect. Specifically, we randomly assigned the treatment regional group and re-estimated the model 500 times, comparing the distribution of these placebo estimates with the actual estimates. As shown in Figure 3, the distribution of the placebo estimates is centered on 0, with p-values exceeding 0.1 in most cases. This result indicates that statistically significant effects were not observed when the treatment group was assigned randomly. In contrast, the actual DiD estimate (indicated by the red line) lies far to the right of this distribution, suggesting that the observed effect is unlikely to be due to chance.

Figure 3. Placebo permutation test in terms of region



Source: Authors' estimation.

The results remain robust to the alternative criteria for defining the treatment group regions related to manufacturing. In Table 2, model (1) uses an alternative specification in which the treatment group consists of 25 regions identified based on the total number of manufacturing-related articles in the KIET database. Although the adjusted R^2 is slightly lower than that of the baseline estimation, the coefficient on the DiD term is slightly larger than that in the baseline model, at 0.049. Model (2) defines the treatment group based on the manufacturing regions identified in Park's (2022) report, published by a South Korean research institute. Although the DiD coefficient in this model is smaller than that in the baseline estimation, it remains statistically significant.

Table 2. Treatment effect estimates with alternative group definitions

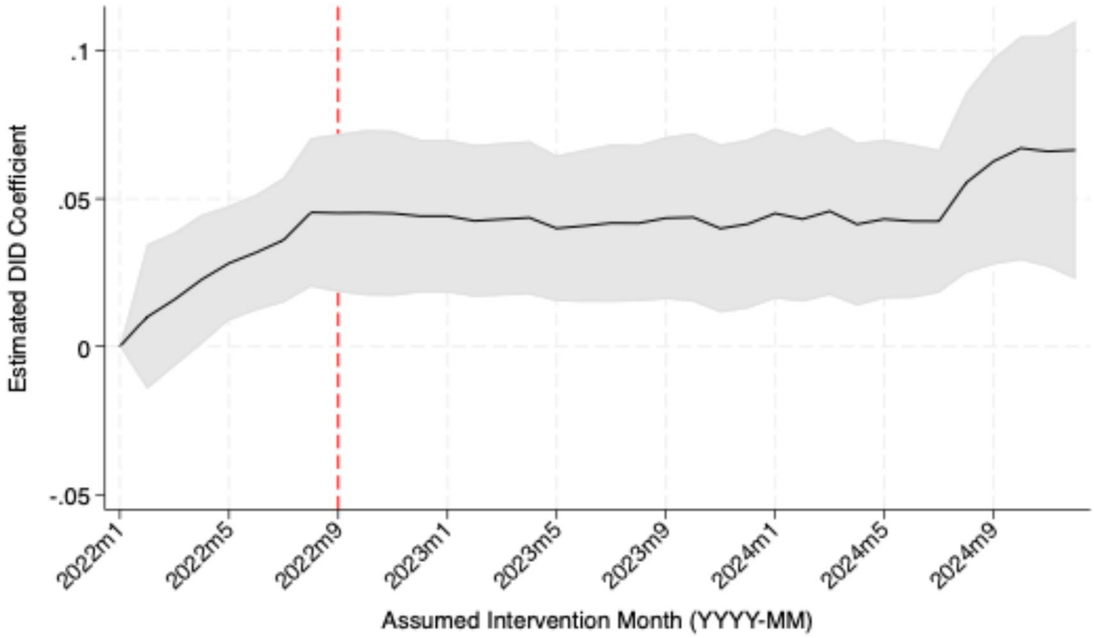
	(1) Manufacturing sectors on KIET data	(2) Definition by Park (2022)
Treat * Post	0.049***	0.039**
	(0.0166)	(0.0175)
Constant	−0.831***	−0.830***

	(0.0017)	(0.0017)
Month FE	Y	Y
City FE	Y	Y
Adjusted R^2	0.89	0.89
Observations	6,510	6,510

Note: The dependent variable is asinh(*radiance*). *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.
Source: Authors' estimation.

Defining September 2022 as the intervention point in the baseline estimation relies on relatively early media reports. Consequently, this timing may include a period before the full-scale production of military supplies had commenced, potentially leading to an underestimated causal effect. Particularly, the visit of North Korean leader Kim Jong-un to Russia and his summit with President Vladimir Putin in September 2023 indicates a further deepening of bilateral relations. We conducted DiD estimation using each month as a potential treatment timing to examine the potential impact of this development. Figure 4 plots the estimated DiD coefficients assuming different intervention months. Each point on the black line indicates the estimated treatment effect (asinh-transformed nighttime light intensity) when the treatment is assumed to have started in that particular month. Our baseline intervention timing captures one of the earliest effects among the time points presented. Statistical significance weakens for earlier placebo interventions. In contrast, no major shift is observed around the September 2023 summit meeting. However, the results indicate new effects in the fourth quarter of 2024.

Figure 4. Placebo permutation test in terms of time



Note: The shaded area represents the 95% confidence interval. The red dashed line marks September 2022, the actual intervention month used in our baseline model.
Source: Authors' estimation.

As demonstrated in the baseline estimation, economic activity has increased notably in heavy industry areas. No evidence indicates the initiation of heavy industry exports to countries other than Russia during this period. Thus, these changes can be reasonably attributed to arms exports to Russia.

4. Conclusion

This study uses monthly nighttime light data to analyze whether the economic activity in North Korea's heavy industry regions has intensified following the reported commencement of arms exports to Russia. The analysis employing a DiD approach reveals that the nighttime light intensity in North Korea's heavy industry regions increased by 5.9 percentage points on average relative to other areas after September 2022. Does this economic uptick translate into improved living standards for North Koreans? Moreover, how can the trajectory of the Russia–Ukraine war exert a medium–long-term impact on the North Korean economy? These questions remain important for future research.

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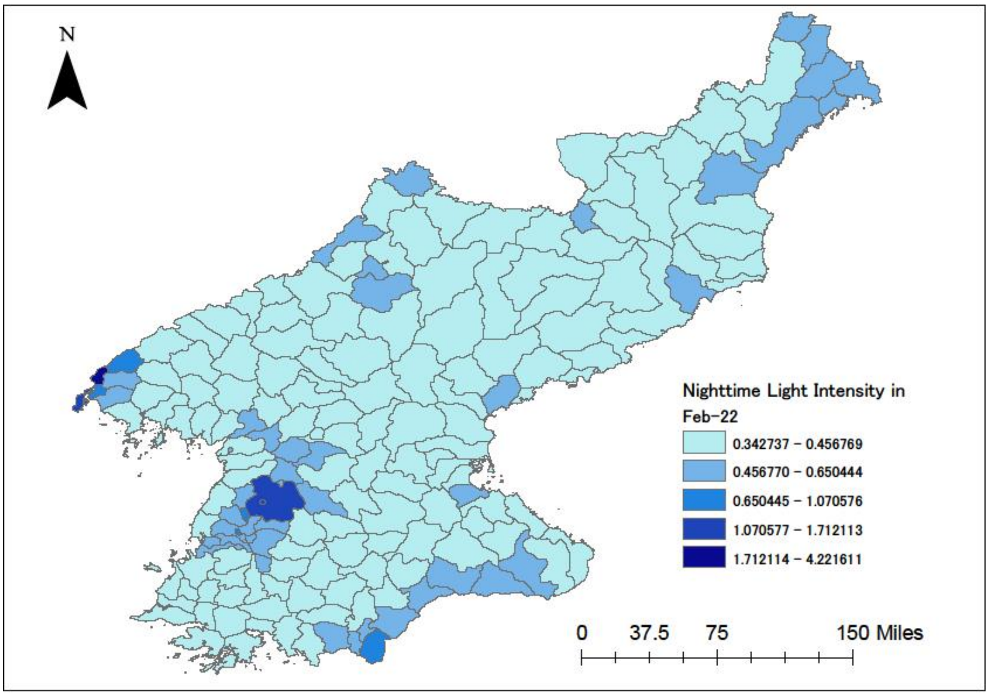
Appendix

Figure A.1. Nighttime light intensity in North Korea (Unit: asinh(*radiance*))

(A) February 2022



(B) February 2023

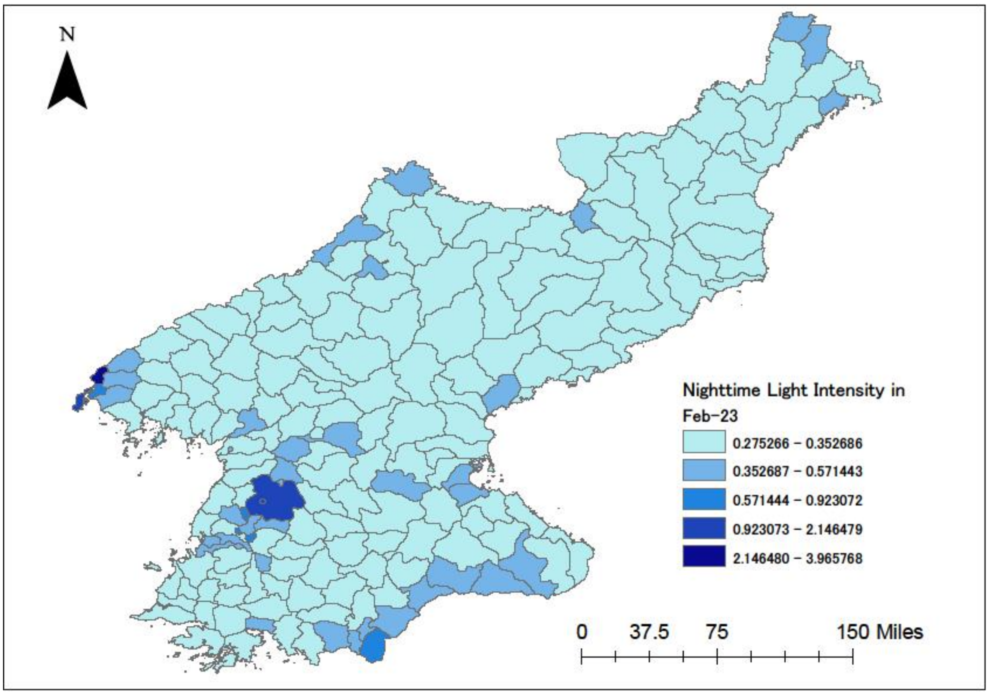
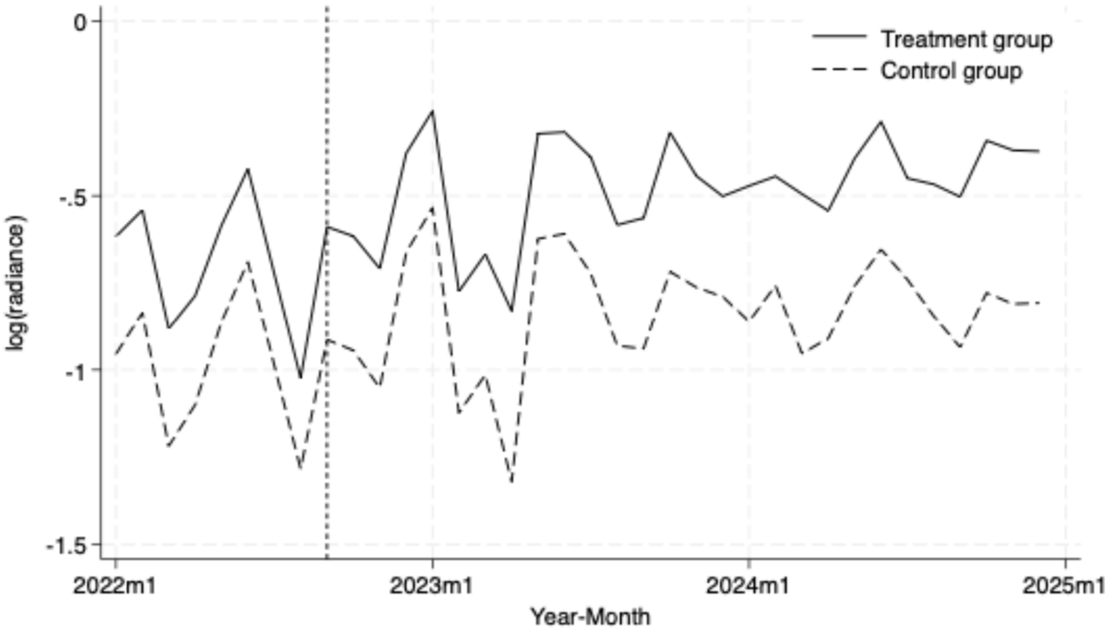


Figure A.2. log(*radiance*) trend comparison between the treatment and control groups



Appendix note 1. Anomaly in July 2022 data

An examination of the nighttime light data reveals an anomaly in July 2022, characterized by an unusually high frequency of zero or near-zero values. For example, among the 6696 observations across the full sample period, the 10 lowest values all come from July 2022. This anomaly stems from a sensor malfunction on the observation satellite during that month (Physical Oceanography Distributed Active Archive Center, 2022). For the North Korean data, we examined the number of cloud-free observations per region. In a typical July, each location would be observed 7–10 times; however, the number of observations in July 2022 was abnormally low. The average number of observations per pixel in July 2022 ranged from a minimum of 0 (i.e., no observations at all in certain areas) to a maximum of 1.9, with a nationwide average of only 0.93. In contrast, July 2023 (a normal reference point) had a minimum of 5.3, a maximum of 11.2, and a nationwide average of 8.33 observations. Therefore, the July 2022 data were deemed anomalous and thus excluded from the analysis. From August 2022 onward, we confirmed that the number of observations returned to normal levels. It is worth noting that when the July 2022 data were included in the estimation, the results of the DiD analysis remain qualitatively robust.

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Appendix note 2. Treatment regions in this study

KIET data's heavy manufacturing region (our baseline treatment group, 25 regions): Anju, Chollima, Chongjin, Dachon, Daean, Dokchon, Haeju, Hamhung, Hanggu, Hyesan, Huichon, Kaechon, Kaesong, Kanggye, Kangso, Kimchaek, Munchon, Onchon, Pyongyang, Pyongsong, Ryonggang, Sariwon, Sinuiju, Waudo, and Wonsan.

KIET data's manufacturing region (for robustness check, 25 regions): Anju, Chollima, Chongjin, Dachon, Daean, Haeju, Hamhung, Hanggu, Hoiryong, Hyesan, Kaechon, Kaesong, Kanggye, Kangso, Onchon, Pyongyang, Pyongsong, Rajin, Ryonggang, Sariwon, Sinuiju, Sonbong, Sunchon, Waudo, and Wonsan.

Park (2022) manufacturing regions (for robustness check, 23 regions): Anju, Chollima, Chongjin, Daean, Haeju, Hamhung, Hanggu, Hyesan, Kaepung, Kangso, Kanggye, Kimchaek, Kusong, Onchon, Pyongyang, Pyongsong, Rajin, Ryonggang, Sakju, Sinuiju, Sonbong, Waudo, and Wonsan.

Appendix note 3. Possible effects of the COVID-19 pandemic

Although the details remain unclear, North Korea have been affected by the spread of COVID-19, including the closure of its border with China in 2021. In May 2022, an outbreak caused by the Omicron variant was confirmed in Pyongyang. In response, a nationwide lockdown was implemented, with reports indicating a return to normal economic activity by August 2022. However, an examination of the nighttime light data for Pyongyang shows no significant fluctuations between April and June 2022. In this study, the potential impact of the lockdown on nighttime light data is addressed in two ways. First, monthly fixed effects are included in the analysis to control for any temporary reductions in light due to specific months. Second, the pre-trend analysis results show no evidence of movements that would bias the comparison between the treatment and control groups.