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# Efficacy of Economic Sanctions against North Korea: Evidence from Satellite Nighttime Lights

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## I. Introduction

The United Nations Security Council (UNSC hereafter) adopted eight resolutions during the period of study, from 2012 to 2019, in condemning threatening actions on the part of North Korea, such as conducting ballistic missiles and nuclear weapons tests.[1] For reference, Kim Jong Un, the current supreme leader of North Korea, took power in 2011. In this paper, I examine the efficacy of sanctions against North Korea using satellite nighttime lights data.

The political system of North Korea is defined as *suryong* dictatorship, in which the dictator (supreme leader or *suryong*) holds absolute power to dictate the country's resources, including its people. The theoretical definition of North Korea's political system is based on the selectorate theory of De Mesquita et al. (2005). In light of the selectorate theory, the North Korean regime successfully divides the country's residents into two segregated groups, the *selectorate* (elites) and the *non-selectorate*. The North Korean regime strictly restricts migration within the country, and takes special care of the capital city, Pyongyang. The regime selectively grants the right to reside in Pyongyang. Moreover, it is well known that the regime prioritizes Pyongyang citizens' welfare and allocates resources to them first and foremost.

Acemoglu et al. (2004) define *kleptocracy* as a political system where the state is controlled and run for the benefit of an individual, or a small group, who use their power to transfer a large fraction of society's resources to themselves. They suggest the *divide-and-rule strategy* as a method that kleptocratic rulers use to stay in power. The divide-and-rule strategy makes it difficult for residents to obtain enough social coordination for revolution against the kleptocratic ruler. On the basis of the evidence

[1] The UNSC Resolutions 2087 and 2094 in 2013; Resolutions 2270 and 2321 in 2016; Resolutions 2356, 2371, 2375, and 2397 in 2017.

and data, I define North Korea's *suryong* dictatorship as a kleptocracy. *Suryong* successfully established the despotic dynasty based on *juche* ideology, and divided the country's residents into two segregated groups, the selectorate and the non-selecotrate. *Suryong* allocates large enough fraction of the country's resources to the selectorate for supporting his political power. In the kleptocratic kingdom, *suryong* appears to successfully obstruct revolution against his political power for a long time. The theory expects that the ruler will transfer a greater fraction of the country's resources to the selectorate as sanctions intensify.

I empirically test the theoretical hypothesis using satellite nighttime lights data. The gross domestic product (GDP) of a country (or a region) is the standard measure of income level and living standard of the country (of the region). However, North Korea has not reported the country's statistics for decades. As a proxy for North Korea's regional economic activities, I use satellite nighttime lights data. Henderson et al. (2012) show that satellite nighttime lights data are a good proxy for GDP, and find that it is correlated with GDP with an elasticity of about 0.3. Given the finding of Henderson et al. (2012), satellite nighttime lights data are widely used as a proxy for local economic activity especially in poor countries in the economics literature (Donaldson and Storeygard 2016; Gibson et al. 2021).

The regression analysis tests the theoretical hypothesis — the ruler is expected to transfer a greater fraction of the country's resources to the selectorate as the sanctions tighten. I find that an additional sanction is associated with an increase in the difference in nighttime lights between the capital city, Pyongyang, and the rest of the country by about 0.4 percent. In translating the lights results to GDP, I use the elasticity estimate of 0.3 suggested by Henderson et al. (2012) for low and middle-income countries. A one percent increase in the nighttime lights translates to about a 0.3 percent increase in GDP. This implies that the GDP gap between Pyongyang and the rest of the country increases by about 0.12 percent with an additional sanctions event. Manufacturing cities, mining areas, the Chinese border region, and Sinuiju become relatively brighter with an additional sanctions event. The magnitude of the estimate is particularly strong for Sinuiju — nighttime lights in Sinuiju become relatively brighter by 3.3 percent. Another notable finding is the estimate on the interaction term with the nuclear development facilities areas, which suggests that the ruler diverts resources and electricity from nuclear development activities to other sectors when sanctions increase. In conclusion, the base regression results confirm the hypothesis — the ruler does transfer a greater fraction of the country's resources to regions where the selectorate are presumed to reside as sanctions intensify.

## II. Sanctions against North Korea

The UNSC adopted eight resolutions during the period examined in this study, condemning the threatening actions of North Korea

such as conducting ballistic missiles and nuclear weapons tests.[2] Prior to 2016, the UNSC sanctions on North Korea were mostly focused on targeted sanctions, such as imposing travel bans and freezing the assets of North Korean individuals and entities, and trade restrictions on weapons-related materials and items. From 2016, the UNSC tightened comprehensive sanctions, such as trade restrictions on coal and oil. Comprehensive sanctions aim to impose costs on the population as a whole, so that the sender country can destabilize the target country's regime by incentivizing revolution against the regime. Targeted sanctions aim to impose costs on only the political elite class of the target country, so that the sender country directly changes the regime's benefit-cost analysis (Baliga and Sjöström 2021).

I put the UNSC sanctions on North Korea into 10 categories: (1) general trade related sanctions (*tr*), which are further put into 5 subcategories: (2) luxury goods related sanctions (*lx*); (3) energy related sanctions (*en*); (4) ore related sanctions (*or*); (5) food related sanctions (*fd*); (6) textile and apparel related sanctions (*tx*); (7) finance related sanctions (*fn*); (8) travel related sanctions (*tv*); (9) logistics (transportation of materials and people) related sanctions; and (10) international cooperation related sanctions (*cp*). The main sanctions index is the cumulative sum of the number of sanction events in each of the ten categories of the UNSC sanctions in each year, with the base year in 2012 normalized to zero.[3] In sum, the main sanctions index is constructed as follows:

$$s_t = \sum_{n=2012}^{2019} s_n^{tr} + s_n^{tx} + s_n^{en} + s_n^{or} + s_n^{fd} + s_n^{tx} + s_n^{fn} + s_n^{tv} + s_n^{lg} + s_n^{cp},$$

where $s_n^{tr}$ is equal to +1 if there were any tightening of trade related sanctions by the UNSC (all other categories of sanction events are counted in the same way). If there were any releasing of trade related sanctions by the UNSC, $s_n^{tr}$ is equal to -1. However, the UNSC never released sanctions on North Korea in any categories of the sanction events in the period. Table 1 summarizes the main sanctions index.

The UNSC started tightening comprehensive sanctions on North Korea in 2016. The comprehensive sanctions include trade restrictions

[2] The UNSC Resolutions 2087, 2094 in 2013; Resolutions 2270, 2321 in 2016; Resolutions 2356, 2371, 2375, 2397 in 2017.

[3] Lee (2018) studies the period of 1992 to 2012, and constructs the sanctions index in the similar manner, but puts the sanction events into 4 categories. As I study the period in which the UNSC widely tightened sanctions on North Korea, I increase the number of categories of the sanction events when constructing the main sanctions index.

on coal[4] and oil[5]. Given that mineral fuels (including but not limited to coal) account for the largest share of exports of North Korea (57.4% in 2012), and that mineral fuels (including but not limited to oil) also account for the largest share of imports of North Korea (21.2% in 2012),[6] the trade restrictions on coal and oil by the UNSC are expected to have a significant effect on the North Korean economy and the regime. Figure 1 illustrates the main sanctions index and the mineral fuels (HS code 27) exports and imports (in 1 million US dollars) of North Korea for the period of 2012-2020, which show a sharp decrease in the mineral fuels exports and imports from 2016.

China accounts for most of the trade volume of North Korea. North Korea's trade with China took up 88.3% in 2012, and it slightly increased to 95.36% in 2019. However, the absolute quantity of North Korean trade with China drastically decreased during the period of 2012-2019, as Figure 2 illustrates.[7]

**Table 1. Sanctions Index**

| Year | Trade | Luxury | Energy | Ore | Food | Textile | Finance | Travel | Logistics | Cooperation | Sanctions index |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2012 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| 2013 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 1 | **8** |
| 2014 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 1 | **8** |
| 2015 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 1 | **8** |
| 2016 | 3 | 3 | 2 | 2 | 0 | 0 | 4 | 4 | 3 | 3 | **24** |
| 2017 | 6 | 3 | 5 | 3 | 2 | 1 | 8 | 8 | 6 | 3 | **45** |
| 2018 | 6 | 3 | 5 | 3 | 2 | 1 | 8 | 8 | 6 | 3 | **45** |
| 2019 | 6 | 3 | 5 | 3 | 2 | 1 | 8 | 8 | 6 | 3 | **45** |

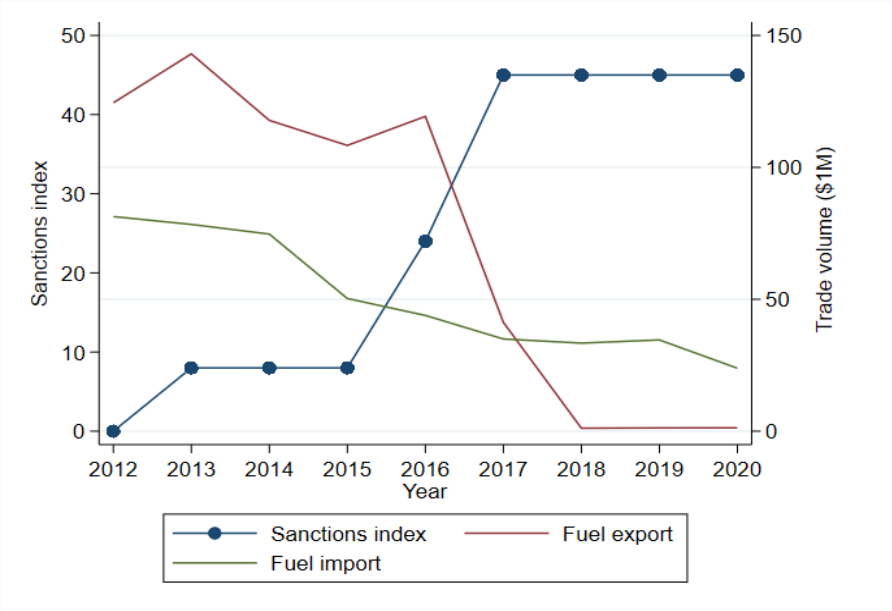
[4] For example, see Paragraph 26 in the UNSC Resolution 2321 adopted in 2016: "total exports to all Member States of coal originating in the DPRK that in the aggregate do not exceed 400,870,018 US dollars or 7,500,000 metric tons per year.".

[5] For example, see Paragraph 14 in the UNSC Resolutions 2375 adopted in 2017: "Decides that all Member States shall prohibit the direct of indirect supply, sale, or transfer to the DPRK ... of all refined petroleum products, decides that the DPRK shall not procure such products, decides that this provision shall not apply with ... 2,000,000 barrels per year."

[6] Data source: Korea Trade-Investment Promotion Agency (KOTRA).

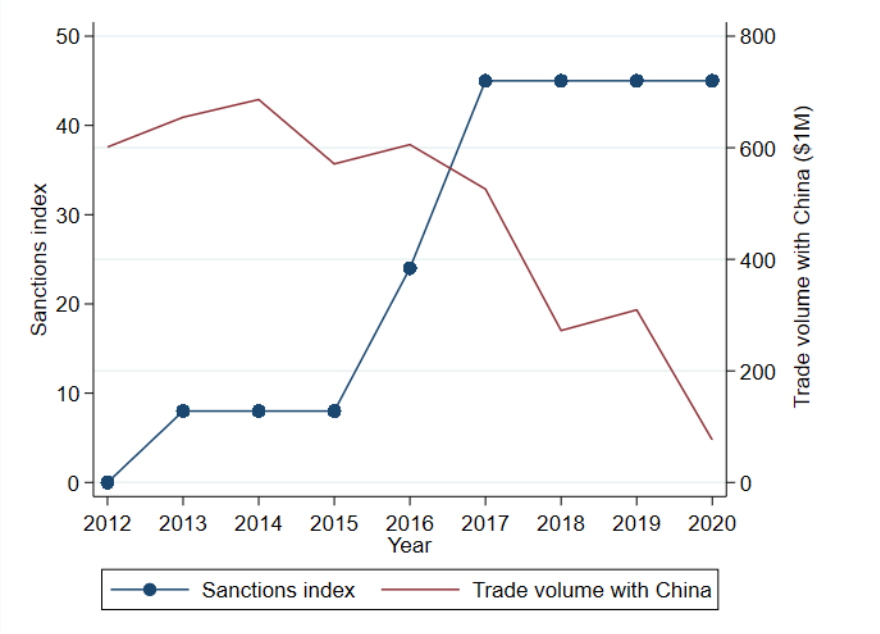
[7] Data source: KOTRA.

**Figure 1. The Main Sanctions Index and Trade Volumes of Mineral Fuels**




Source: Korea Trade-Investment Promotion Agency (KOTRA)

**Figure 2. The Main Sanctions Index and North Korea's Trade with China**




Source: Korea Trade-Investment Promotion Agency (KOTRA)

## III. Empirical Analysis

In this section, I empirically examine the efficacy of the economic sanctions on North Korea using satellite nighttime lights data. The gross domestic product (GDP) of a country (or a region) is the standard measure of income level and living standard of the country (of the region). However, North Korea has failed to report the country's statistics for decades. As a proxy for North Korea's regional economic activities, I use satellite nighttime lights data. Henderson et al. (2012) show that satellite nighttime lights data are a good proxy for GDP, and find that it is correlated with GDP with an elasticity of about 0.3. Given Henderson et al. (2012)'s finding, satellite nighttime lights data are widely used as a proxy for local economic activity especially in poor countries in the economics literature (Donaldson and Storeygard 2016; Gibson et al. 2021).

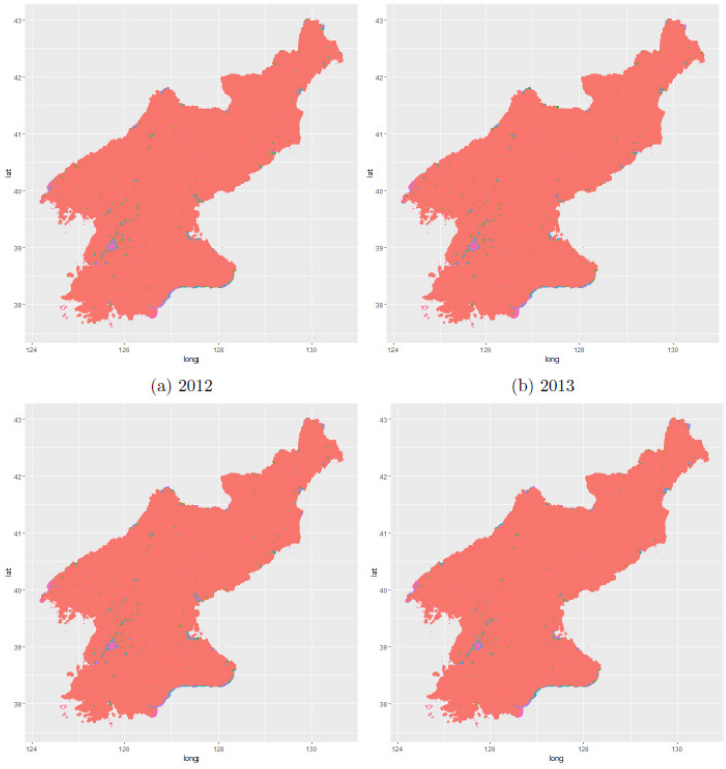
The National Oceanic and Atmospheric Administration (NOAA) provides two sets of nighttime lights data. The first set of data, which is available for the period of 1992-2013, is collected under the Defence Meteorological Satellite Program (DMSP). The second set of data, which is available for the period of 2012-present, is collected by the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument which is aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites. In this current study, I use the VIIRS satellite nighttime lights data to proxy for local economic activity in North Korea.

The spatial resolution of VIIRS data is 375 m, thus the size of each grid cell is approximately 0.14 $km^2$.[8] The number of grid cells within North Korea is 746,311. The pixel values of VIIRS data are absolute radiation values. Figures 3 and 4 graphically illustrate VIIRS data in the map of North Korea for the period of 2012-2019. In Figures 3 and 4, grid cells that read zero values are red-colored — most of the regions in North Korea have zero nighttime lights values. The largest purple-colored area near latitude 39 longitude 126 is Pyongyang, the capital city.

Figures 5 and 6 illustrate locations of major cities (Figure 5-(a)), province capital cities (Figure 5-(b)), port cities (Figure 5-(c)), manufacturing cities (Figure 6-(a)), mining areas (Figure 6-(b)), uranium mining areas (Figure 6-(c)), and nuclear facility areas (Figure 6-(d)).

[8] The VIIRS instruments acquire data in two native spatial resolutions, 375 m (bands I1-5) and 750 m (bands M1-16). See https://lpdaac.usgs.gov/data/get-started-data/collection-overview/missions/s-npp-nasa-viirs-overview/#viirs-spectral-bands for details. In this paper, I use the data acquired in bands I1-5 (375 m).

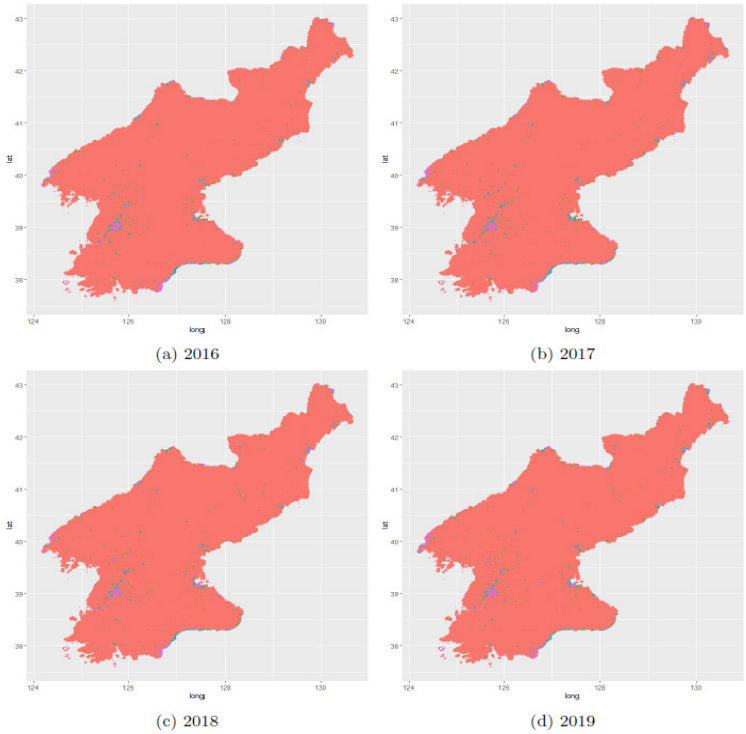
Figure 3. Lights in North Korea by Year from 2012 to 2015




(a) 2012 (b) 2013

(c) 2014 (d) 2015

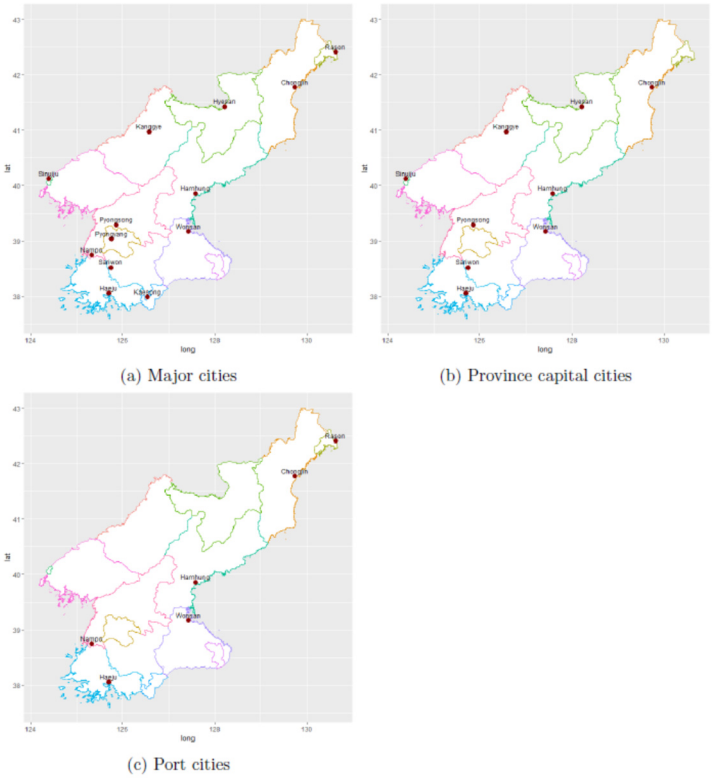
Figure 4. Lights in North Korea by Year from 2016 to 2019




(a) 2016 (b) 2017

(c) 2018 (d) 2019

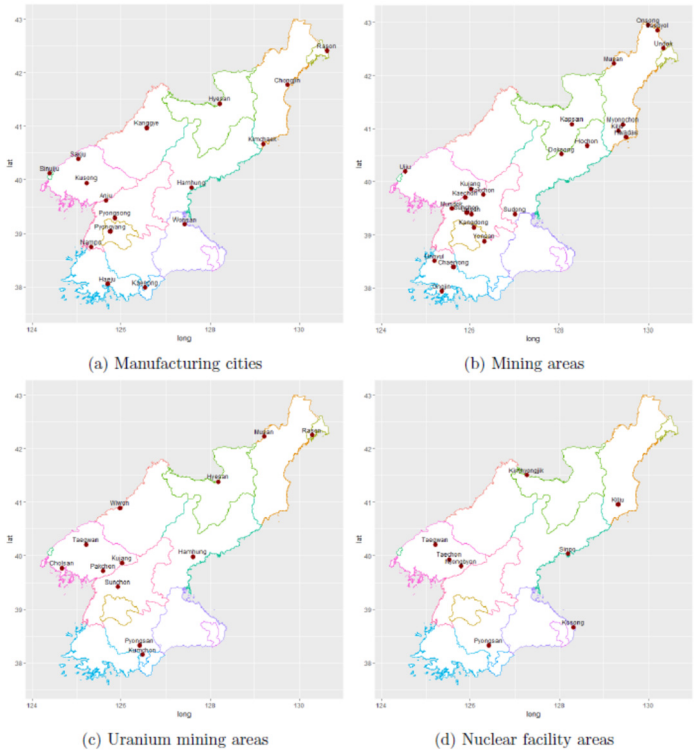
Figure 5. Locations of Major Cities, Province Capital Cities, and Port Cities



(a) Major cities (b) Province capital cities

(c) Port cities

Figure 6. Locations of Manufacturing, Mining, and Nuclear Weapons Development Areas



(a) Manufacturing cities (b) Mining areas

(c) Uranium mining areas (d) Nuclear facility areas

The base regression that tests the hypothesis — i.e., that the ruler is expected to transfer a greater fraction of the country's resources to the selectorate as the sanctions intensifies — is

$$\ln(lights_{ijt}) = \alpha + \beta D_i s_t + \mu_i + \delta_t + \varphi_{jt} + \epsilon_{ijt}$$

where $lights_{ijt}$ is the nighttime light value of each grid cell $i$ in region $j$ in year $t$ plus a small constant 0.01.[9] $D_i$ is the set of dummy variables that identify grid cell characteristics, including dummy variables that equal 1 if the grid cell is in a major city, Pyongyang, a province capital, a manufacturing city, Kaesong, a mining area, within 10 km of the Chinese border, Sinuiju, a port city, a uranium mining area, or a nuclear facility area. The grid cell fixed effects $\mu_i$ control for unobserved and time invariant grid cell characteristics, and the year fixed effects $\delta_t$ control for unobserved annual patterns in the data. $\varphi_{jt}$ is the region-year fixed effects which control for unobserved region-specific annual characteristics. $s_t$ is the sanction index. The coefficient of interest is $\beta$, which is expected to be positive if the difference in nighttime light values between a specified region and the rest of the country increases as sanctions increase. In other words, if the ruler transfers a greater fraction of the country's resources to the selectorate as sanctions intensify, $\beta$ would be positive. Standard errors are clustered by grid cells to account for between grid cells and across time.

Table 2 presents the main regression results. Column (1) first examines the bivariate relation between the main sanctions index and nighttime light values, controlling for grid cell fixed effects and region-year fixed effects. The estimate is negative but statistically insignificant. Column (2) compares the differential impact of sanctions on urban areas (major cities) relative to non-urban areas. The coefficient estimate on the major cities dummy interacted with the main sanctions index is positive and statistically significant — the difference in nighttime light values between urban areas and non-urban areas increases by about 1.2 percent with an additional sanctions event. In column (3), I include the interaction term for the capital city, Pyongyang, and the province capitals. If the ruler (regime) allocates a greater fraction of resources to the capital cities as sanctions tightened, the estimates of these terms would be positive. The estimate on the major cities interaction term is statistically insignificant, but the estimates on the other two interaction terms are positive and statistically significant. The difference in nighttime light values between Pyongyang and the rest of the country increases by approximately 0.7 percent with an additional sanctions event. The estimate on the province capitals interaction term is slightly higher than the one on the Pyongyang interaction term — the difference in nighttime light values between the province capitals and the rest of the country increases by 1.3 percent

[9] I follow the literature by adding 0.01 to each grid cell's light value before taking natural logarithms (Hodler and Raschky 2014; Michalopoulos and Papaioannou 2013, 2014; Lee 2018).

with an additional sanctions event.

### Table 2. Main Regression Results

| Dependent | ln(lights) (1) | ln(lights) (2) | ln(lights) (3) | ln(lights) (4) |
|---|---|---|---|---|
| Sanctions | -0.0000375 (0.0000673) | | | |
| Major*Sanctions | | 0.0126549*** (0.0010423) | -0.0007415 (0.0007467) | |
| Pyongyang*Sanctions | | | 0.0067692*** (0.0009378) | |
| Province capital*Sanctions | | | 0.0133964*** (0.0012749) | |
| Manufacturing*Sanctions | | | | 0.0126549*** (0.0010423) |
| Kaesong*Sanctions | | | | 0.0006929 (0.0006601) |
| Mining*Sanctions | | | | 0.0019843*** (0.0005016) |
| Chinese border*Sanctions | | | | |
| Sinuiju*Sanctions | | | | |
| Port*Sanctions | | | | |
| Uranium mine*Sanctions | | | | |
| Nuclear*Sanctions | | | | |
| R-squared | 0.0169 | 0.0169 | 0.0169 | 0.0169 |
| Observations | 5,926,224 | 5,926,224 | 5,926,224 | 5,926,224 |

Notes: All columns include grid cell fixed effects and region-year fixed effects. Columns (2)-(4) also include year fixed effects. Standard errors are clustered at the grid cell level. *, **, *** indicate statistical significance level at the 10%, 5%, 1% level, respectively.

### Table 3. Main Regression Results (continued)

| Dependent | ln(lights) (5) | ln(lights) (6) | ln(lights) (7) |
|---|---|---|---|
| Sanctions | | | |
| Major*Sanctions | | | |
| Pyongyang*Sanctions | | | 0.0039901*** (0.0006808) |
| Province capital*Sanctions | | | 0.0043891*** (0.0009038) |
| Manufacturing*Sanctions | | | 0.0020375*** (0.0003763) |
| Kaesong*Sanctions | | | 0.0006929 (0.0006601) |
| Mining*Sanctions | | | 0.0019843*** (0.0005016) |
| Chinese border*Sanctions | 0.0004553*** (0.0000527) | | 0.0004553*** (0.0000527) |
| Sinuiju*Sanctions | 0.0390021*** (0.002745) | | 0.0325754*** (0.0029111) |
| Port*Sanctions | 0.0126549*** (0.0010423) | | 0.0062282*** (0.0014235) |
| Uranium mine*Sanctions | | -0.0000672 (0.0001027) | -0.000155 (0.000103) |
| Nuclear*Sanctions | | -0.0009685*** (0.0003112) | -0.0009685*** (0.0003112) |
| R-squared | 0.0169 | 0.0169 | 0.0169 |
| Observations | 5,926,224 | 5,926,224 | 5,926,224 |

Notes: All columns include grid cell fixed effects, region-year fixed effects, and year fixed effects. Standard errors are clustered at the grid cell level. *, **, *** indicate statistical significance level at the 10%, 5%, 1% level, respectively.

In column (4), I include interaction terms that represent manufacturing, mining, and inter-Koreas industrial cooperation (Kaesong). Manufacturing cities and mining areas ought to be preferential, not only because of import substitution and industrial development due to the sanctions, but because the ruler would allocate more resources to the selectorate (who are granted access to manufacturing production technology and relevant business) as the sanctions intensify. The gap in lights between the manufacturing cities and the rest of the country increases by approximately 1.3 percent as the sanctions tightened; and the gap between the mining areas and the rest of the country increases by about 0.2 percent as the sanctions tightened. However, the estimate on the Kaesong interaction term is statistically insignificant. Kaesong industrial park experienced several short-term shutdowns and reopening due to military or diplomatic tension between the two Koreas, and was shutdown permanently in 2016. The statistically insignificant estimate on the Kaesong interaction term seems to suggest that Kaesong remains dubious to the ruler (regime).

In column (5), I examine how nighttime light values in areas within 10 km of the Chinese border, Sinuiju (the trade hub with China), and port cities. The estimates on the three interaction terms are all statistically significant and positive. Moreover, the estimate on the Sinuiju interaction term is stronger than the coefficients on the other interaction terms — the difference in nighttime lights between Sinuiju and the rest of the country increases by approximately 3.9 percent with an additional sanctions event.

I next examine whether the sanctions influence the ruler's allocation decision on nuclear weapons development activities. In column (6), I include interaction terms that identify uranium mining areas and nuclear development facilities. The estimate on the Uranium mining areas is negative but statistically insignificant. I find that the difference in nighttime light values between the nuclear development facilities areas and the rest of the country decreases by about 0.1 percent with an additional sanctions event. This result implies that the ruler (regime) redirects resources from nuclear development activities to other sectors (or regions) as sanctions tightened.

All interaction terms (except the major cities) are pooled together in column (7). The estimates are generally similar to the previous columns. Overall, the results imply that an additional sanction is associated with an increase in the difference in nighttime lights between the capital city, Pyongyang, and the rest of the country by about 0.4 percent. In translating the lights results to GDP, I use the elasticity estimate of 0.3 suggested by Henderson et al. (2012) for low and middle-income countries. A one percent increase in the nighttime lights translates to about a 0.3 percent increase in GDP. This implies that the GDP gap between Pyongyang and the rest of the country increases by about 0.12 percent with an additional sanctions event. Manufacturing cities,

mining areas, the Chinese border region, and Sinuiju become relatively brighter with an additional sanctions event. The magnitude of the estimate is particularly strong for Sinuiju — nighttime lights in Sinuiju become relatively brighter by 3.3 percent. Another notable finding is the estimate on the interaction term with the nuclear development facilities areas, which suggests that the ruler diverts resources and electricity from nuclear development activities to other sectors when sanctions increase. In conclusion, the base regression results confirm the hypothesis — the ruler does transfer a greater fraction of the country's resources to regions where the selectorate are presumed to reside as sanctions intensify.

## IV. Concluding Remarks

In this paper, I defined the political system of North Korea as *suryong* dictatorship, which is considered a kleptocracy. On the basis of the definition of North Korea's political system, *suryong* successfully established the despotic dynasty based on *juche* ideology, and divided the country's residents into two segregated groups, the selectorate and the non-selecotrate. *Suryong* allocates a large enough fraction of the country's resources to the selectorate to support his political power. The resources of the country under *suryong*'s allocation decision may include not only goods, materials, and cash, but also the opportunity of education and access to production technology and trade. In the kleptocratcy kingdom, *suryong* appears to successfully obstruct revolution against his political power for a long time. The theory predicts that the ruler (kleptocrat) transfers a greater fraction of the country's resources to the selectorate as sanctions intensify.

The regression results confirmed the theoretical hypothesis — the ruler does transfer a greater fraction of the country's resources to the selectorate as sanctions tighten. I found that an additional sanction is associated with an increase in the difference in nighttime lights between the capital city, Pyongyang, and the rest of the country by about 0.4 percent. As a one percent increase in the nighttime lights translates to about a 0.3 percent increase in GDP, this result implies that the GDP gap between Pyongyang and the rest of the country increases by about 0.12 percent with an additional sanctions event. Manufacturing cities, mining areas, the Chinese border region, and Sinuiju become relatively brighter with an additional sanctions event. The magnitude of the estimate is particularly strong for Sinuiju — nighttime lights in Sinuiju become relatively brighter by 3.3 percent. Another notable finding is the estimate on the interaction term with the nuclear development facilities areas, which suggests that the ruler diverts resources and electricity from nuclear development activities to other sectors when sanctions increase. KIEP