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Countering Sanctions: The Unequal Geographic Impact of Economic Sanctions in North Korea.

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Abstract

This paper examines how an autocratic regime domestically counters the impact of economic sanctions. A stylized model predicts that, as long as non-compliance is not too costly, the autocrat redistributes resources to the more valuable urban area when sanctions increase. Empirically, I examine the case of North Korea. I use the satellite night lights data to create average luminosity for each one minute by one minute cell between 1992 and 2010. I construct a sanctions index that varies based on the international response to North Korea's nuclear pursuit. I find that sanctions increase the urban-rural luminosity gap by 1.07%. Consistent with urban elite capture, Pyongyang, the center of power is best shielded from sanctions followed by province capitals. The hinterlands respond: luminosity near the Chinese border increases with sanctions. Sanctions that fail to change the leader's behavior increase inequality at a cost to the already marginalized hinterlands.

Keywords: Economic sanctions, Urban capture, Regional inequality, Satellite lights data
JEL codes: F51, O18, R13, P20

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"A nation that is boycotted is a nation that is in sight of surrender. Apply this economic, peaceful, silent, deadly remedy and there will be no need for force. It is a terrible remedy. It does not cost a life outside the nation boycotted but it brings a pressure upon the nation which, in my judgment, no modern nation could resist" (Woodrow Wilson, Address in 1919)

"It is hard to bully a bully with economic measures" (Hufbauer et al., 2009)

1. Introduction

Countries impose economic sanctions to punish and hopefully change the behavior of the target country. The international community sanctioned South Africa during its apartheid regime. In recent years, North Korea and Iran have been sanctioned for their nuclear pursuit, Syria for mass civilian killings, and Russia for annexing Crimea. Sanctions have become a more frequent foreign policy tool and whether sanctions effectively achieve their intended goals is of interest to academics, policy makers, and the general public. Hufbauer et al. (2009) document that between 1915 and 2000 there were 174 sanction cases, of which only 34 percent were at least partially successful, and that most of the successes happened before the 1970s. In recent decades, sanctions have been mostly ineffective. This paper examines one potential explanation: how the sanctioned regime domestically counters the impact of economic sanctions.

Sanctions are imposed to sway the target country's decision makers, often autocrats. But, how would the target country's elites respond to sanctions and impact the domestic population? A stylized model predicts that, as long as non-compliance is not too costly, autocrats would respond to economic sanctions by redistributing resources to the economy's more valuable urban sector. However, unequal resource distribution could promote revolts and threaten the stability of the regime. The military deters revolts and autocrats with a stronger military hold would be able to suppress potential revolts better. I empirically study the case of North Korea, an oppressive dictatorship where sanctions have had no impact on changing the regime's pursuit for nuclear weapons. North Korea is one of many autocratic regimes that refuse to yield to sanctions, but its isolation and hereditary dictatorship render it a particularly good example to study the impact of economic sanctions in autocratic regimes. Furthermore, North Korea's rigid society enables one to study urban elite capture while controlling for domestic migration, which often confounds identification in empirical studies. However, data on North Korea is almost non-existent and what is available is often unreliable.[1]

To empirically examine the impact of sanctions within North Korea, I use the Defense Meteorological Satellite Program's lights data. The satellite night lights data have been used in the literature to proxy for economic activity in countries where economic data are sparse, particularly at sub-national levels (Chen et al. 2011, Henderson et al. 2012, Michalopolous et al. 2014). I create an average luminosity measure for each one arc minute by one arc minute grid, which translates to approximately a one mile by one mile grid, between 1992 and 2000. I document North Korea's nuclear provocations and agreements that led countries and the UN to tighten or relax sanctions on North Korea. These events were triggered by North Korea's nuclear ambitions, military first policy, and Juche ideology, an ideology that strives for international independence. I aggregate the events by year and type, i.e., trade, finance, aid or remittance, and travel sanctions, to create a sanctions index. I find that an additional sanction increases the urban-rural luminosity gap by 1.07% or the urban-rural GDP difference by 0.21%, where luminosity increases by 0.57% or GDP by 0.11% in the cities and luminosity decreases by 0.5% or GDP by 0.1% in the hinterlands. I create rings around the city center and find that most of the differential impact of sanctions on luminosity occurs within the urban core, the area within10km of the city center. The impact of sanctions on the urban-rural luminosity gap is robust to whether I use subsamples that cover different years, different latitudes, exclude borders, exclude unlit cells, include regional time trends, or use different sanctions indexes. Furthermore, the results are not driven by a general pattern of urbanization and economic growth nor reverse causality. There is a tiered response among administrative cities that is consistent with urban elite capture: luminosity increases more in the center of power, Pyongyang, relative to province capitals, when sanctions increase. I map North Korea's army corps and the main air force and navy bases but find no differential sanctions impact on the military base areas relative to the hinterlands. Lastly, the hinterlands also respond to sanctions as urban-rural inequality increases. I examine the fringe areas near the borders and the neighboring countries. The border with South Korea is heavily militarized and the sanctions have no impact on South Korea. However, sanctions increase luminosity along the relatively porous Chinese border, both on the North Korean and Chinese

[1] Two censuses have been conducted by North Korea under the supervision of the UN. However, the demography literature has found evidence that the North Korean census may have been manipulated to conceal the extent of its military population, refugee camps, and death during the famine.

side. As sanctions increase the hinterland population becomes economically deprived, and more may be prompted to engage in underground market activities along the border or migrate to China. Overall, the empirical results indicate that when external sanctions generate hardships in the domestic economy, the urban elites, whether by disproportionately promoting economic activity or diverting electricity, shields from the negative impact at a cost to the hinterland population. In short, sanctions that fail to change the behavior of leaders increase regional inequality and impose a higher cost on the more marginalized hinterlands.[2]

The literature has examined why sanctions might be ineffective but have mainly focused on cross-country comparisons and international responses. Davis and Engerman (2003) find that globalization and the interdependency among countries in the latter half of the 20th century have made trade sanctions less effective. Eaton and Engers (1999) point out that studying the actual implementation of sanctions provides only a narrow understanding of the impact of sanctions because sanctions arise through a strategic process between the sanctioning and sanctioned. Accordingly, Whang et al (2013) analyze the threat stages of sanctions in addition to the actual imposition of sanctions. The type of governments also matters. Sanctions are more successful when imposed on democratic regimes relative to autocratic regimes (Huffbauer et al. 2009). But most sanctioned countries are not democracies. I contribute to this literature by focusing on the impact of sanctions on the domestic population. Levy's (1999) analysis of South Africa is similar in spirit. He discusses how sanctions actually caused the Nationalist Party to increase its oppression on the blacks. I believe my paper further contributes to the literature by empirically illustrating how autocrats domestically counter economic sanctions and the distributional consequences.

The paper proceeds as follows. Section 2 presents a stylized model of how an autocracy allocates resources between the city and the hinterland under economic sanctions. Section 3 provides background on the economic sanctions imposed on North Korea and how the sanction index is constructed. Section 4 introduces the data and Section 5 develops the empirical strategy. Section 6 discusses the empirical results and Section 7 potential channels. Lastly, Section 8 concludes.

[2] The findings also relate to the urban primacy and urbanization literature. Ades and Glaeser (1995) show that political factors increase urban concentration and that dictatorships extract resources from hinterlands to the capital, causing higher urban concentration. The diversion of resources from the hinterlands to the urban areas in response to economic sanctions may be one potential source of urbanization.

2. A Simple Model of Economic Sanctions in an Autocracy

Consider an autocracy that is divided into two regions: the city and the hinterland. The autocrat allocates resources, including capital and labor, to each region. Note that this assumption implies no migration. Population and industry are distributed across regions according to a central plan, a feature of planned economies like North Korea and the early days of communist China and Soviet Union. Total resource in the country is normalized to one. The autocracy faces economic sanctions imposed by the external world.

Each location generates an economic value. Let $V^c(r_c, s)$ indicate the value generated in the city using resource r_c when the external sanction level is s. $V^h(r_h, s)$ is the value generated in the hinterland using r_h. The total economic value generated is $V^c(r_c, s) + V^h(r_h, s)$ and the autocrat decides how to allocate resources between the city and the hinterland while satisfying the resource constraint $r_c + r_h = 1$. The location specific value function $V^i(.)$ for $i=c$ and h, is continuous and twice differentiable with $\partial V^i(.)/\partial\,(r_i) > 0$, $\partial^2 V^i(.)/\partial(r_i)^2 < 0$, $\partial V^i(.)/\partial\,(s) < 0$, and $\partial^2 V^i(.)/\partial(s)^2 > 0$. Economic value increases with resources but at a diminishing rate and decreases with sanctions at an increasing rate. Economic value generated in the city is always greater than that in the hinterland at any given level of resource and sanction, i.e. $V^c(r, s) > V^h(r, s)$. This implies that the autocrat allocates more resources to the city. I further assume $\partial^2 V^i(.)/\partial\,(s)\partial(r_i) < 0$. For any given location, when more resource is being employed the negative impact of sanctions becomes larger in magnitude.

In addition to the economic value generated in the economy, the autocracy values stability of the regime. There is always the probability of a revolt that can overturn the regime, and the autocrat wishes to minimize such probability. Inequality, i.e., the resource gap between the city and hinterland, increases the probability of a revolt. Since the hinterland receives lower amounts of resources in the model, one can think of the workers or the managers in charge of production in the hinterland as the proponents of a potential revolt. I denote the probability of a revolt as $\pi(\Delta r)$, where $\Delta r = r_c - r_h$, the urban rural resource gap. The probability of a revolt increases with the resource gap at an increasing rate, i.e., $\partial\pi(.)/\partial\,(\Delta r) > 0$ and $\partial^2\pi(.)/\partial(\Delta r)^2 > 0$. Ultimately, the autocracy chooses r_c and r_h to maximize the sum of the economic values produced in the two regions and the political value of regime survival

$$U = V^c(r_c, s) + V^h(r_h, s) + V(1 - m^{-1}\pi(\Delta r)) \quad (1)$$

under the constraint $r_c + r_h = 1$. V denotes the autocrat's valuation of regime continuity. m measures the autocrat's power to oppress any uprisings. A stronger control of the military m reduces the probability of a successful revolt.

Now consider the autocracy's decision of whether or not to concede to sanctions. Denote the autocracy's optimal value U given sanction s as $U^*(s)$ and the autocracy's minimum value for non-compliance as $\underline{U}$. The autocracy will not concede to sanctions as long as $U^*(s) \geq \underline{U}$. The envelope theorem implies that $\partial U^*(.)/\partial\,(s) < 0$. Hence, once sanctions reach a certain threshold $\underline{s}$ the autocrat will concede, at which point s=0 and $U^* = \underline{U}$.

The first-order condition of equation (1) is

$$V_1^c(r_c, s) - V_1^h(1 - r_c, s) - 2Vm^{-1}\pi_1(2r_c - 1) = 0$$

where the subscript 1 indicates the partial derivative relative to r_c. I am interested in how the urban resource share responds to economic sanctions s and to the autocrat's oppressive power m. One can find using the implicit function theorem that $\partial r_c/\partial\, m > 0$: the dictatorship allocates more resources to the city when it has greater oppressive power. Similarly, one can find that if $\partial^2 V^c(.)/\partial(r_c)\partial\,(s) > \partial^2 V^h(.)/\partial(r_h)\partial\,(s)$, then the dictatorship allocates more resources to the city as sanctions increase. This condition implies that if the drop in marginal value due to sanctions in the city is smaller than that in the hinterlands, then the autocrat will allocate more resources to the city.

In order to graphically illustrate the implications of the model I parameterize equation (1) as follows.

$$V^c(r, s) = Ae^{-\kappa s} r^{\alpha},$$

$$V^h(r, s) = e^{-\gamma s} r^{\beta},$$

and

$$\pi(\Delta r) = \Delta r^{\delta},$$

where $A > 1, 0 < \beta < \alpha < 1, 0 < \kappa < \gamma < 1,$ and $\delta > 1$. Figure 1 presents the equilibrium outcomes of the urban resource share $r_c(s)$ and the optimal value $U^*(s)$ as sanctions increase. I fix A =1.2, $\alpha = 0.5$, $\beta = 0.4$, $V = 1$ and $\underline{U} = 1.5$, and present different variations depending on the values of κ, γ, and m. Panel A assumes $\kappa = 0.1, \gamma = 0.2$, and $m = 10$. When sanctions equal zero the optimal urban resource share is 0.64 and the optimal value is 2.62. As sanctions increase the urban resource share (solid line) increases and the optimal value (dashed line) decreases. For any sanction level that results in an optimal value less than $\underline{U}$, the autocrat concedes and the urban resource share re-optimizes to the case of $s = 0$. Panel B increases the autocrat's oppressive power m to 50. The urban resource share increases at all levels of s and the cutoff sanction level $\underline{s}$ increases slightly from 9.3 to 9.45. Autocracies with a stronger military hold will be able to better oppress potential uprisings and also withstand higher levels of sanctions. Lastly in Panel C, I present the case where κ to 0.05 so that the impact of sanctions on the city is reduced, or put differently the autocracy can better shield the city's economic activity from sanctions. In this case the optimal value does not reach its minimum concession point $\underline{U}$ even at high levels of sanctions and urban rural inequality continues to increase. This simple model explains several patterns consistent with North Korea. North Korea has not conceded and continues to find ways to better shield itself from increasing economics sanctions. There has been no successful revolt over its history, and one is unlikely as long as the autocrat maintains a strong and oppressive regime. In these circumstances, North Korea would minimize the impact of sanctions by reallocating resources to the urban sector, and ultimately increase urban-rural inequality. The resource allocation prediction that arises from this simple model could imply either an increase or a relatively smaller decrease in economic value in the city when sanctions increase. This depends on how responsive the function $V^i(.)$ is to economic sanctions s, that is the magnitude of $\partial V^i(.)/\partial\,(s)$. If $\partial V^i(.)/\partial\,(s)$ is large in magnitude then sanctions will reduce the optimal value produced in both the city and hinterland. However, if $\partial V^i(.)/\partial\,(s)$ is relatively small in magnitude, then the optimal value produced in the city could actually increase when more resources become allocated to the city. To empirically test the implications of the model, I later use the satellite lights data to examine how luminosity changes across different geographies in response to sanctions.

3. Economic Sanctions against North Korea

Economic sanctions against North Korea have been an ongoing process since the Korean War broke out in 1950. The US Department of Treasury then issued the Foreign Assets Control Regulations, which restricted financial transactions related to North Korea and froze North Korean assets under US jurisdiction. North Korea has maintained normal relations with the then communist countries, but has consistently been shut out from the more prosperous western world. Several notorious international bombings against South Korea by North Koreans during the

1980s (Rangoon bombing, KAL flight 858 bombing) further tightened sanctions against North Korea, and in 1988 the US added North Korea to the Department of State's list of state sponsors of international terrorism. Animosity between North Korea and South Korea did not dissipate and there were minimal economic interaction between the Koreas during most of the 20th century.

The sanctions against North Korea started to ease during the 1990s with South Korea's engagement policy with the North under Kim Dae Jung, and the Clinton administration's signing of the Agreed Framework with North Korea in 1994. Under the framework North Korea agreed to replace its nuclear reactors, which could easily produce weapon grade plutonium, to light water reactors, which could not. In return, several countries would fund the development of the light water reactor with funding primarily coming from South Korea, and then Japan and the US. This naturally led to the ease of trade, finance, and travel sanctions. Furthermore, North Korea was hit by a deadly famine the same year and the international community increased humanitarian aid. However, the relaxing of economic sanctions was short lived as North Korea admitted to having a uranium enrichment program and reactivated its nuclear reactor in 2002. North Korea officially withdrew from the Nuclear Non-Proliferation Treaty in 2005 and countries started to reinstate various sanctions. North Korea performed two nuclear tests in 2006 and 2009, which were each followed by a unanimous UN Security Council Resolution that restricted North Korean activities in all dimensions.

The main sanctions index used in the analysis is the cumulative sum of the number of sanction events each year, with the base year in 1992 normalized to zero. An event related to the easing of any of the four types (trade, finance, aid or remittance, and travel) of sanctions is coded as -1 and a tightening of sanctions is coded as +1. Summing across the event types, the index declines to -10 in 2003 and then increases to 4 by 2010. I also try two other measures, one more aggregated and the other less aggregated. The more aggregated index does not separate the type of sanctions and increases by one if any sanction type was imposed. This index ranges from -5 to 1. The less aggregated index separates out import versus export sanctions, financial regulation versus asset freezes, and aid sanctions versus remittance sanctions. This index ranges from -14 to 9. Table 1 summarizes the events that constitute the sanctions index.

4. The Data

4.1 The night lights data

The National Oceanic and Atmospheric Administration provides the satellite night lights data collected under the Defense Meteorological Satellite Program (DMSP). The DMSP satellites collect images around the globe twice per day, which are then archived and processed by the National Geophysical Data Center. Data processing involves extensive tasks that include adjustment for cloud covers, glares, and fires. The final data product is gridded in 30 arc-second resolutions that spans -180 to 180 degree longitude and -65 to 75 degree latitude and is available for the years 1992 through 2010. Six different satellites have collected the night time lights data, with some overlap across years. Each composite data set is named with the satellite and the year.[3] For the purpose of this paper, I extract data that cover 123 to 131 degree longitude and 32 to 44 degree latitude, which includes the Korean peninsula, parts of China, islands, and the surrounding seas. Figure 1 presents the extracted areas from 2010.

The annual lights data are reported in digital numbers that range from 0 to 63. In order to aggregate the lights data across different geographic units, the digital numbers need to be converted into radiance using the formula Radiance = $(\text{Digital Number})^{3/2}$ where the unit is 10^{-10} watts/cm^2/ sr/um (Elvidge et al. 1999, Chen et al. 2011). After converting the digital numbers into radiance for each pixel, I take the arithmetic mean of each 2 pixel by 2 pixel grid. Each resulting grid cell represents a 1 arc minute by 1 arc minute grid in latitude and longitude which converts to approximately a 1 mile by 1 mile grid. I refer to this averaged radiance value as luminosity throughout the paper. This procedure generates 46,704 grid cells within North Korea. Top-coding of the lights data due to over-saturation of the satellite light censors is a concern for researchers using the night lights data (Henderson et al. 2012, Kulkarni et al. 2010). Fortunately, this is not a concern for North Korea. During the nineteen years period I examine, none of the maximum values reach 500.047, the top-coded luminosity value. Appendix Table 1 provides the summary statistics of the night time luminosity measure in North Korea for each year. Even Pyongyang, North Korea's capital and brightest city does not reach the top coded value.

4.2 Administrative and distance data

The night lights data is then merged with North Korea's administrative boundaries in GIS software. I merge to each grid cell the administrative region information and calculate for each

[3] The data can be accessed at http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html.

grid cell the distance to the nearest city center, distance to the province capital, and distance to the Chinese border. City centers were geographically identified as the brightest pixel in each city. A grid cell is considered urban if it is located in one of the cities listed in Appendix Table 2. I also identify whether a city is a province capital or a specialized city, which has province level status. Specialized cities include the capital Pyongyang and special economic zones or industrial parks. Using distance to the closest city, I identify whether each grid cell is located within 10 km, between 10 km and 25 km, or between 25 km and 50 km from the city center. I collect information on the locations of the major military bases in North Korea. They are mostly army bases with a few air force bases and a couple navy headquarters as illustrated in Appendix Figure 1. I do not have information on the exact coordinates and thus military base status is identified at the city or county level. Table 2 provides the summary statistics for the main variables.

5. Estimation Strategy

The empirical work analyzes the impact of a national level sanctions index on the urban-rural luminosity gap. Economic sanctions on North Korea were imposed based on North Korea's nuclear ambition which was driven by North Korea's Juche ideology, and is likely exogenous to the urban-rural luminosity gap. The main empirical analysis uses OLS regressions with fixed effects and since there is unlikely to be a convincing instrumental variable for an annual sanctions index, I employ a multitude of robustness checks to confirm the validity of the main results.

First, I account for the different satellite effects. Six different satellites collected the night lights data. If unobservable satellite characteristics are correlated with the sanctions index the sanctions effect would be biased. Year fixed effects would control for unobserved satellite characteristics as well as unobserved annual patterns in the data. However, year fixed effects are perfectly collinear with the annual sanctions index. Hence, I first partial out the satellite fixed effects over Figure 2 which includes not only North Korea but also South Korea, parts of China, and the water bodies in between. Specifically, I first run the following regression

$$ln(lum_{it}) = \alpha + \mathbf{D}_{SAT} + \varepsilon_{it} \qquad (2)$$

where $ln(lum_{it})$ is log of the luminosity measure of each grid cell i in year t, α is a constant term, and $\mathbf{D}_{\mathbf{SAT}}$ is a set of five satellite fixed effects with the most recent satellite being the omitted category. I then use $\hat{\alpha} + \widehat{\varepsilon_{it}}$ as the satellite adjusted luminosity measure. The main regression used to examine the urban-rural luminosity gap is

$$ln(alum_{it}) = \alpha + \beta \mathbf{D}_i s_t + \mu_i + \delta_t + \varepsilon_{it} \qquad (3)$$

where $ln(alum_{it})$ is log of the adjusted luminosity measure of grid cell *i* in year *t*. $\mathbf{D_i}$ indicates the urban status. Based on the specifications, $\mathbf{D_i}$ can be a simple dummy variable that equals 1 if the grid cell is in an urban area, the log distance between grid cell *i* to the province capital, or a set of city ring indicators of different distances. μ_i and δ_t represent grid cell fixed effects and year fixed effects. s_t is the sanctions index. The coefficient of interest is β. If urban areas are better shielded from economic sanctions relative to the hinterlands, we would expect β to be positive.[4] I estimate variations of equation (3) to examine the robustness of the main result. I run regressions on subsamples with different years and areas. Since light blooming across national borders can be a problem, I examine samples excluding the borders. I test for reverse causality by examining lags and leads. I also examine whether sanctions on North Korea impact luminosity in South Korea and China. In all regressions, standard errors are clustered by the county equivalent administrative region to account for correlations between grid cells within region and across time.

6. The Impact of Sanctions on Luminosity

6.1 Descriptive evidence

I first present descriptive evidence using the unadjusted luminosity data for North Korea in Figures 3A and 3B. Figure 3A illustrates how the luminosity measure evolved over time in the urban and rural areas. Urban luminosity gradually decreases on average then increases after 2007. Rural luminosity is relatively flat. Figure 3B plots the urban-rural luminosity gap, the difference between the two lines in Figure 3A. The difference gradually decreases during the 1990s, flattens out during the first half of the 2000s, and then sharply increases after 2007. I then juxtapose the sanctions index to this line. The sanction index exhibits a similar U-shape and the timing of the sanctions seems to precede the luminosity gap.

[4] Since the year fixed effects are perfectly collinear with the main sanction effect s_t, and the grid cell fixed effects are perfectly collinear with the urban status variable $\mathbf{D}_i$, s_t and $\mathbf{D}_i$ are not identified in equation (3). I also estimate a model without the fixed effects, $ln(alum_{it}) = \alpha + \beta \mathbf{D}_i s_t + \gamma s_t + \delta \mathbf{D}_i + \varepsilon_{it}$. In this specification γ measures the impact of sanctions on the hinterlands and β represents the differential impact of sanctions on cities.

The luminosity measures used in Figures 3A and 3B come from several different satellites. Different satellites have different light censors and might process lights differently. To account for the difference in satellites, I regress the log unadjusted luminosity measure on year fixed effects over the area of Figure 2, and then use the residual luminosity measure in Figures 3C and 3D. The year fixed effects capture the different satellite effects as well as common annual fluctuations. The steep increase in urban luminosity towards 2010 is no longer visible in Figure 3C. However, the luminosity gap and the sanctions index in Figure 3D exhibit similar trends as before. The relaxing and tightening of sanctions seem to be driving the luminosity gap.

Before turning to the econometric analysis, I examine whether this pattern is unique to North Korea and perform a counterfactual visual analysis on South Korea. Figure 4 presents the corresponding graphs for South Korea. Unlike in North Korea, luminosity steadily increases in both the urban and rural areas and the urban-rural gap is increasing as well. This pattern does not depend on whether I use the raw measure or partial out the year fixed effects, and there is no consistent relationship between the North Korea sanctions index and South Korea's urban-rural luminosity gap.

6.2 The unequal geographic impact of sanctions

Table 3 presents the main regression results. Column (1) presents result without the fixed effects. The coefficient estimate on the sanctions index is -0.005 and statistically significant. An additional sanction event decreases luminosity by about 0.5% on average in rural North Korea. The coefficient estimate on the city dummy is significant and positive at 0.5, indicating that urban areas are on average about 65% brighter than rural areas. The coefficient estimate on the interaction term is significant at 0.0107. The urban-rural luminosity gap increases by about 1.07% with an additional sanction event. In other words, luminosity in urban areas actually increases by 0.57% when sanctions increase. In column (2), I include year fixed effects to control for unobserved annual effects that may be correlated with the sanctions index, and grid cell fixed effects for unobserved location specific characteristics in luminosity. The main effects are subsumed in the fixed effects and the coefficient estimate on the interaction term is the same as before with slightly smaller standard errors.[5] Column (2) assumes that sanctions are exogenous conditional on year and location fixed effects, which is less stringent than column (1)'s assumption that sanctions are strictly exogenous. Hence, I use the fixed effects specification throughout the empirical analysis.

In translating the luminosity results to GDP, I use the elasticity estimate of 0.3 in Henderson et al. (2012) for low and middle-income countries. Further adjusting the raw digital numbers they use to the luminosity measure I use, a one percent increase in luminosity translates to a 0.2 percent increase in GDP.[6] This implies that an additional sanctions event increases the urban-rural GDP difference by 0.21 percent. If we interpret the column (1) estimates, an additional sanction event decreases rural GDP by about 0.1 percent but increases urban GDP by about 0.11 percent. When sanctions increase, the autocrat diverts resources to the city at a cost to the hinterlands.

The rest of Table 3 examines the robustness of the main result by using various sub-samples within North Korea. As Figure 3 illustrates sanctions decreased steadily throughout the 1990s and the early 2000s and then continued to increase afterwards. The results in column (2) may be driven by either when sanctions decrease or increase. I split the sample into two periods, the years from 1992 to 2003 and from 2004 to 2010. The coefficient estimates are both statistically significant and positive. The impact on the urban-rural luminosity gap holds regardless of whether sanctions decrease or increase. The impact seems to be somewhat stronger when sanctions are decreasing, but the estimate in column (3) is not statistically different from that in column (4).

Columns (5) and (6) examine different regions of North Korea. I split North Korea by latitude and run regressions on the sub-samples that cover 38 to 40 degrees latitude and 40 to 42 degrees latitude. The coefficient estimates are larger and nearly identical between the two. Sanctions impact the more mountainous north and the flatter south in a similar manner. As many researchers have noted, light blooming across borders can confound analysis that use the satellite night lights data. I exclude grid cells within 10km of the Chinese or South Korean border in column (7). The estimate is slightly smaller but remains statistically significant at the 10% level.

[5] The coefficient estimates on the interaction terms in columns (1) and (2) are identical because the year fixed effects are perfectly collinear with the sanctions index and the grid cell fixed effects are perfectly collinear with the city dummy.

[6] The transformation is based on the formula Radiance = (Digital number)$^{3/2}$ where the unit is 10^{-10} watts/cm^2/ sr/um (Elvidge et al. 1999, Chen et al. 2011).

Column (8) excludes all grid cells that were unlit across all years. About 88% of the grid cells are never lit. These areas could be uninhabited land or agricultural land. Excluding these areas increases the magnitude of the estimate to 0.029. Lastly, in column (9) I include additional urban and rural time trends to the fixed effects specifications. The inclusion of the time trends has no impact on the estimate.

6.3 Impact by sanction type

Researchers have found that trade sanctions have become less effective in today's globalized economy and that financial sanctions are more effective (Davis and Engerman 2003, Radcliff et al. 1977). In Table 4, I disaggregate the sanctions index by type and create trade, finance, aid or remittance, and travel specific sanctions indexes. I first examine each in four separate regressions and then include all sanction types in column (5). Since the four sanction types are correlated, the estimates in the first four columns of Table 4 are likely to be biased and should be read with such caveat in mind. The coefficient estimates on the sanctions indexes are all positive in columns (1) to (4). However, when all sanction types are included in column (5), only financial sanctions have a significant effect. The dictatorship seems to be responding to financial sanctions more so than the other types of sanctions. Financial sanctions, by freezing North Korean assets or curtailing transactions with related banks, can effectively constrain the economic activity of the elites. One of the unexpected yet most effective sanctions against North Korea was the US Treasury's allegation in 2005 that Banco Delta Asia, a small bank in Macao, was a source of money laundering by North Korea, and Washington's warning that all US financial institutions would cut ties with Banco Delta Asia. Soon after, there was a run on the Banco Delta Asia's deposits. Furthermore, fearing cutoff from US financial institutions, other international banks that had done business with North Korea voluntarily cut North Korean ties. The Banco Delta Asia incident seems to have had a real impact on the North Korean elites. Soon after, North Korea demanded the US to relax the financial sanctions in order to move forward with the nuclear six-party talks (Haggard and Noland 2010).

6.4 Impact by distance and urban rings

Table 5 examines the differential impact of sanctions on cities by distance to city centers. Columns (1) and (2) examine the relation between luminosity and distance to province capitals.

Column (2) indicates that luminosity decreases by 0.13 percent when distance to province capitals increases by 1 percent. However, the magnitude of this elasticity further increases by 0.005 percentage points with additional sanctions. When sanctions increase, the luminosity decreases with distance from the city center at a faster rate.

Columns (3) and (4) further examine the spatial scope of the impact of sanctions on cities. For each major city in North Korea I draw 10, 25, and 50 km radius circles around the city center. I examine how the impact of sanctions differs relative to areas outside the 50 km radius circle. The luminosity "premium" of being in cities as sanctions increase is 2.6 percent for areas within 10 km of the city center (the city core) and 0.5 percent for areas in between 10 km and 25 km of the city center (the second ring). There is no effect for areas between 25 km and 50 km of the city center (the third ring). In terms of GDP, the city core sees an increase of 0.5 percent and the second ring an increase of 0.1 percent relative to the hinterlands when sanctions increase. In column (4), I drop the grid cell fixed effects to examine the average luminosity differences between the urban rings. The city core is on average three times brighter than the hinterlands, and the second ring about 21 percent brighter. The third ring is no different from the hinterlands. Columns (3) and (4) indicate that the urban core, which is already significantly brighter than the other regions, exhibits the largest increase in luminosity when economic sanctions increase.

6.5 Additional robustness tests

Table 6 further examines the robustness of the main results. Panel A performs sensitivity analysis on the urban dummy specification of Table 3 column (2), and Panel B the urban ring specification of Table 5 column (3). I exclude the greater Pyongyang area in column (1) to examine whether the urban premium effect is dominated by the capital city Pyongyang. The urban premiums in both Panels A and B slightly decrease but are still statistically significant. The slight decrease implies that Pyongyang receives more resources relative to the other cities when sanctions increase, which I confirm in the next section. In column (2), I use a sanctions index that excludes all sanctions imposed by South Korea. South Korea's foreign policy against North Korea is much more nuanced compared to that of the US, Japan, or the UN. Especially, with the establishment of the Kaesong Industrial Complex, the two Koreas have maintained economic ties even when North Korea was testing its long-range missiles and nuclear arsenal. Excluding South Korean sanctions return results nearly identical to that of the base specification.

Column (4) uses the less aggregated sanctions index and column (5) the more aggregated sanctions index as described previously in Section 3. The results exhibit very similar patterns as before regardless of which sanctions index I use. The magnitudes are smaller when I use the more disaggregated index and larger when I use the more aggregated index.

Economic growth and urbanization often occur concurrently and the change in urban-rural luminosity gap could be reflecting the change in North Korea's per capita income. To examine this alternative hypothesis, I use North Korea's GDP per capita in place of the sanctions index in column (5). There is actually a negative relationship between the luminosity gap and North Korea's GDP per capita in Panel A, so economic growth is not driving urbanization in North Korea. The correlation between the sanctions index and North Korea's GDP per capita is positive and close to zero at 0.047. Hence, the column (5) result is not simply driven by a negative relationship between the sanctions index and North Korea's income level. Another alternative hypothesis could point to North Korea's reliance on China for its energy supply. China's economic condition could impact energy supply to North Korea and thus the urban-rural distribution of electricity within North Korea. In column (6), I use China's GDP per capita in place of the sanctions index but find no significant impact.

Lastly, I examine the timing of the sanctions. In column (7), I use the one year before sanctions index. The coefficient estimates exhibit a similar pattern and are slightly larger in magnitude compared to when I use the contemporaneous sanctions index. In column (8), I use the one year later sanctions index to see if reverse causality might be an issue. If the difference in the urban and rural economic conditions in North Korea impacted the degree of sanctions being imposed, then the coefficient estimates in column (8) would be significant. The estimate in Panel A is small and statistically insignificant. There is a positive effect on the urban core in Panel B but the magnitude is small, which may reflect a lingering effect. Columns (7) and (8) indicate that reverse causality is not driving the main results.

7. Urban capture and the hinterland response

7.1 Urban capture

I have documented that economic sanctions cause luminosity in the urban areas to increase relative to the hinterlands. I motivated a model in which the autocrat redirects resources to the more valuable areas in response to sanctions. A place could be valuable to the autocrat because it is more productive or because it is the center of power. But not all cities are the same. The autocrat and higher ranks in the government reside in the capital city. The regional administrative cities implement orders from the capital and control locally. There may be cities more connected to the outside world by trade and more directly exposed to international actions. I examine the differential impact of economic sanctions on Pyongyang, the center of power, the province capitals, and Kaesong, the special administrative region that operates an industrial park jointly with South Korea.[7] I also examine the areas with a major military base presence. I collect information on the location of all army corps, and major air force and navy bases in North Korea, and generate a dummy variable equal to one if a county or city contains any one of these corps or bases.[8] Appendix Figure 1 illustrates the types and location of the military bases. Table 7 column (1) presents the regression results. The sanctions index has no impact on the military regions. However, the impact on administrative cities is tiered with Pyongyang being better shielded from sanctions than the province capitals. An additional sanctions event increases the luminosity gap by 3.3 percent in Pyongyang compared to 1.1 percent in the province capitals. The urban elites of the Communist Party seem to take precedence over the military when sanctions are imposed.[9] The impact of sanctions on Kaesong is negative and statistically significant. Since Kaesong touches the South Korean border, the estimate could be impacted from light blooming across borders.[10] Taking the estimate as is, an additional sanctions event decreases luminosity in Kaesong by about 0.8 percent more relative to the rural areas. Kaesong is an important source of hard currency for North Korea, but economic activity in the area has been subject to political turbulence. Factory production occasionally halted when inter-Korea relations chilled since 2008, which coincides with when international sanctions on North Korea were tightening.[11]

[7] Kaesong Industrial Park opened in 2004 as a joint agreement between the Koreas. South Korean companies manufacture goods by hiring workers and renting space from North Korea. The wages and rent are paid directly to the North Korea government.
[8] I collect this information from multiple sources including Federation of American Scientists (FAS) reports, South Korea's Ministry of Defense White Papers, and newspaper articles.
[9] The fact that I can only identify a larger county or city area much larger than the actual military base could be diluting any effect. Also, military bases may intentionally reduce night lights to minimize exposure to foreign satellites.
[10] If the light bleeding across borders were random the measurement error per se would not bias the estimate. However, systematic light bleeding related to the sanctions index would bias the estimate.
[11] Though the industrial park never fully closed during my sample years, there were instances where North Korea would unilaterally reduce the number of people allowed to cross the borders (2008), shut down the road when South Korea participated in joint military exercise with the US (2009). South Korea also restricted new investment after the North Korea attacked the South Korean battleship Cheonan in 2010.

An alternative hypothesis to urban elite capture could be voluntary migration. The rural population could have migrated to the larger cities during economic hardships to take advantage of the urban public goods or job opportunities, a phenomenon often observed in many developing countries. If sanctions promote urban migration, the urban-rural luminosity gap would also increase. However, migration is unlikely to be driving the results in this paper. First, voluntary migration is constrained in North Korea. Technically, households can only move when the party orders them to move. People could bribe officials to purchase urban residential permits but this implies that the relatively few better off migrate to the city, unlike migration triggered by the poor. Furthermore, if deteriorating economic conditions motivate people to move to urban areas then land squatting and urban slums would be prevalent. However, strict control has deterred urban slum development, if any, in North Korea. Lastly, when central city migration is strictly limited, migrants would settle towards the periphery of the city. However, the urban ring luminosity results in Table 5 indicate that luminosity disproportionately increases in the urban core. Strict migration control in North Korea provides a unique setting where one can identify the extent of urban capture due to economic sanctions.[12]

7.2 The hinterland response

As urban-rural inequality increases with economic sanctions, the hinterlands are likely to respond as well. I examine the response from North Korea's periphery, i.e., the area that borders China. The border with South Korea is heavily militarized and strictly closed. The Chinese border, however, is relatively porous. There are official economic zones, Sinuiju and Rason, which attract Chinese investments. Many households are relying on black markets near the border for food and goods. North Koreans have been crossing the Chinese border to trade or become economic refugees. How would economic sanctions impact areas along the Chinese border? Though China did approve the UN Security Council's resolution for sanctions on North Korea, people have questioned China's implementation of the sanctions and have speculated that sanctions may have actually increased North Korea's reliance on China for trade. I create for each grid cell in North Korea the distance to the Chinese border and create a dummy variable

[12] If migrants could move relatively freely, like in many countries, both urban elite capture as well as urban migration would drive urban concentration. In such setting, the degree of urban concentration due to sanctions could be larger.

equal to one if that distance is less than 10 km. Table 7 column (2) adds the 10km dummy variable and its interaction with the sanctions index. An additional sanction event increases the luminosity gap within 10 km of the Chinese border by 1.1%. The magnitude is as large as the coefficient estimate on province capitals and is statistically significant at the 1% level. There is no impact further away from the border, i.e., 10 to 25km from the border, as shown in column (3). The border effect may reflect more economic activity on the North Korean side but also the Chinese side with light blooming across the border. Economic hardship in the hinterlands due to sanctions may have prompted more North Koreans to engage in economic activities near the periphery or to migrate to China. I further explore the latter channel in the next section.

7.3 Impact of sanctions on neighboring countries

Two countries border North Korea: South Korea and China. The border with South Korea is the most heavily militarized border in the world with fences spanning the whole length. There is no border crossing. On the other hand, the border with China is relatively porous. In Table 8, I examine the impact of sanctions on South Korea and China. Columns (1) and (2) present results for South Korea. The coefficient estimates on the sanctions index and the sanctions interacted with the city dummy are small and statistically insignificant. The increase in the urban-rural luminosity gap from sanctions is indeed unique to North Korea and is not a region wide phenomenon.

The next set of columns examines how economic sanctions on North Korea impact the area of China near North Korea. In total there are four Chinese provinces in the data. Most of the observations are in two provinces that share borders with North Korea: Jilin and Liaoning.[13] There is a large presence of ethnic Koreans in these provinces and commerce on both sides of the border is relatively active. Column (3) examines the impact of the sanctions index on the China sample. Luminosity increases with the sanctions index as well as the urban-rural gap. Column (4) examines the two provinces that border North Korea, and column (5) the provinces that do not. There are no cities in the column (5) sample. The sanctions index only impacts the bordering Chinese provinces. Column (6) focuses on the bordering counties and finds statistically strong effects. Why would sanctions on North Korea impact this area of China? Scholars have found

[13] The other two are Inner Mongolia and Heilongjiang. Out of all the China pixels in the sample, only 5.4% are in these two provinces and the rest are in Jilin and Liaoning.

that North Korean migration to China and reliance on Chinese merchants and goods increase when economic conditions in North Korea deteriorate (Haggard and Noland 2011). Table 8 indicates that the increase in sanctions on North Korea have generated similar spillover effects on both the urban and rural areas of the bordering Chinese provinces.

8. Conclusion

This paper examines how an autocracy responds domestically to economic sanctions. Using the satellite night lights data from North Korea I find that economic sanctions decrease luminosity in the hinterlands but increase luminosity in urban areas, especially the urban core. I find the increase to be larger in Pyongyang than the province capitals, but find no difference between the rural areas and the areas with major military bases. The results suggest that the dictatorship countered the effects of sanctions by reallocating resources to the urban areas. I further find that luminosity increases in areas near the Chinese border both on the North Korean and Chinese side. The hinterlands seem to respond to the deteriorating economic conditions by relying more on China or economic activities near the border. In short, this paper finds that sanctions that fail to change the behavior of the autocrat may eventually increase urban-rural inequality. In countries where the hinterlands already suffer the most from autocrats, economic sanctions may further deteriorate the well-being of the marginalized population.

Sanctions will likely be inefficient as long as North Korea can maintain powerful centralized control and oppress any discontent that arises due to increasing inequality. Since North Korea has adapted to sanctions for a long period of time, additional sanctions may simply be perceived as "inconveniences". Financial sanctions seem to cause more inconvenience, but it seems unlikely that sanctions can effectively deter nuclear proliferation. One could imagine extremely stringent sanctions that basically cut all flows of energy, goods, and money into the target country. Such sanctions could hypothetically reach its goal. But the feasibility of such sanctions requires all nations to enforce sanctions to the same degree. Even if sanctions were imposed to its full capacity, the marginalized population, as this paper finds, would suffer most from such sanctions until the autocrat concedes. One can easily imagine, humanitarian organizations objecting to such suffering, or the autocrats playing up the suffering of its own people to claim the inhumanity of sanctions by the western world. More research on sanctions could shed light on when sanctions can be effective, but sanctions as a foreign policy tool seem limited in its ability to change behavior of regimes.

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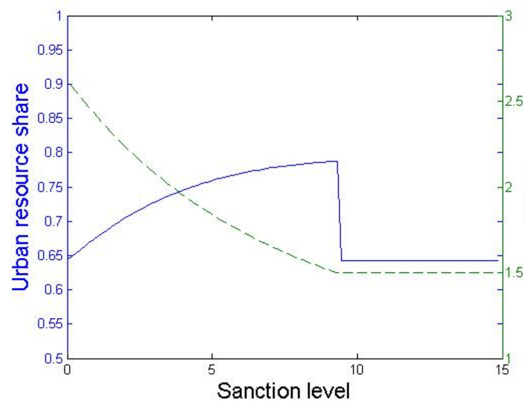
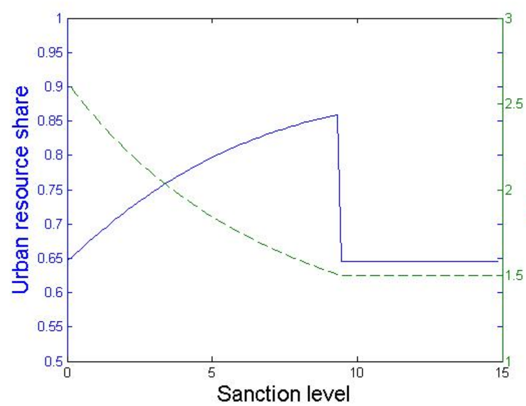
Figure 1. Relation between economic sanctions and urban resource share: Model predictions

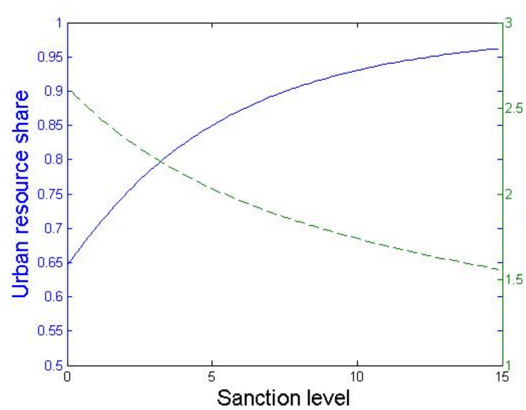
A. $\kappa = 0.1, \gamma = 0.2$, and $m = 10$



B. $\kappa = 0.1, \gamma = 0.2$, and $m = 50$

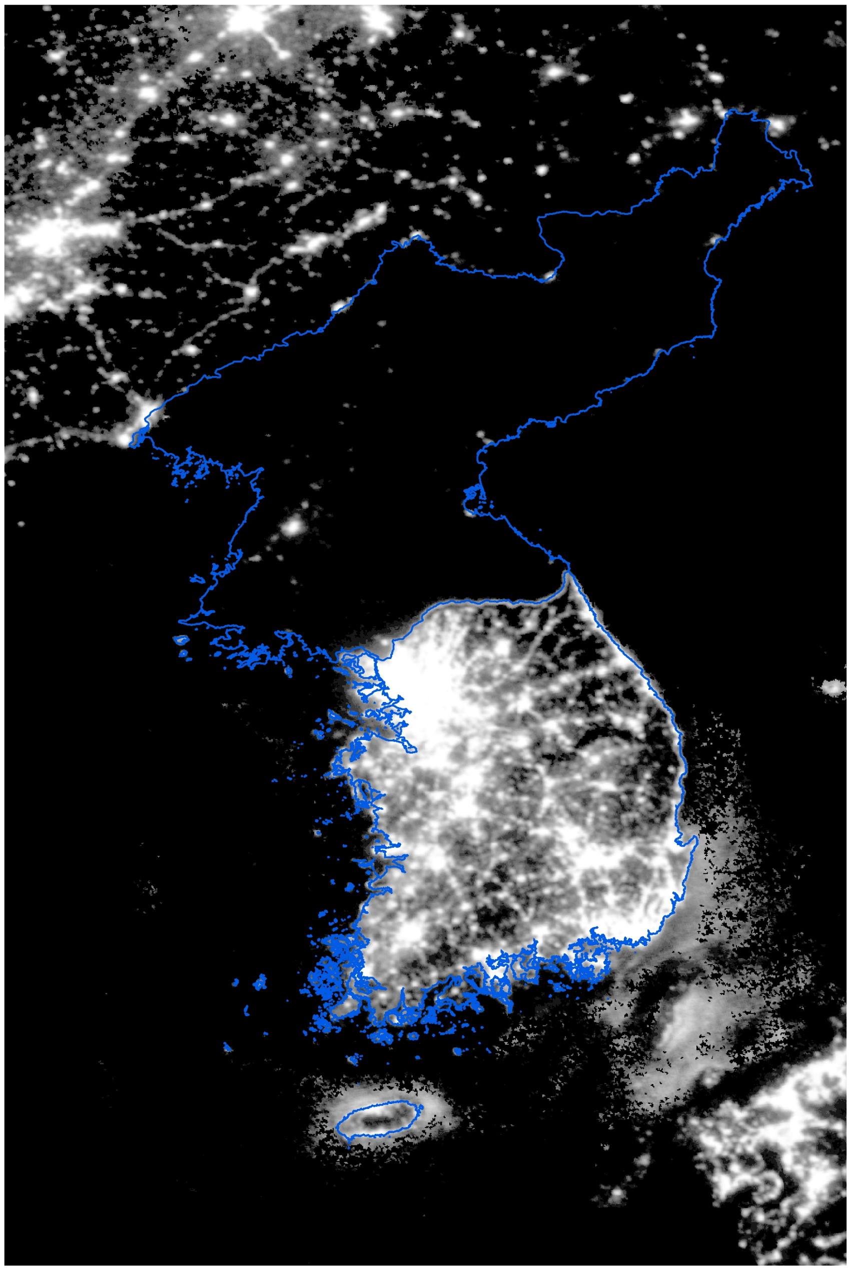


C. $\kappa = 0.05, \gamma = 0.2$, and $m = 50$



Notes: The solid line indicates the urban resource share and is measured on the left vertical axis. The dashed line indicates the optimal value of the autocrat's maximization problem and is measured on the right vertical axis.

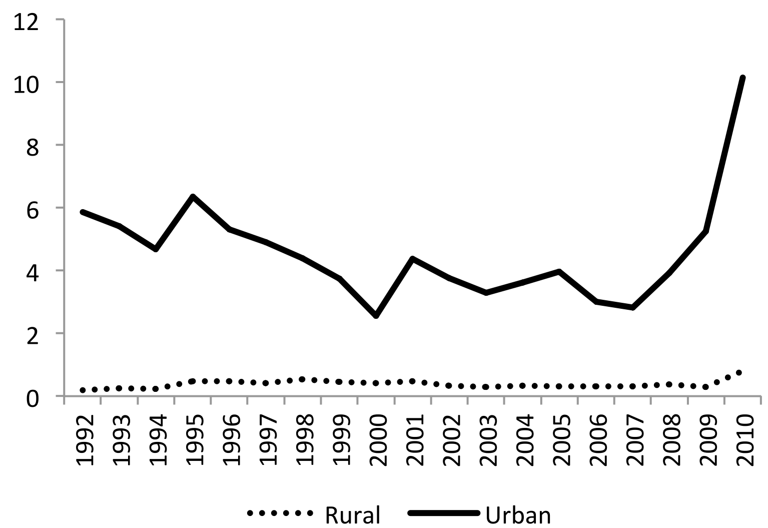
Figure 2. Satellite Image of the Korean Peninsula (2010)



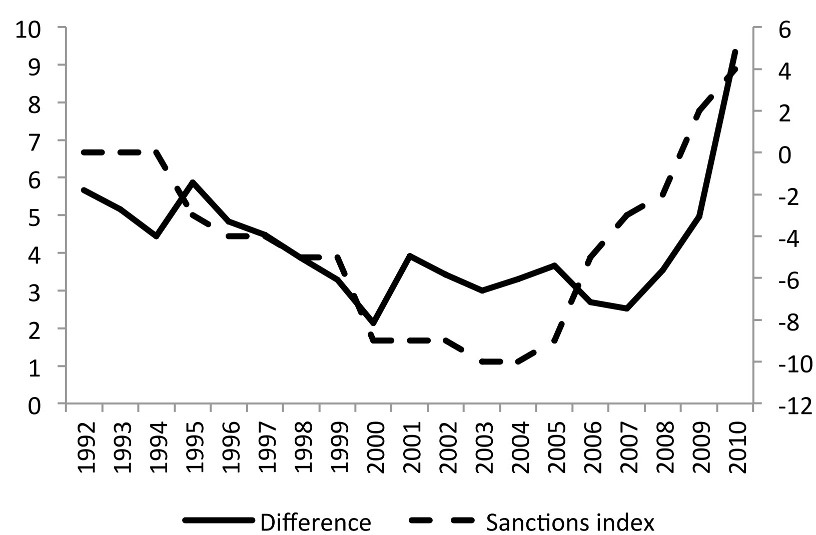
Notes: The area covers 123 to 131 degree longitude and 32 to 44 degree latitude. Image is extracted from satellite number F18 for the year 2010.

Figure 3. The urban and rural luminosity gap and the sanctions index: North Korea

A. Urban and rural luminosity using the raw data: North Korea



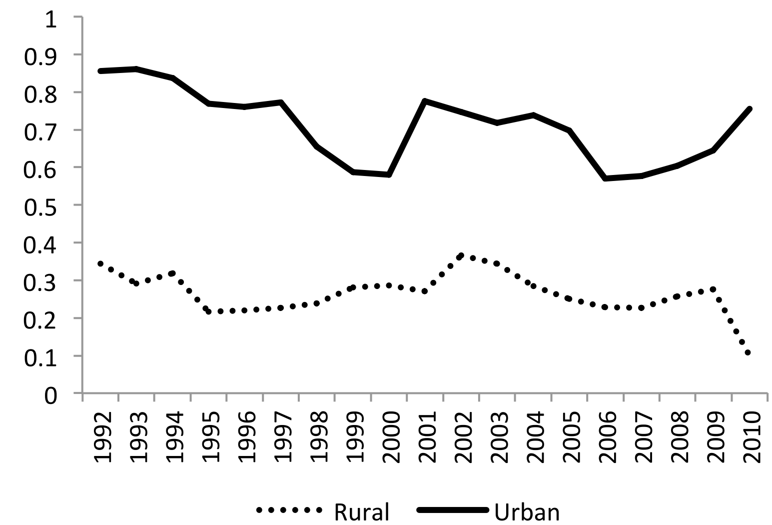
B. Luminosity gap and the sanctions index using the raw data: North Korea



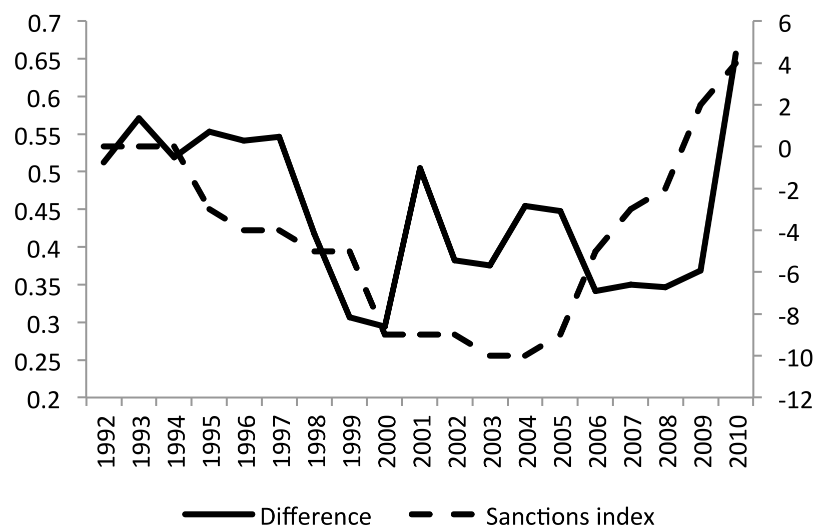
Notes: Figures A and B use the raw luminosity measures that do not adjust for the different satellites used in collecting the data. The luminosity gap in Figure B is the difference between the two lines in Figure A. In Figure B, the left vertical axis measures the luminosity gap and the right vertical axis measures the sanctions index.

Figure 3 continued. The urban and rural luminosity gap and the sanctions index: North Korea

C. Urban and rural luminosity using the adjusted data : North Korea



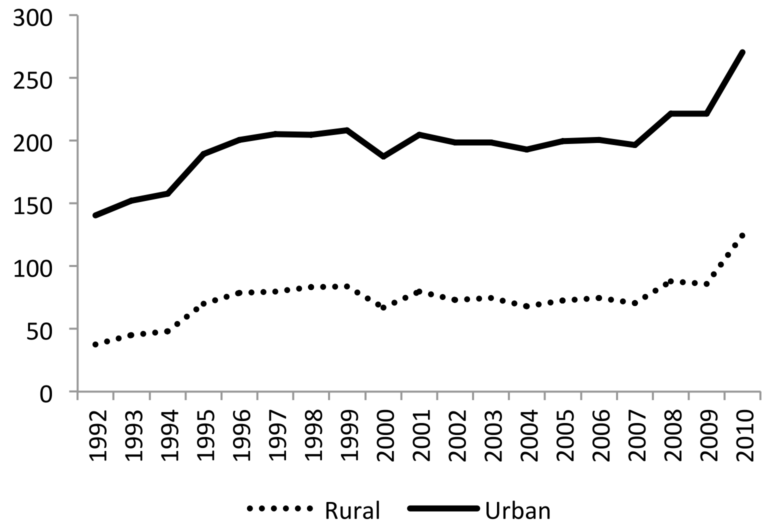
D. Luminosity gap and the sanctions index using the adjusted data: North Korea



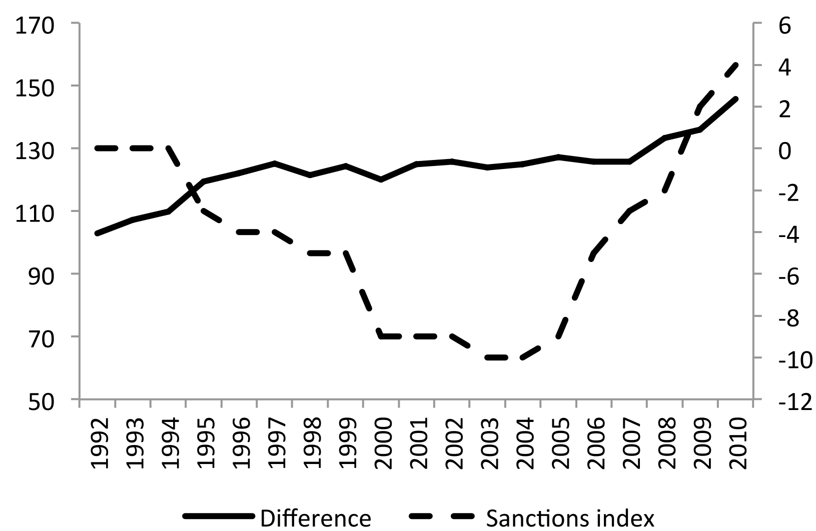
Notes: Figures C and D use an adjusted luminosity measure, the residual in the regression of the unadjusted luminosity measure on the year fixed effects over the area in Figure 2. The year fixed effects captures the different satellite effects as well as common annual fluctuations. The luminosity gap in Figure D is the difference between the two lines in Figure C. In Figure D, the left vertical axis measures the luminosity gap and the right vertical axis measures the sanctions index.

Figure 4. Counterfactual exercise for South Korea: the urban-rural luminosity gap and the sanctions index

A. Urban and rural luminosity using the raw data: South Korea



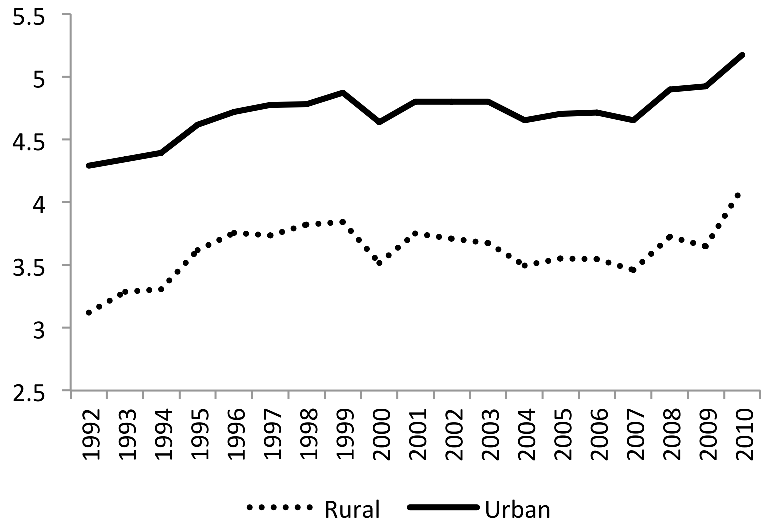
B. Luminosity gap and the sanctions index using the raw data: counterfactual exercise for South Korea



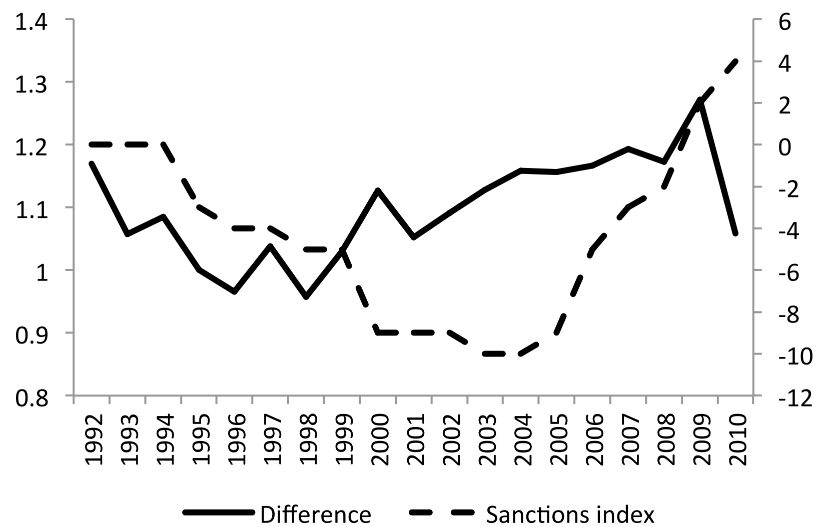
Notes: Figures A and B use the raw luminosity measures that do not adjust for the different satellites used in collecting the data. The luminosity gap in Figure B is the difference between the two lines in Figure A. In Figure B, the left vertical axis measures the luminosity gap and the right vertical axis measures the sanctions index.

Figure 4 continued. Counterfactual exercise for South Korea: the urban-rural luminosity gap and the sanctions index

C. Urban and rural luminosity using the adjusted data : South Korea



D. Luminosity gap and the sanctions index using the adjusted data: counterfactual exercise for South Korea



Notes: Figures C and D use an adjusted luminosity measure, the residual in the regression of the unadjusted luminosity measure on the year fixed effects over the area in Figure 2. The year fixed effects captures the different satellite effects as well as common annual fluctuations. The luminosity gap in Figure D is the difference between the two lines in Figure C. In Figure D, the left vertical axis measures the luminosity gap and the right vertical axis measures the sanctions index.

Table 1. Chronology of the sanctions on North Korea

Year	Sender	Content	Trade	Finance	Aid	Travel
1995	US	Multiple economic sanctions eased based on the 1994 Agreed framework. LWR related trade, financial transactions, and travel allowed. Relaxation of North Korean asset freeze.	-	-		-
1996	US	Humanitarian aid, donation, remittances allowed			-	
1998	South Korea	South Koreans start travel into Kumgang Mountain				-
2000	US	Further relaxation on trade, finance, travel, and aid based on President Clintons 1999 anouncement	-	-	-	-
2003	South Korea	South Korea invests in Kaesong Industrial Park		-		
2005	US	North Korea announces to end its missile testing moratorium. Financial sanction imposed on North Korean entities. Banco Delta Asia is designated as institution of "money laundary conern" and Macau voluntarily freezes North Korean account		+		
2006	UN	DPRK first nuclear test. UN Security Council adopts Resolution 1695 which aims to restrict trade of weapons and luxury goods. Financial transaction and travel are restricted.	+	+		+
	Japan	Japan imposes own multi dimensional sanctions due to the missile tests	+	+	+	+
	US	Freezes US assets of entities dealing with DPRK entities labeled as WMD proliferator.		+		
2007	US	Impose license requirements for export to DPRK and travel further regulated.	+			+
2008	South Korea	Terminates travel into Kumgang Mt. after a NK soilder shoots and kills one SK visitor.				+
2009	UN	Second NK nuclear test. UN Security Council adopts Resolution 1874 further restricting DPRK activities on all dimensions.	+	+	+	+
2010	South Korea	Trande and Investment sanctions after NK attacks on SK's Chonan ship	+	+		

Source: National Committee on North Korea

Table 2. Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
		Panel A: North Korea			
Ln(luminosity)	886103	0.293	0.488	0	6.38
Dummy for ever lit	886103	0.118	0.322	0	1
Sanction index	886103	-4.263	4.153	-10	4
City dummy	886103	0.064	0.245	0	1
Distance to administration city	886103	62.35	32.99	0.25	180.20
Within 10 km of city center	886103	0.028	0.164	0	1
Between 10-25 km of city center	886103	0.130	0.336	0	1
Between 25-50 km of city center	886103	0.306	0.461	0	1
Within 10 km of Chinese border	886103	0.072	0.258	0	1
Within 25 km of Chinese border	886103	0.162	0.368	0	1
		Panel B: South Korea			
Ln(luminosity)	688750	3.728	1.424	0.00	6.49
Dummy for ever lit	688750	0.998	0.048	0	1
City dummy	688750	0.102	0.303	0	1
		Panel C: Parts of China near North Korea			
Ln(luminosity)	1453462	0.992	1.320	0.00	6.49
Dummy for ever lit	1453462	0.574	0.495	0	1
City dummy	1453462	0.069	0.254	0	1

Table 3. The impact of sanctions on the urban rural luminosity gap in North Korea

	Full sample		Years 1992 to 2003	Years 2004 to 2010	Between latitudes 38 and 40	Between latitudes 40 and 42	Exclude border areas	Exclude unlit grid cells	Include time trends
Dependent variable: Ln(luminosity)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Sanction index	-0.00494***								
	(0.000649)								
City dummy * Sanction index	0.0107**	0.0107**	0.0175**	0.00663**	0.0167***	0.0169**	0.00856*	0.0293***	0.0105**
	(0.00455)	(0.00443)	(0.00845)	(0.00327)	(0.00613)	(0.00718)	(0.00474)	(0.00994)	(0.00445)
City dummy	0.492**								
	(0.194)								
Year fixed effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban time trend									Yes
Rural time trend									Yes
Observations	886,103	886,103	559,644	326,459	365,712	444,980	807,956	104,158	886,103
R-squared	0.052	0.801	0.806	0.852	0.794	0.770	0.770	0.731	0.801

Notes: The sample covers all areas of North Korea from 1992 to 2010. Standard errors are clustered at the county level. *, **, *** represent statistical significance at the 10%, 5%, and 1% level.

Table 4. Impact of sanctions by type

Dependent variable: Ln(luminosity)	(1)	(2)	(3)	(4)	(5)
City dummy * Trade sanctions index	0.0329**				-0.0606
	(0.0137)				(0.0475)
City dummy * Finance sanctions index		0.0450**			0.0461*
		(0.0188)			(0.0243)
City dummy * Aid or remittance sanctions index			0.0602**		0.0205
			(0.0274)		(0.0275)
City dummy * Travel sanctions index				0.0314**	0.0358
				(0.0136)	(0.0218)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	886,103	886,103	886,103	886,103	886,103
R-squared	0.801	0.801	0.801	0.801	0.801

Notes: Table 4 disaggregates the sanctions index and examines trade, finance, aid/remittance, and travel specific sanctions separately. Standard errors are clustered at the county level. *, **, *** represent statistical significance at the 10%, 5%, and 1% level.

Table 5. Impact of sanctions by distance and urban rings

Dependent variable: Ln(luminosity)	(1)	(2)	(3)	(4)
Ln(distance to state capital)		-0.132***		
		(0.0400)		
Ln(distance to state capital)* Sanction index	-0.00528***	-0.00528***		
	(0.00149)	(0.00145)		
Within 10 km* Sanction index			0.0260***	0.0260***
			(0.00606)	(0.00590)
Between 10-25 km* Sanction index			0.00506**	0.00506**
			(0.00205)	(0.00200)
Between 25-50 km* Sanction index			0.00130	0.00130
			(0.00110)	(0.00107)
Within 10 km of city center				1.138***
				(0.282)
Between 10-25 km of city center				0.194**
				(0.0752)
Between 25-50 km of city center				0.00374
				(0.0146)
Year fixed effects	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes		Yes	
Province fixed effects		Yes		
Observations	886,103	886,103	886,103	886,103
R-squared	0.801	0.24	0.802	0.136

Notes: The sample covers all areas of North Korea from 1992 to 2010. Distance in columns (1) and (2) are distance to the center of the province capital. Distance in columns (3) and (4) are distance to the nearest city center. City centers were identified by geographically identifying the brightest pixel in each city. Standard errors are clustered at the county level. *, **, *** represent statistical significance at the 10%, 5%, and 1% level.

Table 6. Robustness tests

Dependent variable: Ln(luminosity)	Excluding Pyongyang (1)	Sanctions index excluding S.Korea (2)	More aggregated sanctions index (3)	Less aggregated sanctions index (4)	Log N.Korea GDP per capita (5)	Log China GDP per capita (6)	Lag sanction index (7)	Lead sanction index (8)
Panel A. Urban dummy variable results								
City dummy * *Sanction measure*	0.00781* (0.00410)	0.00914** (0.00427)	0.0282** (0.0120)	0.00445** (0.00208)	-0.138** (0.0677)	-0.0407 (0.0314)	0.0138*** (0.00510)	0.00351 (0.00304)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	866,761	886,103	886,103	886,103	886,103	886,103	839,466	839,466
R-squared	0.778	0.801	0.801	0.801	0.801	0.801	0.810	0.806
Panel B. Urban ring results								
Within 10 km* *Sanction measure*	0.0225*** (0.00613)	0.0251*** (0.00627)	0.0637*** (0.0152)	0.0475*** (0.0163)	-0.164* (0.0834)	-0.00225 (0.0506)	0.0302*** (0.00703)	0.0141*** (0.00495)
Between 10-25 km* *Sanction measure*	0.00379** (0.00180)	0.00458** (0.00207)	0.0128** (0.00538)	0.0141*** (0.00513)	-0.0494 (0.0318)	-0.00254 (0.0175)	0.00556** (0.00220)	0.00158 (0.00183)
Between 25-50 km* *Sanction measure*	0.00130 (0.00111)	0.00145 (0.00130)	0.00315 (0.00261)	0.00381 (0.00260)	0.00108 (0.0102)	0.00548 (0.00463)	0.000911 (0.000905)	0.00111 (0.00121)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	866,761	886,103	886,103	886,103	886,103	886,103	839,466	839,466
R-squared	0.779	0.801	0.802	0.801	0.801	0.800	0.811	0.806

Notes: The sanction measure in columns (1), (7), and (8) are identical to the index used in the previous tables. The sanction measure in column (2) is an index that excludes all South Korean sanctions. Column (3) uses the sanction index based on the more aggregated sanction index and column (4) uses the less aggregated sanctions index as described in Section 3. Column (5) uses North Korea's GDP per capita and column (6) uses China's GDP per capita in place of the sanctions index. Standard errors are clustered at the county level. *, **, *** represent statistical significance at the 10%, 5%, and 1% level.

Table 7. Urban elite capture and the periphery response

Dependent variable: Ln(luminosity)	(1)	(2)	(3)
Pyongyang*Sanction index	0.0331***	0.0339***	0.0332***
	(0.000683)	(0.000699)	(0.000737)
Kaesong*Sanction index	-0.00769***	-0.00686***	-0.00756***
	(0.000683)	(0.000699)	(0.000737)
Administration city*Sanction index	0.0113**	0.0107**	0.0113**
	(0.00476)	(0.00432)	(0.00474)
Military base*Sanction index	0.00008	0.000961	0.000164
	(0.00201)	(0.00192)	(0.00203)
10 km from China*Sanction index		0.0107***	
		(0.00238)	
10 to 25 km from China*Sanction index			0.00133
			(0.00127)
Pyongyang	1.643***	1.655***	1.638***
	(0.0152)	(0.0157)	(0.0166)
Kaesong	0.804***	0.815***	0.798***
	(0.0152)	(0.0157)	(0.0166)
Administration city	0.417***	0.408***	0.417***
	(0.135)	(0.128)	(0.135)
Military base	-0.0455	-0.0336	-0.0488
	(0.0470)	(0.0441)	(0.0473)
10 km from China		0.144***	
		(0.0523)	
10 to 25 km from China			-0.0533**
			(0.0257)
Year fixed effects	Yes	Yes	Yes
Observations	886,103	886,103	886,103
R-squared	0.116	0.119	0.116

Notes: The military base variable is a dummy variable equal to one if the grid cell is in a county or city that contains any of North Korea's army corps or major air force or navy bases. The distance variables are dummy variables equal to one if the grid cell lies within 10 km or between 10km and 25 km from the Chinese border. Standard errors are clustered at the county level. *, **, *** represent statistical significance at the 10%, 5%, and 1% level.

Table 8. The impact of sanctions on the urban rural luminosity gap in South Korea and China

				China		
	South Korea		China	Bordering provinces	Non-bordering provinces	Bordering counties
Dependent variable: Ln(luminosity)	(1)	(2)	(3)	(4)	(5)	(6)
Sanction index		-0.00108	0.0129***	0.0137***	-0.00007	0.00384**
		(0.00235)	(0.00260)	(0.00276)	(0.000761)	(0.00160)
City dummy * Sanction index	0.00115	0.00115	0.0140*	0.0132*		0.0104***
	(0.00412)	(0.00401)	(0.00755)	(0.00761)		(0.00340)
City dummy		1.104***	1.189***	1.148***		1.137***
		(0.260)	(0.266)	(0.269)		(0.281)
Year fixed effects	Yes					
Grid cell fixed effects	Yes					
Observations	688,750	688,750	1,453,462	1,374,042	79,420	660,896
R-squared	0.931	0.055	0.049	0.047	0.000	0.053

Notes: The sample covers all areas of South Korea, and parts of China near North Korea from 1992 to 2010. The China sample contains parts of Jilin and Liaoning which share borders with North Korea, and Inner Mongolia and Heilongjiang which do not border North Korea. Cities in South Korea are metropolitan cities and province capitals. Cities in China were identified by urban district status. Standard errors are clustered at the county level. *, **, *** represent statistical significance at the 10%, 5%, and 1% level.

Appendix Figure 1. North Korea Military Base Location

Source: http://www.fas.org/nuke/guide/dprk/facility/dprk_mil_map.htm

Appendix Table 1. Summary statistics of luminosity by satellite year for North Korea

Variable	Obs	Mean	Std. Dev.	Min	Max
f101992	46704	0.5500235	7.212407	0	396.8941
f101993	46704	0.5905189	6.474554	0	369.8041
f101994	46704	0.5181007	6.278265	0	391.3828
f121994	46704	0.7306121	8.559078	0	453.1876
f121995	46704	0.8565573	8.820439	0	433.209
f121996	46704	0.7812363	7.875371	0	436.0771
f121997	46704	0.7105542	7.15524	0	399.7381
f121998	46704	0.7883546	7.954495	0	400.224
f121999	46704	0.6691241	7.405976	0	430.5641
f141997	46704	0.3819561	5.109976	0	351.2615
f141998	46704	0.5470805	5.428331	0	359.728
f141999	46704	0.5042964	5.219042	0	333.1252
f142000	46704	0.5501406	5.192014	0	250.6851
f142001	46704	0.7183504	6.572791	0	341.5628
f142002	46704	0.555202	6.419962	0	408.5233
f142003	46704	0.4806779	5.640976	0	356.5726
f152000	46704	0.8086805	6.944908	0	360.8193
f152001	46704	0.8352334	6.8543	0	408.5233
f152002	46704	0.7641265	7.076884	0	377.7722
f152003	46704	0.5035468	5.178538	0	364.7671
f152004	46704	0.5402522	5.76497	0	378.8447
f152005	46704	0.5456281	6.21107	0	425.0025
f152006	46704	0.4823811	5.573951	0	365.5663
f152007	46704	0.4666759	5.612405	0	314.572
f162004	46704	0.6377714	7.013708	0	427.6711
f162005	46704	0.5567929	5.940559	0	353.7655
f162006	46704	0.5728918	6.397513	0	383.1805
f162007	46704	0.7559353	7.355366	0	376.1018
f162008	46704	0.6086034	7.414615	0	403.3745
f162009	46704	0.6043093	8.58357	0	473.5084
f182010	46704	1.400737	13.22129	0	491.1769

Notes: Summary statistics for the luminosity measures used in the paper are presented. Variables are identified by satellite and year. For example, F121995 is from satellite number F12 for the year 1995. The data can be accessed at http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html.

Appendix Table 2. List of North Korean Cities

City	City type	population 2008	latitude	longitude
Pyongyang	Capital city	3255288	39.0417	125.7517
Rason	Special city	196954	42.4083	130.625
Nampo	Special city	366815	38.9417	125.575
Chongjin	Province capital	667929	41.775	129.7417
Hamhung	Province capital	668557	39.8583	127.575
Kaesong	Special zone/ Industrial park	308440	37.9917	126.5417
Pyongsong	Province capital	284346	39.2917	125.8583
Sinuiju	Province capital	359341	40.125	124.3917
Kanggye	Province capital	251971	40.975	126.575
Hyesan	Province capital	192680	41.425	128.2083
Haeju	Province capital	273300	38.0583	125.6917
Sariwon	Province capital	307764	38.525	125.7417
Wonsan	Province capital	363127	39.175	127.425

Notes: The latitudes and longitudes are for city centers which were identified by geographically identifying the brightest pixel in each city.