International Isolation and Regional Inequality: Evidence from Sanctions on North Korea[*]

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Abstract

This paper examines how the spatial distribution of economic activity, and hence regional inequality, evolves when a country becomes increasingly isolated because of economic sanctions. Sanctions could render the target country, often an autocracy, to redirect resources to the capital city. The country could develop its manufacturing regions to substitute for imports, or if limited access to capital and goods inhibit production, rely more on its natural resources. Lastly, economic activity could move to regions that see a relative reduction in trade costs. I examine the case of North Korea. Using nighttime lights data, I find that Pyongyang, the center of power, is well shielded from sanctions. Lights near the Chinese border increases with sanctions, as well as trade with China, which did not enforce the sanctions. Manufacturing and mining areas become relatively brighter with sanctions. However, using product level trade data I find that production shifts away from capital intensive products to natural resource intensive products. In a country where labor is immobile, such divergence in economic activity implies that people in the hinterlands are literally left in the dark, while those with political power, trade or mining connections shield themselves from the negative impact of sanctions. Despite the intention to change the behavior of the elites, sanctions can increase inequality at a cost to the already marginalized populace.

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1. Introduction

Countries have increasingly used economic sanctions to punish and hopefully change the behavior of target countries by isolating them from the benefits of international trade and finance. In reality, sanctions have been mostly ineffective in changing the target country's behavior (Hufbauer et al. 2009).[1] Examining how countries respond to sanctions is fundamental to the understanding of the efficacy and consequences of sanctions. However, economics research has been surprisingly sparse on this topic. This paper examines how the spatial distribution of economic activity, and hence regional inequality, evolves when a country becomes increasingly isolated because of economic sanctions.

How might sanctions affect regional economic inequality? Existing research provide insights to this question. Krugman and Livas Elizondo (1996) theoretically show that producers in a closed economy benefit from locating near large cities because of the close linkages producers have with consumers and intermediate goods suppliers. In an open economy the benefits of locating near large cities diminish as producers can sell and buy from abroad. Ades and Glaeser (1995) empirically confirm that trade protectionism is associated with higher urban concentration in a cross-section of countries. Since sanctions isolate countries from global trade, the urban concentration predictions from protectionism could similarly follow through with sanctions. However, Ades and Glaeser also find that political factors, rather than trade policy, are stronger determinants of urban concentration. Urban concentration is stronger in dictatorships and politically unstable regimes, since dictators exploit the hinterlands at little cost and politically unstable regimes disproportionately cater to the population near the capital city to maintain power. Furthermore, the literature on distributive politics and regional favoritism find that leaders favor their hometowns, and that such favoritism is starker in non-democracies. Hodler and Rashcky (2014) find that the nighttime light intensity near the leaders' birthplaces becomes brighter when leaders come into power, especially in autocratic countries. Similarly, Burgess et al. (2015) find that more roads are built in districts that have the same ethnicity as the incumbent president in Kenya, and such ethnic favoritism weakens during democratic periods.

Sanctions could also impact regional economic activity via industrial development. Recently, when the West imposed sanctions against Russia for invading Crimea in 2014, a senior Russian official mentioned that sanctions could serve as a powerful incentive for Russia to development her industries and seek out new trade partners.[2] The argument that economic isolation or protectionism can result in

[1] Hufbauer et al. (2009) document that of the 174 sanction cases between 1915 and 2000 only 34 percent were at least partially successful, and moreover, most of the successes happened before the 1970s.

[2] In an interview with a Russian newspaper, Sergei Ivanov, the head of the Kremlin administration, stated that "…the imposed sanctions could serve as a powerful incentive for our industries to take more active part in our own development…" (http://sputniknews.com/russia/20140921/193153341/Western-Sanctions-to-Boost-Russian-Industry-Development.html) The Moscow Times notes that after a year of sanctions, "import substitution" and

industrial development is not new. As a matter of fact, the import substitution policies pursued by many post-colonial countries in the mid-20th century follows the same logic. If sanctions indeed promote industrial development, manufacturing cities as a consequence could see relative increase in economic activity compared to other parts of the country. Though research on the impact of sanctions on domestic industrial production is limited, researchers have examined the impact of trade embargoes (Irwin 2005; Etkes and Zimring 2015) and trade blockades (Juhasz 2014). In particular, Juhasz (2014) uses events surrounding the Napoleon blockade in the 18th century and finds that the blockade led France to upgrade its textile industry, particularly in regions where trade costs were higher. However, in the context where sanctions aim to curtail not only the flow of consumption goods, but intermediate goods, and more importantly capital, the argument that sanctions could promote industrial development may not carry through. If sanctions effectively constrain production capabilities, especially by restricting the flow of capital, target countries might rely more on existing endowments, such as, natural resources for production.

Sanctions also alter the relative trade costs between countries. Lee (2015) finds that sanctioned countries divert trade towards non-sanctioning countries. As a consequence, domestic production could move to regions that benefit most from the relative change in trade costs. For example, Hanson and Krugman (1993) found that the Mexico-US Free Trade Agreement increased Mexico's production activities in regions near the US border.

The above channels suggest how sanctions might affect regional economic activity. The regional favoritism channel hypothesizes that leaders of sanctioned countries, often autocrats, would disproportionately distribute resources to areas of political power. The industrialization channel hypothesizes that sanctions could trigger countries to import substitute and divert resources to manufacturing regions or shift production towards areas rich in natural resources. The economic geography of trade channel predicts that, as sanctions alter bilateral trade costs, the geographic location of production and trade would move to regions that see a relative reduction in trade costs. Also, limited access to foreign consumers and producers could push domestic producers to rely more on the close linkages to large urban areas. The objective of this paper is to empirically examine whether the above channels are at work, and then to discuss the inequality implications and efficacy of sanctions. This paper examines the case of North Korea. North Korea has been sanctioned essentially since the birth of the country, and the intensity of sanctions has fluctuated considerably, which provides sufficient variation for empirical analysis. The North Korea case is particularly appealing because internal migration is strictly controlled. Hence, the observed changes in the geographic distribution of economic activity

"localization" is Russia's new slogan. (http://www.themoscowtimes.com/opinion/article/how-much-have-sanctions-really-hurt-russia/525228.html).

predominantly reflect centralized planning and not voluntary migration towards better economic conditions. This distinction is important since migration towards urban areas for better economic opportunities would not necessarily imply that rising regional inequality reflect increasing economic inequality. However, the main challenge is that data on North Korea especially at subnational levels are almost non-existent.

To examine the impact of sanctions in North Korea I use two data sets, the Defense Meteorological Satellite Program's nighttime lights data and the UN Comtrade's product level international trade data. The nighttime 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 (Xi and Nordhaus 2011, Henderson et al. 2012, Michalopoulos and Papaioannou 2014, Hodler and Raschky 2014). I create an average luminosity measure for each one by one arc minute grid, which translates to approximately a one by one mile grid, between 1992 and 2013. I document North Korea's nuclear provocations and agreements that led countries and the UN to tighten or relax sanctions and create a sanctions index. In the 1990s North Korea agreed to abandon its nuclear program and various pre-existing sanctions were relaxed. However, the pattern reverses and sanctions on North Korea ramp up starting in the early 2000s when North Korea resumed long-range missiles and nuclear tests. During this period the number of North Korea's trade partners and products decline. One misconception about North Korea is that it barely trades with other countries. North Korea was exporting to 141 countries in 2005 and by 2013 was still exporting to over 120 countries. However, the share of trade with China, North Korea's main trading partner and one that did not enforce the sanctions, increased drastically. By 2013 trade with China comprised more than 80 percent of North Korea's trade.

Sanctions on North Korea were likely exogenous to the evolution of light intensity across regions within the country. However, to alleviate endogeneity concerns, I also present 2SLS estimates that use the share of US House Foreign Affairs Committee members with the same party affiliation as the president to instrument for the sanctions index. The US House Foreign Affairs Committee oversees legislation and performs oversight on issues related to sanctions. When there are more Committee members with the same party affiliation as the president, the Committee may be better able to convince the US government and allies to levy and implement sanctions against North Korea. The first-stage results indicate that the instrument is positively and significantly related with the sanctions index.

I find that an additional sanction increases the difference in nighttime lights between the capital Pyongyang and the rest of the country by 5.8%, or by 1.7% in terms of GDP. I use Henderson et al.'s (2012) elasticity estimate of 0.3 when translating lights to GDP. For manufacturing cities the difference in nighttime lights increases by 1.3% with an additional sanction. I map North Korea's mineral deposits and mining areas by latitude and longitude and identify regions within 3km of the coordinates. I find that the difference in nighttime lights between mining areas and the rest of the country increases by 4% or by 1.2% in terms of GDP with an additional sanctions event. The luminosity gap between Sinuiju, a trading hub abutting China, and the rest of the country increases by more than 10% with an additional sanction. As China did not impose the sanctions on North Korea, the relative trade costs with China became substantially lower, and economic activity increases in areas near the Chinese border. To the contrary, I find that traditional port areas become relatively darker when sanctions increase. In short, sanctions caused economic activity to concentrate relatively more in the capital city, manufacturing and mining areas, and regions bordering China. Various robustness checks find that the results are not driven by China's growth or the rise in world mineral prices during this period. Nor is internal migration driving the results. This increase in regional inequality implies that the urban elites in Pyongyang or communist party members with manufacturing and mining connections, or trading rights with China were shielded from the sanctions when the rest of the population became worse off.

The relative increase in nighttime lights in manufacturing and mining areas could either imply import substitution and industrial upgrading or more reliance on natural resources for production. To probe into this, I examine how sanctions impact North Korea's product exports and imports by factor intensity. I find that exports shifts away from capital intensive products and towards natural resource intensive products. Furthermore, sanctions increase the imports of capital intensive products. This suggests that sanctions did not induce industrial upgrading nor the production of more capital intensive goods, but rather shifted industrial production towards natural resource intensive goods, potentially deterring the country to progress on the industrial development spectrum. Modern sanctions not only target final products but also intermediate goods and financial flows, and hence the argument that sanctions could incentivize a country to promote industrial development seems unsupported.

This paper finds that sanctions increase domestic regional inequality, in a way that benefits the people at the center of political power and trade, and pushes the target country to rely more on domestic natural resources for production. Moreover, despite the fact that sanctions aim to punish the target country's leadership, sanctions increase inequality at a cost to the already marginalized hinterlands. To the best of my knowledge this is the first paper that empirically examines how externally enforced isolation via economic sanctions alters regional economic inequality within the target country. The economics literature has examined the consequences of sanctions in relation to international trade and finance (Haidar 2014, Lee 2015, Besedes et al. 2016, Crozet and Hinz 2016) and the efficacy of sanctions (Eaton and Engers 1992; 1999, Dashti-Gibson et al. 1997, Davis and Engerman 2003, Hufbauer et al. 2009).[3] However, the economics literature has focused less on how sanctions differentially affect the

[3] Eaton and Engers (1992, 1999) theoretically examine the conditions under which sanction threats and imposition occur and when sanctions might be an effective tool to influence foreign policy. Davis and Engerman (2003) argue

populace of the target country. Public health studies have found that sanctions negatively affect childhood mortality (Ali and Shah 2000, Daponte and Garfield 2001), and such findings have triggered the policy world to redesign sanctions to specifically target the elites. Levy (1999) argues that sanctions on South Africa could have caused the apartheid government to increase its oppression on the blacks and that blacks were often more hurt by mass layoffs. My paper examines the regions and population that have been shielded or hurt from sanctions, and thereby contributes to our understanding of what happens on the ground when countries are sanctioned.

The paper is divided into six sections. The next section provides some background on the North Korean economy and the sanctions imposed. Section 3 introduces the data and present descriptive patterns on the nature of isolation caused by sanctions. Section 4 discusses the estimation and identification strategy. Section 5 discusses the empirical results based on the nighttime lights data and Section 6 the trade data. Section 7 concludes.

2. The North Korean Economy and Sanctions against North Korea

Since its establishment in 1948, North Korea has maintained a hereditary dictatorship and a centrally controlled economy. Despite the collapse of the Soviet bloc in the 1990s and China's gradual integration into the world economy, North Korea has been able to maintain core features of a centrally planned economy. The communist party dictates industrial production activities and allocates labor accordingly, restricting any type of migration within the country. Despite the popular reference as a hermit kingdom, North Korea has political and trade relationships with many third world and past communist countries. However, it has consistently been shut out from the developed world and maintains diplomatic relationships with only a handful of western nations. When communism started to decline in the late 20th century, North Korea responded by strengthening the hereditary dictatorship and adhering to the home-grown ideology of Juche, which emphasizes self-reliance. In this light, North Korea pushed for the development of nuclear weapons and has conducted nuclear weapons test and missile launches every few years since the early 2000s. Such pursuits have further isolated the already isolated country.

Sanctions are not new to North Korea. North Korea has been sanctioned essentially since birth. The US Department of Treasury issued the Foreign Assets Control Regulations, which restricted financial transactions related to North Korea and froze North Korean assets under US jurisdiction since the Korean War broke out in 1950. Several notorious international bombings against South Korea by North Korean agents 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

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that globalization and the interdependency among countries in the latter half of the 20th century have made trade sanctions less effective.

international terrorism. Animosity between North Korea and South Korea did not dissipate and there was minimal economic interaction between the Koreas during most of the 20th century.

Sanctions against North Korea started to ease during the 1990s when South Korea's then liberal government pushed for engagement policies with the North, and the Clinton administration signed 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, with which plutonium enrichment becomes substantially difficult. In return, several countries would jointly fund the development of the light water reactor with funding primarily coming from South Korea, 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 2004 and countries started to reinstate various sanctions. North Korea performed nuclear tests in 2006, 2009, 2013, and most recently in 2016. Each test triggered additional sanctions and UN Security Council Resolutions that restricted North Korean activities in multiple dimensions. Initially, sanctions focused on banning the trade of weapons related materials and goods, but further expanded to luxury goods to target the elites. Sanctions also expanded to financial assets and banking transactions, and general travel and trade. Table 1 summarizes the main events that affected the intensity of sanctions against North Korea since 1992.[4]

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. Figure 1 graphically illustrates how the main sanctions index evolved over time. The 1990s was a period when various pre-existing sanctions against North Korea were being relaxed. However, the pattern reverses in the early 2000s when North Korea started conducting long-range missiles and nuclear tests. I also create two other measures, one more aggregated and the other less aggregated. These are later used in the robustness tests. 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.

[4] Haggard and Noland (2010) provide a more detailed analysis surrounding North Korea's nuclear pursuit and international sanctions. The Congressional Research Service Report for Congress by Rennack (2006) also provides detailed background on sanctions against North Korea.

3. The Data and Descriptive Patterns

Though data on North Korea is scarce, I am able to compile multiple datasets to examine the question at hand. The satellite nighttime lights data provides measures of sub-national economic activity at fine geographies each year. Administration boundary data provides information on county and urban status, including which cities are province capitals and special economic zones. South Korean government reports provide information on manufacturing cities and port cities. Geological data provides information on the coordinates of mines, mining facilities, and mineral deposits. Overlaying these information into Geographic Information System (GIS) and merging in the sanctions information generates a rich data set that I can use to examine the impact of sanctions on the intra-regional dynamics of nighttime lights by city characteristics. Finally, I use trade data to examine how sanctions shift commodity production patterns by capital, human capital, and natural resource intensity. The following describe each data in more detail.

3.1 The nighttime lights data

The National Oceanic and Atmospheric Administration provides the nighttime 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 various tasks, such as, adjustment for cloud covers, glares, and fires. The final data product is gridded in 30 arc-second by 30 arc-second pixels that spans -180 to 180 degree longitude and -65 to 75 degree latitude, and is available for the years since 1992. Six different satellites have collected the lights data, with some overlap across years.[5] The light intensity is reported in digital numbers that range from 0 to 63 for each pixel, with higher numbers implying brighter nighttime lights. Henderson et al. (2012) find that satellite nighttime lights is correlated with GDP with an elasticity of about 0.3 and serves as a good proxy for economic output when subnational data is not well reported. Given that consumption, production, and government service all use lights at night, the literature has increasingly used the night lights data to examine the distribution of regional economic output (Donaldson and Storeygard 2016).

I take the arithmetic mean of each 2 x 2 pixel grid, which results in a 1 x 1 arc-minute grid, as my geographic unit of analysis. This converts to approximately a 1 x 1 mile grid. This procedure generates 47,820 grid cells within North Korea. Since a substantial share of the digital numbers are zero in North Korea, I follow the literature by adding 0.01 to the average before taking natural logarithms (Hodler and

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[5] Each composite data set is named with the satellite and the year. The data can be accessed at http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html.

Raschky 2014, Michalopoulos and Papaioannou 2013, 2014). Adding the small constant allows estimation on the full sample, but also accounts for the fact that a digital number of zero does not necessarily imply no lights at all, but that lights may be too low for detection by the satellites. A bigger concern in the literature tends to be the top-coding of the lights data due to over-saturation of the satellite light censors. (Henderson et al. 2012, Kulkarni et al. 2010). Fortunately, this is not a concern for North Korea. During the 22 years period I examine, none of the values reach 64, the top-coded digital number. Even Pyongyang, North Korea's capital and brightest city caps at 63.

3.2 Administrative Boundaries and Geographic Information

The nighttime lights data is then merged with North Korea's administrative boundaries in GIS software. Each grid cell is then identified by province and sub-province (city if urban and county if rural). Grid cells were further identified by dummy variables indicating province capitals, special economic cities, manufacturing cities, port areas, and mining areas. There are two specialized cities, Kaesong and Sinuiju, each abutting the borders with South Korea and China. The Kaesong Industrial Park was established as a joint effort by both Koreas to rebuild economic ties. The park allowed South Korean small and medium size manufacturing firms to use North Korean labor for production. As labor wages are given directly to the North Korean government, Kaesong serves as an important source of foreign currency for North Korea. Operations of the industrial park were often subject to the bilateral relations between the two Koreas. Sinuiju is a port and border city at the western tip of the Korean Peninsula and serves as the main trading hub between North Korea to China. Appendix Table 1 lists North Korea's main cities and categorization.

South Korean government documents provide information on manufacturing and port cities. Manufacturing information is available only for very aggregated industries at the city level. Hence, I am only able to identify whether a grid cell lies within a manufacturing city, but not the type of industry. Similarly, government report provides the names of port cities only. To better examine how sanctions impact economic activity on potential port areas, I identify ports as the area within 2 km of the shore for each port city.

The US Geological Survey has coordinate information on the mines and mineral deposits. I identify the areas within 3kms of the coordinate as mining areas. I include both the mine locations and mineral deposit locations to capture both actual and potential mining activity at the time of survey.

For each grid cell I calculate the distance to the city center of province capitals, and distance to the Chinese border. City centers were geographically identified as the brightest pixel in each city. Using distance to the city center, I also create whether each grid cell is located within 5 km, between 5 and 10 km, or between 10 and 25 km from the city center.

3.3 Product level trade data

I use the Harmonized System (HS) 6 digit level trade data from UN Comtrade and extract all reported trade with North Korea from 1992 to 2013. Since North Korea do not report any trade statistics, the data is based on what is reported by the countries that trade with North Korea. Since some trade information may have not been included, the trade data is likely an underestimate of actual trade. Also, weapons related trade may have not been fully reported in UN Comtrade. I later discuss how such data may affect the interpretation of the empirical results. I merge in the revealed factor intensity indices at the product level constructed by Shirotori et al. (2010). Indices for three factors, i.e., capital, human capital, and natural resource, for each HS 6 digit level product are available. The indices were constructed as the weighted average of the factor abundance of the countries that export each commodity, where the weights use revealed comparative advantage measures. I use the 1992 measures for in the empirical analysis.

3.4 Descriptive patterns

I first present aggregate trade patterns to descriptively examine the nature of isolation North Korea faced under economic sanctions. Figure 2 indicates that both exports and imports were on an increasing trend over the whole period. The spike in imports in 2001 and 2008 represent bulk oil imports from the Middle East. Though there does not seem to be any evident correlation between the intensity of sanctions and aggregate trade, trade could have increased more had there not been sanctions. The dashed lines represent trade with China. Imports from China increases at a faster rate around 2005, which is when sanctions on North Korea started to tighten. Exports to China also increase drastically later in that decade. Figure 3 shows that increasing sanctions were accompanied by the decrease in number of trade partners. The number of countries North Korea exported to peaks in 2005 at 141 and then gradually declines. The number of countries North Korea imported from is smaller but similarly exhibits an inverse U-shape. The number peaks in 2005 at 99. Figure 3 indicates that sanctions resulted in the reduction in the number of trade partners. Figure 4 presents the number of exported and imported products at the HS 6-digit level. The products that North Korea imports are much more diverse than what it exports. However, both similarly exhibit an inverse U-shape. These figures illustrate several points. First of all, that North Korea does not trade with the outside world is a misperception. Though the trade volumes may not be large, North Korea indeed trades with many countries. Second, the isolation faced by North Korea due to sanctions was not towards autarky, but towards fewer trade partners and products. This is natural given that several of the sanctioning countries severed trade ties when North Korea continued to conduct nuclear tests. Lastly, despite the reduction in trade partners and traded products, aggregate trade volume has been increasing throughout this period.

I next present descriptive evidence from the nighttime lights data. Figure 5 is a satellite image of the Korean Peninsula in 2010. The dark area between brightly lit South Korea and China is North Korea. Pyongyang, the North Korean capital, is lit as if an island in the ocean. North Korea looks so dark one might wonder whether there is any variation in lights across regions to examine. However, closer inspection reveals interesting changes in lights over time. Figure 6 presents the satellite image of the Pyongyang area from 1992, 2002, and 2012. There are more lights around the center, which represents the urban area, in 1992 and 2012. Also the share of lit pixels in each box is smaller in 2002, when the intensity of sanctions was low. Though suggestive, the figures illustrate that the intensity of sanctions may have affected the concentration of lights around Pyongyang.

Figures 7 and 8 illustrate how nighttime lights evolved over time in the capital cities (both the province capitals and Pyongyang) relative to the rest of the country. The solid line in Figure 7 plots the share of total lights in the capital cities. In 1992 over 50 percent of lights were in these cities. However, this share continues to decrease to around 30 percent in the early 2000s and then increases to about 40 percent in the 2010s. I juxtapose the sanctions index to this trend. The sanctions index exhibits a similar U-shape and the movement of the sanctions index seems to precede that of the share of lights in capital cities. In Figure 8 I plot the difference in the average nighttime light between province capitals and the rest of the country. The line again exhibits a U-shape and the patterns are strikingly similar to the sanctions index. Furthermore, it is more evident that the sanctions index is leading the downward and upward trend. The relaxing and tightening of sanctions indeed seem to be driving the different in nighttime lights between the two regions. The regression analysis that follows will more formally test whether this pattern holds across different types of cities.

4. Estimation using the Lights Data

The base OLS regression used to examine the intra-regional difference in nighttime lights is

$$ln(light_{it}) = \alpha + \beta \mathbf{D}_i s_t + \mu_i + \delta_t + \varepsilon_{it} \qquad (1)$$

where $light_{it}$ is the average light value of each grid cell i in year t plus a small constant, 0.01. The light values are coded zero for a larger number of cells. As the literature points out zero likely implies very low levels of light and does not necessarily imply that there is no human activity. Hence the general practice has been to add a small number, which also deals with observations being dropped when taking logs. $\mathbf{D_i}$ = $\{D_i^1, D_i^2, D_i^3, \ldots\}$ is the set of dummy variables identifying grid cell characteristics. Based on the specifications, $\mathbf{D_i}$ can include dummy variables that equal 1 if the grid cell is in an urban area, a capital city, a manufacturing city, a port area, a mining area, or within 10 km of the Chinese border. In certain specifications $\mathbf{D_i}$ will be the log distance between grid cell i to the province capital, or a set of dummy variables indicating certain distances from the city center. Six different satellites collected the nighttime lights data. The year fixed effects δ_t control for unobserved satellite characteristics as well as unobserved annual patterns in the data. The grid cell fixed effects μ_i control for time invariant location specific factors. Lastly, s_t denotes the sanctions index. The coefficient of interest is β. If the nighttime light difference between a specified region and the rest increases when sanctions increase, we would expect β to be positive. Standard errors are clustered by the county equivalent administrative region to account for correlations between grid cells within region and across time.

Economic sanctions on North Korea were imposed based on North Korea's nuclear and weapons pursuit, which was driven by North Korea's Juche, i.e., self-reliance, ideology. The international relations context that altered the intensity of sanctions seem exogenous to the domestic regional variation in nighttime lights. Nonetheless, there may be concerns of endogeneity. Some may worry that the pursuit of nuclear weapons itself could trigger regional inequality. To further alleviate such concerns, I use the share of the US House Foreign Affairs Committee (US HFAC) members that have the same party affiliation as the president to instrument for the sanctions index and present both OLS and 2SLS estimates in the empirical analysis. The US House Foreign Affairs Committee oversees legislation and performs oversight on issues related to sanctions. This member share can change when members win or loss local elections, retire, or become ill. These events are most certainly unrelated to North Korea's nuclear program. However, a larger member share in the president's party may better influence the US government, e.g., the Senate and House of Representatives, or the Treasury, the UN, and the US allies to levy and implement sanctions against North Korea. Figure 9 plots how the two variables evolve over time and figure 10 plots the scatterplot of the two variables. The president party share fluctuates over time but exhibits a U-shaped pattern. The scatterplot reveals positive and strong correlation between the two variables. The 2SLS procedure instruments the set of $\mathbf{D_i}\, s_t$ in equation (1) with the corresponding set of $\mathbf{D_i}\, z_t$, where z_t is the share of the US House Foreign Affairs Committee members with the same party affiliation as the president in year t. The sanctions index s_t and the share variable z_t vary by time only and the D_i's by location only. This implies that the first stage which regresses each variable in $\mathbf{D_i}\, s_t$ on the set of $\mathbf{D_i}\, z_t$, controlling for grid cell i and time t fixed effects, effectively becomes a regression of s_t on z_t controlling for the grid cell fixed effects, i.e., the regression,

$$s_t = \gamma z_t + \mu_i + u_{it} \,. \qquad (2)$$

To see this more clearly, suppose the endogenous variables are $\{D_i^{capital} s_t,\, D_i^{port} s_t,\, D_i^{mining} s_t\}$ in equation (1) and the instruments $\{D_i^{capital} z_t,\, D_i^{port} z_t,\, D_i^{mining} z_t\}$. Then one of the first stage regressions is

$$D_i^{capital} s_t = \alpha + \beta_1 D_i^{capital} z_t + \beta_2 D_i^{port} z_t + \beta_3 D_i^{mining} z_t + \mu_i + \delta_t + \varepsilon_{it}.$$

β_1 is identified only when $D_i^{capital}$ is not zero, i.e, the grid cell lies in the capital city, and in such cases the first stage regression reduces to equation (2) because of collinearity. The first stage regression for each $\mathbf{D_i}$ s_t is effectively the same, and hence I report one first stage F-statistic in the empirical results. Since the variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at the other levels. Same as with the OLS estimates in equation (1), the second stage of the 2SLS regression is clustered at the county level to account for correlations between grid cells within region and across time.[6]

5. Main Results

5.1 OLS Estimates

I first report the OLS estimates in Table 3. Column (1) reports the bivariate relation between the sanctions index and nighttime lights, controlling for grid cell fixed effects. The estimate is very close to zero and statistically insignificant. The remaining columns examine the regional variations by reporting different versions of equation (1). Columns (2) and (3) explore the regional favoritism channel. Column (2) compares the differential impact of sanctions on urban areas relative to non-urban areas. Though the coefficient estimate on the urban dummy interacted with the sanctions index is positive, it is statistically insignificant. In column (3), I include the interaction terms for the national capital, Pyongyang, and the province capitals. If the dictatorship redirects resources to where it resides and to places it deems politically important when sanctioned, one would expect to see a positive estimate. The estimate on the urban interaction term is essentially zero, but the estimates on the other two interaction terms are positive and statistically significant. The estimates imply that an additional sanctions index increases the difference in nighttime lights between Pyongyang and the rest of the country by about 2.8 percent. The differential impact for provincial capitals is smaller at 1.65 percent and is statistically significant at the 10 percent level. These findings are consistent with the literature's finding that autocrats preferentially favor home regions and further shows that sanctions exacerbate regional favoritism.

Column (4) examines the industrialization hypothesis. I include interactions terms that represent two mutually exclusive manufacturing regions – North Korean cities with large manufacturing presence and Kaesong, the joint industrial park with South Korea - to equation (1). Unlike the other manufacturing cities, production at the Kaesong Industrial Park relies on the South Korean cooperation and hence belligerent behavior by North Korea often resulted in temporary shutdowns. The estimates imply that the difference in nighttime lights between manufacturing cities and non-manufacturing regions increase with sanctions, but decreases between Kaesong and the rest of the country. Relatively more resources are diverted to manufacturing regions controlled by North Korea when sanctions increase. This potentially

[6] The 2SLS estimates can also be estimated by using the predicted $\widehat{s_t}$ in equation (1) and cluster bootstrapping standard errors at the county equivalent level in the second stage. The bootstrapping method returns nearly identical results as the one-step 2SLS estimation.

suggests that isolation from international trade might be promoting industrial policies and import substitution.

Alternatively, sanctions could push countries to rely more on its natural resource endowments by inhibiting access to international capital and intermediate goods. Mineral exports and mining plays an important role in North Korea's economy. I additionally examine how nighttime lights change in mining areas, i.e., regions with mineral deposits or mines, with sanctions in column (5). Mining areas become relatively brighter when sanctioned and the estimates on the manufacturing cities are unaffected by the inclusion of the mining interaction term.

I next examine whether sanctions affect the regional distribution of nighttime lights in ways consistent with North Korea's increasing reliance on China for trade. If sanctions reduce the relative trade friction with China, then regions with the lowest trade cost to China, that is, places closer to China will likely see a relative increase in economic activity. In column (6), I examine how nighttime lights in areas within 10km of the Chinese border and Sinuiju, the main trade hub with China, respond relative to the rest of the country with sanctions. An additional sanctions event significantly increases the difference in nighttime lights between the border region and the rest of the country, and the magnitude of the effect is particularly strong for Sinuiju. In column (7) I additionally examine whether the increase in lights near China is accompanied by a relative reduction in nighttime lights at traditional trading ports. Given that all port cities are major manufacturing cities I examine how the port areas defined by the areas within 2km of the shore within each port city respond relative to the overall port cities. The estimate is negative but statistically insignificant.

Finally in column (8), I pool all three potential channels in one regression. I drop the urban dummy interaction term as the estimate is always close to zero and insignificant, and the port city interaction term since manufacturing cities nest port cities. The estimates are similar to the previous columns, except for that of the province capital interaction term, which becomes small and statistically insignificant.

5.2 2SLS Estimates

Table 4 column (1) examines the underlying first-stage regression that corresponds to equation (2). There is a strong positive correlation between the instrument and the sanctions index. The first-stage Kleibergen-Paap F-statistic is above 19. As column (1) and Figures 9 and 10 show, it is very unlikely that the 2SLS estimates are biased by weak instruments. In terms of magnitude, a one percentage point increase in the share of US HFAC members in the president's party is approximately related to one additional sanction event. Column (2) reports the 2SLS estimates on the affect of sanctions on average lights controlling for grid cell fixed effects. The magnitude is negative and substantially larger than the

OLS estimate at -0.002, but is not statistically significant. The remaining columns examine the 2SLS estimates of equation (1). Columns (3) and (4) examine the regional favoritism channel. As in the OLS estimates the urban dummy interaction term is close to zero and statistically insignificant, while the Pyongyang interaction term and province capital interaction terms are positive and significant. Compared to the OLS results the estimate on the Pyongyang interaction term is substantially larger. Similarly, in the remaining columns that examine the industrialization and economic geography channels, the 2SLS estimates are larger in magnitude compared to the OLS estimates and are statistically significant. The 2SLS estimates on the port area interaction dummy is now negative and statistically significant.

Focusing on column (9), the 2SLS estimates imply that an additional sanction on North Korea causes the difference in nighttime lights between the national capital, Pyongyang, and the rest of the country to increase by 5.8 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 an additional sanctions event increases the GDP gap between Pyongyang and the rest of the country by about 1.7%. When sanctions increase, the autocrat diverts resources to the capital and the difference in economic output between the two regions increase. Manufacturing cities become relatively brighter by 1.3 percent and Kaesong relatively darker by 6.7 percent. Sanctions dramatically increase mining activities. Nighttime lights in mining regions become relatively brighter by 4 percent. Finally, areas along the Chinese border become relatively brighter by 2.4 percent and Sinuiju an additional 8.4 percent. On the other hand, port areas become darker by 3.15 percent relative to the rest of the city. As sanctions increasingly isolate the autocratic country, economic resources are diverted (1) to the center of power and the dictator's hometown, i.e., Pyongyang, (2) to manufacturing cities and mining areas, and (3) to areas near China, North Korea's main trading partner and the country that did not impose the sanctions.

The finding that Pyongyang is shielded from sanctions echoes the literature that finds evidence of regional favoritism in many other non-democracies. Also, the increasing lights along the Chinese border and decreasing lights in Kaesong, reflect how sanctions change the relative trade costs with different countries and eventually affect the geographic location of economic activity. This result is similar to Hanson and Krugman's (1993) finding of Mexican firm's moving to the US border when trade cost with the US declined after the Mexico-US trade agreement.

However, the relative increase in nighttime lights in manufacturing cities and mining areas posits the question whether such shift is toward import substitution and domestic industrial development or towards the reliance on mining resources for production and exports. These have significantly different implications for development. Industrialization, and particularly industrial upgrading is a fundamental process of economic development. For instance, the shifting of manufacturing from labor intensive to capital intensive industries and then to high-tech industries is how many countries have developed their industries. On the other hand, reliance on natural resources as a source of wealth is often associated with negative development consequences, e.g., the Dutch disease. Hence, understanding whether the isolation from sanctions actually promoted industrial upgrading and self-sufficiency or triggered the target country to rely more on domestic natural resources is important. I explore this further in Section 6 with the trade data. But first, I will examine the robustness of the main results and whether alternative hypotheses, such as, China's economic growth, the rise in world mineral prices, and internal migration, can explain what I find in Tables 3 and 4.

5.3 Robustness of the main results

In this section, I examine the robustness of the both the OLS and 2SLS estimates. One concern may be that the baseline specification does not capture the underlying persistence of nighttime lights in each location. I model the dynamics of nighttime lights in columns (1) and (2) of Table 5 by additionally controlling for one-year lagged lights. The inclusion of lagged lights slightly reduces the magnitudes of the OLS and 2SLS estimates but have similar patterns and statistical significance as before. The first-stage statistic also remains quite strong in the 2SLS regression. The inclusion of the lagged dependent variable in a fixed effects regression introduces bias but in panels where time dimension is large the bias becomes relatively small (Nikell 1981, Nunn and Qian 2014). In columns (3) and (4), I include county specific time trends to the fixed effects specifications. The county specific time trends capture unobserved county characteristics that change over time in a linear fashion. Despite the inclusion of the time trends both the OLS and 2SLS estimates remain similar to that from previous tables. In the next two columns, I exclude grid cells that were unlit across all years. About 87% of the grid cells are never lit. As previously discussed, unlit may imply that lights were too low to be detected by the satellites or that the area was truly uninhabited. Excluding unlit areas generally increases the magnitude of the estimates. The 2SLS estimates in column (6) indicate that lit areas within 10km of the Chinese border become substantially brighter relative to the other lit areas. Since there may be a time lag in how the autocrat responds to sanctions, I use the previous year sanctions index in columns (7) and (8). The estimates are similar to the base specification and show same statistical significance. Finally, in the remaining columns, I replace the sanctions index with a less aggregated sanctions index and a more aggregated sanctions index as previously described in Section 3. The results exhibit qualitatively similar patterns as before regardless of which sanctions index I use.[7]

[7] In Appendix Table 2 columns (1) through (6), I examine the effect of sanctions by country. I construct each country's sanctions index as the cumulative sum of the number of sanction events imposed by the each country every year, with the base year in 1992 normalized to zero. The first stage of the 2SLS estimates show that the first

5.4 Alternative hypothesis 1 – China's economic growth

China's economic growth during this period raises the concern that the relative increase in North Korea's nighttime lights near the Chinese border and mining areas may have been driven by China's increasing supply of manufactured goods and demand for North Korean mineral products, rather than externally imposed sanctions. In Table 6, I split the sample years and separately examine the first half when sanctions were decreasing in columns (1) and (2), and the latter half when sanctions were increasing in columns (3) and (4). Note that China's economy was increasing throughout the whole period. If China's economic growth were driving the overall results in the previous tables, one would expect to see zero or opposite effects during the periods when sanctions were decreasing. However, both the OLS and 2SLS estimates oin columns (1) and (2) show that this is not the case. For instance, the coefficient estimate on the mining area interaction terms is very similar to that from the main results in Tables 1 and 2, and is statistically significant at the 1 percent level. Since this is a period when sanctions were decreasing the estimates imply that mining regions were becoming relatively darker compared to the rest of the country. Also, the estimates on the Chinese border region interaction term and Sinuiju interaction terms are positive and statistically significant. Again this implies that during the period when sanctions were decreasing these areas became darker compared to the rest of the country. The estimates on the other interaction terms are similar to the main results both qualitatively and in terms of statistical significance. Given that China was consistently growing at a rapid rate during this period it seems unlikely that China's rise is driving the sanctions result. The post-2003 period estimates, and especially the 2SLS estimates in column (4), are also similar to the previous results as well as the pre-2004 period estimates. The fact that the estimates are similar regardless of whether sanctions were decreasing or increasing over the long run further confirms that sanctions, not China's economic growth, was not driving the regional distribution of nighttime lights in North Korea.

In columns (5) and (6), I exclude all grid cells within 10kms of the Chinese and South Korean border. By excluding these regions I focus on the part of North Korea that is less likely to be impacted by any economic spill over from China as well as from light blooming across borders. Naturally, the Chinese border interaction term and Sinuiju interaction terms drop. Focusing on the 2SLS estimates, they are again very similar to the estimates from the full sample in Table 3.

As an additional robustness test, I examine how North Korean sanctions impact urban-rural inequality within Chinese provinces and counties that border North Korea in Table 7. I find that sanctions on North Korea have no significant impact on the urban-rural inequality in China. The results are robust

stage is strongest for US sanctions and South Korea sanctions, but not the UN sanctions. In general, the 2SLS results are qualitatively similar from that of the main sanctions index.

to when I split the sample periods in columns (3) through (6). Examining China also alleviates the concern that the satellite sensors might be picking up urban and rural lights differentially in a consistent manner that might be correlated with the sanctions. Despite the strong influence China has on North Korea's economy, China's growth is not driving the regional dynamics of nighttime lights that sanctions cause in North Korea.

5.5 Alternative hypothesis 2: North Korea's nuclear program.

North Korea's nuclear weapons development was the main driving force behind the fluctuation in North Korean sanctions. When North Korea agreed to halt it's nuclear weapons development program sanctions relaxed. When it was revealed that it was still enriching uranium and resumed weapons tests sanctions increased. One may be concerned that the development of nuclear weapons and the resources that goes into it may directly influence the dynamics of regional inequality, especially the relative increase in lights in manufacturing and mining areas. North Korea does have uranium deposits and use domestic minerals for their nuclear weapons development. However, if resources were being diverted to develop nuclear weapons there does not seem to be any apparent reason that the capital city Pyongyang or areas near the Chinese border should become relatively brighter. In columns (7) and (8) of Table 6, I additionally control for two regions that were directly related to North Korea's nuclear program. One is Yongbyun the primary site of North Korea's nuclear development program. North Korea's research and development for nuclear weapons as well as uranium enrichment have been conducted on this site. Another is Kumho, where the light water reactors were being built by South Korea and the US to replace North Korea's existing nuclear program. Enrichment of fissile material is substantially more difficult with a light water reactor and the reactor in Kumho was offered by the US, South Korea, and partner countries as an alternative to shutting down Yongbyun. Though the coefficient estimate on the Yongbyun interaction term is small and insignificant, the estimate on Kumho is negative and statistically significant. However, controlling for both nuclear sites does little to alter the 2SLS estimates. Since the nighttime lights in these regions would be highly correlated with the dynamics of North Korea's nuclear weapons policy, the fact that the original estimates change little imply that the regional redistribution of lights were unlikely driven by North Korea's nuclear program.[8]

[8] I also examined areas with major military base presence. I collected information on the location of all army corps, and major air force and navy bases in North Korea and generated a dummy variable equal to one if a county or city contains any one of these corps or bases. Appendix Figure 1 presents the location of the bases. I find that the sanctions index have no effect on the nighttime lights of military regions. Results are presented in columns (7) and (8) of Appendix Table 2. The non-effect should take into consideration that I am unable to identify military base regions at a finer geography other than the country or city. Furthermore, military base areas may intentionally restrict the emission of nighttime lights for strategic purposes.

5.6 Alternative hypothesis 3: World mineral prices

North Korea's main exports are minerals, primarily coal and iron ore, and the world price of these minerals could have affected North Korea's mining and trade. Appendix 2 illustrates how coal and iron ore prices have fluctuated during this period.[9] In Table 8 columns (1) and (2), I include the set of region dummies interacted with the world coal price to the base regression framework. Column (1) presents the OLS estimates and column (2) the 2SLS estimates. The OLS estimates on the region dummies interacted with the sanctions index are qualitatively similar to that of the base regression in Table 3 column (8). However, the OLS estimate on *mining area*sanctions index* is reduced by almost 50% and is no longer statistically significant at the 10 percent level. On the other hand, the coefficient estimate on *mining area*ln(coal price)* is large and significant at the 5 percent level. It is reassuring to find that there is strong correlation between coal prices and nighttime lights in mining areas. However, when we focus on the 2SLS estimates in column (2), the effect of sanctions on mining regions remains significant and even stronger when coal prices are controlled for. In columns (3) and (4), I control for iron ore prices. The OLS estimates in column (3) indicate that nighttime lights in Sinuiju are significantly correlated with world iron ore prices, more so than the sanctions index. However, the 2SLS results in column (4) again show that the effect of sanctions on regional inequality carries through. Overall, table 8 indicates that coal and iron ore prices are associated with relatively less lights in Pyongyang but more lights in Kaesong and Sinuiju. However, the effects sanctions have on the regional distribution of lights are qualitatively similar to the base results in Table 3 and 4, even when world coal or iron prices are controlled for.

5.7 Alternative hypothesis 4: Internal migration

Another alternative explanation of the nighttime results could be that people voluntarily migrated to cities with better economic prospects when sanctioned, rather than that the autocrat centrally reallocated resources across regions. The rural population in developing countries often migrate to urban areas to take advantage of job opportunities and public goods, and the increasing luminosity gap across regions could be a reflection of internal migration when sanctions increase. However, migration is unlikely to be the driving force in North Korea. First, voluntary migration is restricted in North Korea. Technically, households can only move when the communist party orders them to move. People could bribe officials to purchase urban residential permits but this applies only to the relatively few well off with party connections. Furthermore, if deteriorating economic conditions motivate people to move to urban areas then land squatting and urban slums would be prevalent around cities. Unlike most

[9] World coal prices is based on the Australian coal prices in US dollars per metric ton and world iron prices are based on Chinese iron ore import prices in US dollars per metric ton. Both are adjusted with North Korea's GDP deflator. The price information comes from the IMF commodity price data.

developing countries urban slums are unseen and unheard of in North Korea. The nighttime lights data can be useful in empirically examining this issue. If migration and slums were driving the results, given that central city migration is strictly limited, migrants would settle in the periphery of the city and nighttime lights would increase relatively more around the urban periphery. In Table 9, I examine how sanctions affect the distribution of nighttime lights *within* urban areas. I first examine the relation between nighttime lights and distance to the center of province capitals. The 2SLS estimate in column (2) indicates that the elasticity of nighttime lights relative to distance to the city center decreases by 0.009 with an additional sanction. This implies that when sanctions increase, nighttime lights decrease at a faster rate as one moves away from the city center. Columns (3) and (4) further examine the impact of sanctions around cities. For Pyongyang and each province capital I draw 5, 10, and 25km circles from the city center. I then examine how the impact of sanctions on these areas differs relative to areas outside the 25 km ring. The luminosity "premium" of being in cities as sanctions increase is 4.3 percent for areas within 5 km of the city center and 3.2 percent for areas in between 5 and 10 km. However, there is no difference for areas between 10 and 25 km of the city center. These results indicate that sanctions cause nighttime lights to disproportionately increase in the urban core. Internal migration and urban slums are not the cause of the urban concentration of lights.

6. Industrial upgrading or reliance on natural resources? Evidence from the trade data

In this section, I further probe into whether the relative increase in nighttime lights in manufacturing and mining areas imply import substitution and industrial upgrading or more reliance on natural resources for production. To probe into this, I examine how sanctions impact product level exports and imports by factor intensity. Before examining the impact of sanctions on the composition of North Korea's product trade, I first examine how sanctions affected North Korea's aggregate and bilateral trade patterns. In Table 10, I examine aggregate trade volume, number of trade partners, and number of commodities. I examine exports in Panel A and imports in Panel B. As before I report both OLS and 2SLS estimates. Since these are aggregate time series regression, Newey-West standard errors are reported to account for serial correlation. In column (1) the OLS estimates on aggregate exports and imports are both small and statistically insignificant. However, the 2SLS estimates in column (2) are both negative, larger in magnitude, and for imports statistically significant at the 5 percent level. The impact of sanctions on the log number trade partners is negative for both exports and imports and the 2SLS estimates are statistically significant at the 10 percent level. The last two columns indicate that sanctions significantly reduce the number of traded products. The 2SLS estimates in column (6) imply that an additional sanction reduces the number of products that North Korea exports by 3.8 percent and imports by 3.2 percent. Given that there are only 22 observations this is a surprisingly strong result and indicates that the patterns observed in Figures 3 and 4 hold econometrically.

Another pattern that was examined in the descriptive study was the drastic increase in North Korea's trade with China when sanctions were increasing. In Table 11, I examine whether sanctions triggered the differential increase in trade with China. Despite UN Security Council resolution, China did not enforce sanctions against North Korea. Because of China's non-enforcement, North Korea's trade cost with China saw a relative decline, which would likely result in increased trade with China. This is born out econometrically in Table 11. Columns (1) and (2) present OLS and 2SLS results of the regression of log exports or imports on the sanctions index interacted with China, while controlling for year fixed effects, trading country fixed effects, and the log of the trading country's GDP. The control variables were included based on a simple gravity equation framework - the year fixed effects capture unobserved annual North Korea demand or export capability, the partner country fixed effect controls for time fixed bilateral resistance terms, such as distance, language, etc., and the partner country GDP proxies for the partner country's time varying demand or export capability. The OLS and 2SLS estimates on the China interaction terms are all positive for both exports and imports and statistically significant at the one percent level. Focusing on column (2), the estimates imply that an additional sanctions event increases exports to China relative to the rest of the world by 11 percent and imports from China by 7 percent. The 2SLS estimates for the log number of commodities traded in column (4) are also positive and statistically significant. Tables 10 and 11 indicate that sanctions decreased North Korea trade at the aggregate level, but relatively increased trade with China.

Finally, in Table 12 I examine how sanctions caused North Korea to shift exports and imports in the product space based on the capital intensity, human capital intensity, and natural resource intensity of the product. In practice, I run the following regression,

$$ln(Y_{pct}) = \alpha + \beta_1 lncap_p s_t + \beta_2 lnhum_p s_t + \beta_3 lnnat_p s_t + \mu_p + \delta_t + \theta_{ct} + \varepsilon_{pct} \qquad (3)$$

where Y_{pct} is the export or import value of product p from country c in year t, and s_t is the sanctions index. $lncap_p$ is the natural logarithm of the capital intensity measure of product p measured in the initial year 1992, $lnhum_p$ is the logarithm of the human capital intensity measure, and $lnnat_p$ the logarithm of the natural resource intensity measure. For the factor intensity measures I use the revealed factor intensity indices constructed by UNCTAD (Shirotori et al. 2010). The indices were constructed as a weighted average of the factor abundance of countries that export each product, where a variant of the Balassa's Revealed Comparative Advantage indices were used as the weights. The HS 6-digit level is most disaggregated product classification for which the revealed factor intensity indices were constructed, and I run equation (3) at that level.

Table 12 Panel A presents the OLS and 2SLS results on North Korea's exports. As before, in the 2SLS regression the interaction terms with the sanctions index are instrumented with the interaction terms with the majority party share in the US House Foreign Affairs Committee. I examine all trade partners in columns (1) and (2). The OLS and 2SLS estimates are quite similar. Focusing on the 2SLS estimates, sanctions cause North Korea to reduce exports of capital intensive products by 2.9 percent but increase exports of human capital intensive products by 4.7 percent and natural resource intensive products by 1.1 percent. The estimates are all statistically significant. If the isolation from sanctions trigger countries to pursue industrial development policies, then one would expect to see an increase in the production and export of capital intensive goods. However, the estimates show the contrary, and rather an increased reliance on natural resource intensive goods for exports. The increase in nighttime lights in mining areas in the previous section reflects this change. Furthermore, the relative increase in nighttime lights in manufacturing cities more likely reflects mining related production rather than the production of capital intensive goods. The shift to natural resource intensive goods potentially implies industrial downgrading. In light of this result, the Russian official's claim that sanctions could incentivize domestic industrial development may not span out as expected.

Again North Korea's reliance on China for trade and China's world wide demand for mineral goods raise the concern that these results may be driven by China. In columns (3) and (4) I examine product trade with China and in columns (5) and (6) trade with the rest of the world. The estimates for exports to China are all statistically insignificant. Sanctions did not cause any differential change in North Korea's export patterns to China and is not confounded by China's appetite for mineral goods. Furthermore, these results may also support the fact that China did not enforce sanctions on North Korea. However, the main results directly carry over to the rest of the world.

One could argue that the decrease in the export of capital intensive goods from sanctions may not necessarily imply the decrease in the domestic production of such goods. However, the import results in Panel B column (2) indicate that sanctions cause North Korea to increase imports of capital intensive goods as well. Sanctions are indeed inhibiting the production of capital intensive goods and North Korea is meeting its demand by importing more. In terms of natural resource intensive products, North Korea is importing less as sanctions increase, which may be a reflection of its increased domestic production and exports. When I separately examine China in column (4), the estimates on the capital intensive products and natural resource intensive products are not statistically significant. However, sanctions do cause the import of human resource intensive goods from China to decrease, which could be a reflection of North Korea's reliance on another endowment less impacted by sanctions, i.e., human capital. As before, the main results on imports hold for the rest of the world in the last two columns.

This section shows that sanctions cause exports to shift away from capital intensive goods and towards natural resource intensive goods. Furthermore, sanctions increase the imports of capital intensive goods. This shows that sanctions did not result in industrial upgrading to capital intensive goods, but rather shifted industrial production towards natural resource intensive goods, potentially pushing the country backwards along the industrial development spectrum. Given that modern sanctions not only target final goods, but intermediate goods, and financial flows, the argument that sanctions could incentivize a country to promote industrial development seems unsupported.

7. Conclusion

Global trade has increased at an unprecedented rate since the 1990s. At the same time, countries have increasingly used economic sanctions to punish other countries and isolate them from the gains from trade. This paper examined how domestic economic activity and regional inequality evolve when a country becomes increasingly isolated from international trade and finance because of sanctions.

Using nighttime lights to examine the North Korean case, I find that Pyongyang, the center of power, is well shielded from sanctions. Lights near the Chinese border increases with sanctions as well as trade with China, which did not enforce the sanctions. On the other hand, traditional port areas become darker. Manufacturing cities and mining areas also become relatively brighter as sanctions increase. However, investigation of the trade data reveals that production shifts away from capital intensive goods to natural resource intensive goods. In short, as the country becomes more isolated economic activity shifts towards the capital city, trade hubs with China, and regions with mining related industries. The divergence in nighttime lights in an autocratic country where labor is immobile implies that people in the hinterlands are literally being left in the dark, while the elites with political power, trade or mining connections shield themselves from the negative impact of sanctions.

Despite the intention to change the behavior of autocrats, sanctions increase inequality at a cost to the already marginalized hinterlands. Sanctions will likely be inefficient in autocracies as long as countries like North Korea can maintain centralized control and oppress any discontent that arises due to the increasing inequality. Furthermore, North Korea's increasing reliance on China for trade suggests that the efficacy of sanctions also depend on how easily trade can be diverted to non-sanctioning countries. The main findings of this paper present a dilemma. One could imagine an extremely stringent sanction that cuts all flows of energy, goods, and capital into the target country. Furthermore, suppose that all nations enforce the sanctions so that the target country could not divert trade. Such sanctions could hypothetically reach its goal and force the autocrat to eventually concede. However, this paper finds that in autocracies the marginalized population could suffer more from such sanctions rather than the elites.

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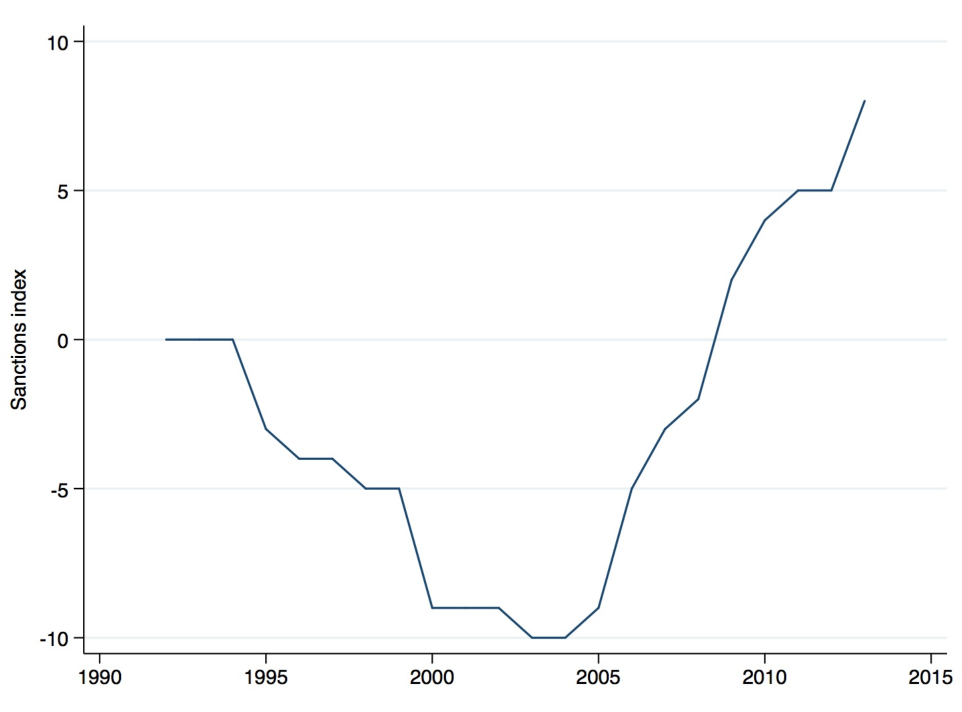
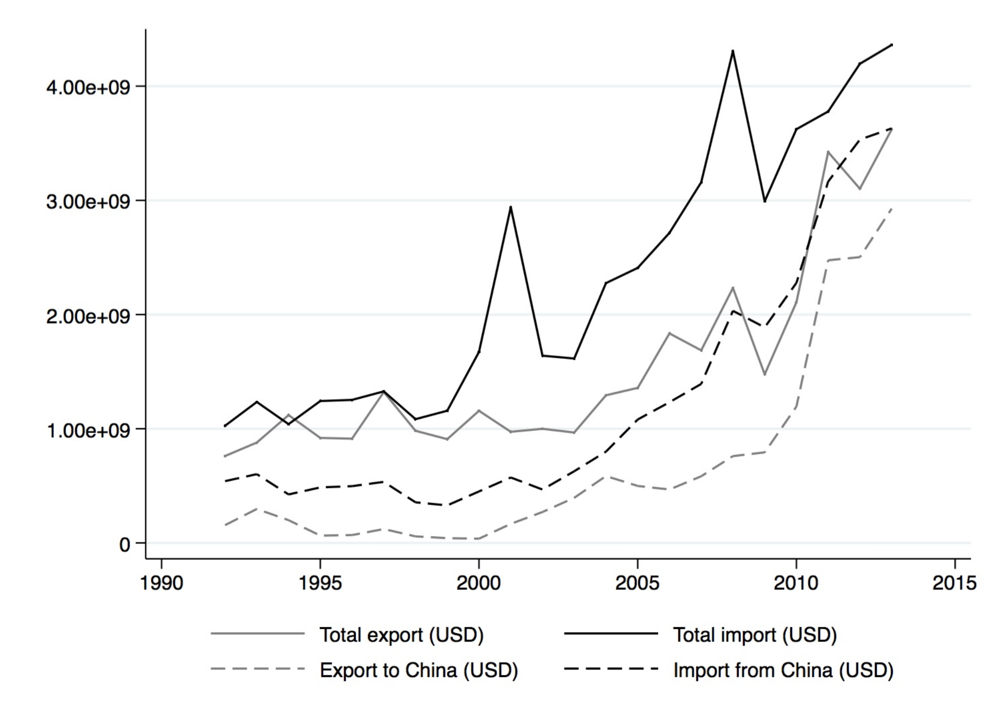
Figure 1. Evolution of the sanctions index



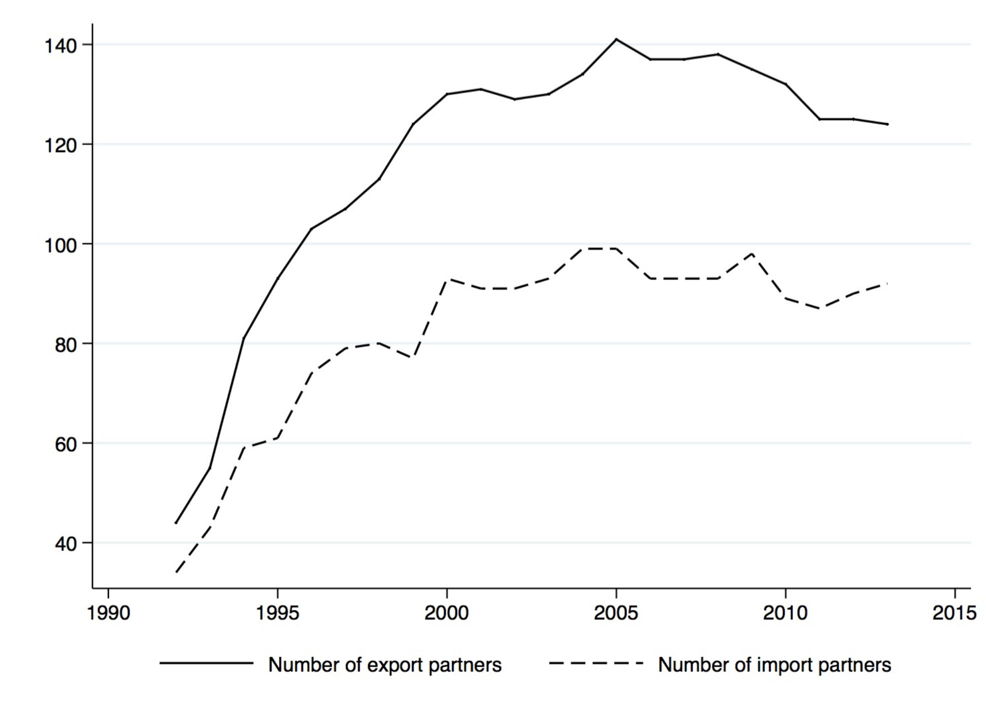
Notes: The main sanctions index is the cumulative sum of the number of sanction events each year, with the base year in 1992 normalized to zero. An event related to the easing of any of the four types (trade, finance, aid or remittance, and travel) of sanctions is coded as -1 and a tightening of sanctions is coded as +1. Table 1 summarizes the main events that affected the intensity of sanctions against North Korea between 1992 and 2013.

Figure 2. North Korea trade over time



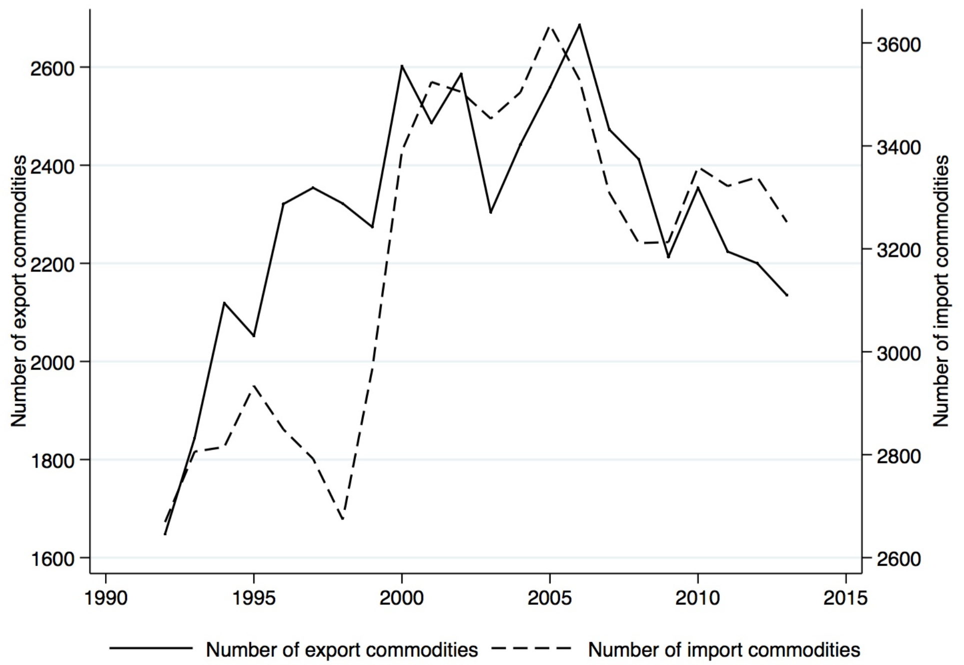
Notes: The solid black line represents North Korea's annual exports and the solid grey line annual imports in current USD. The dashed lines represent exports and imports to China in current USD. The North Korea trade data is based on the UN Comtrade data and is constructed based on the partner countries' reported trade amounts with North Korea.

Figure 3. Trade partners over time



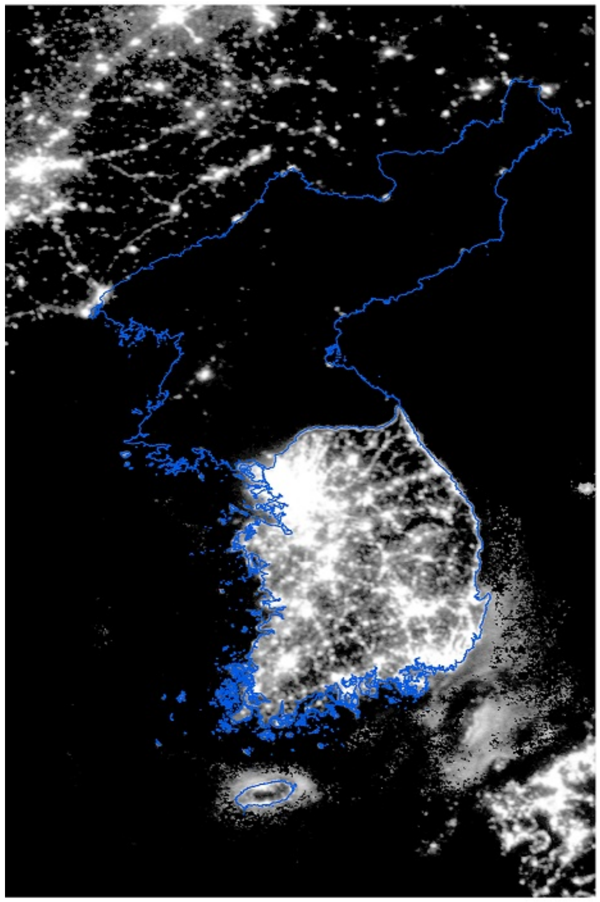
Notes: The solid line indicates the number of countries that North Korea exported to and the dashed line the number of countries that North Korea imported from. The numbers are based on the UN Comtrade data and are constructed based on the partner countries' reported trade with North Korea.

Figure 4. Number of products traded over time



Notes: The solid line indicates the number of different products that North Korea exported and the dashed line the number of different products that North Korea imported. Products are defined as HS level 6 commodities in the UN Comtrade data.

Figure 5. Satellite Image of the Korean Peninsula in 2010.



Notes: The above map covers the area between 123 and 131 degrees longitude, and 32 and 44 degrees latitude. The bright area in the middle of North Korea is the Pyongyang, the capital city, region.

Figure 6. Lights near Pyongyang in 1992, 2002, and 2012.

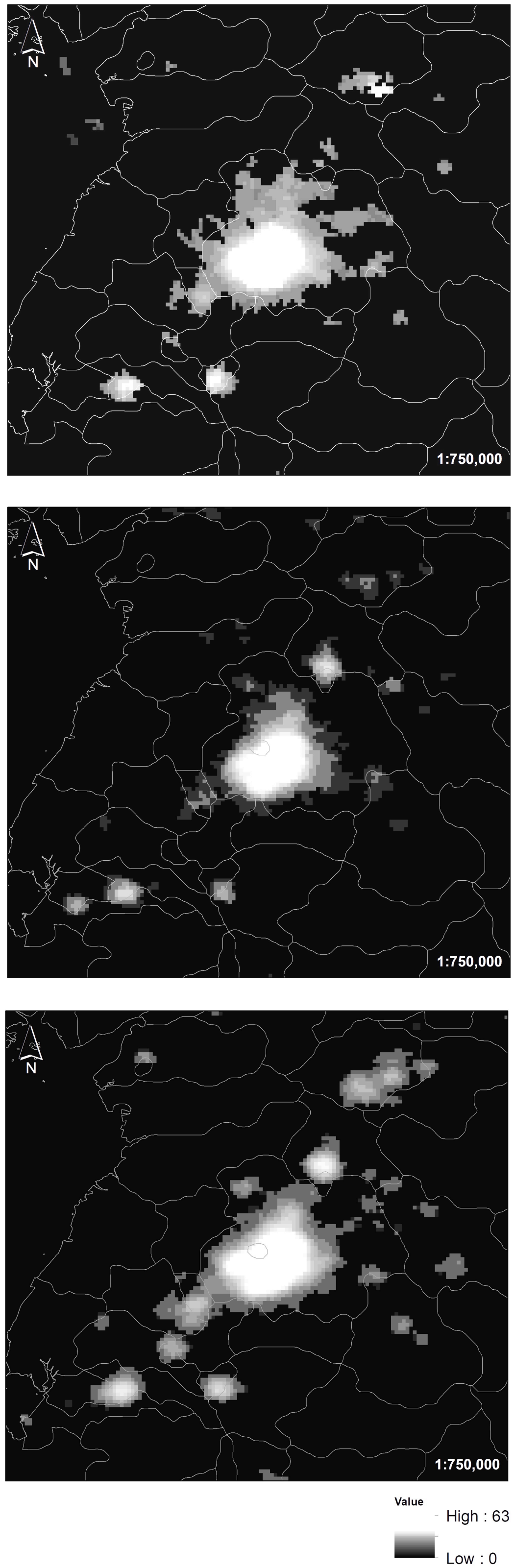
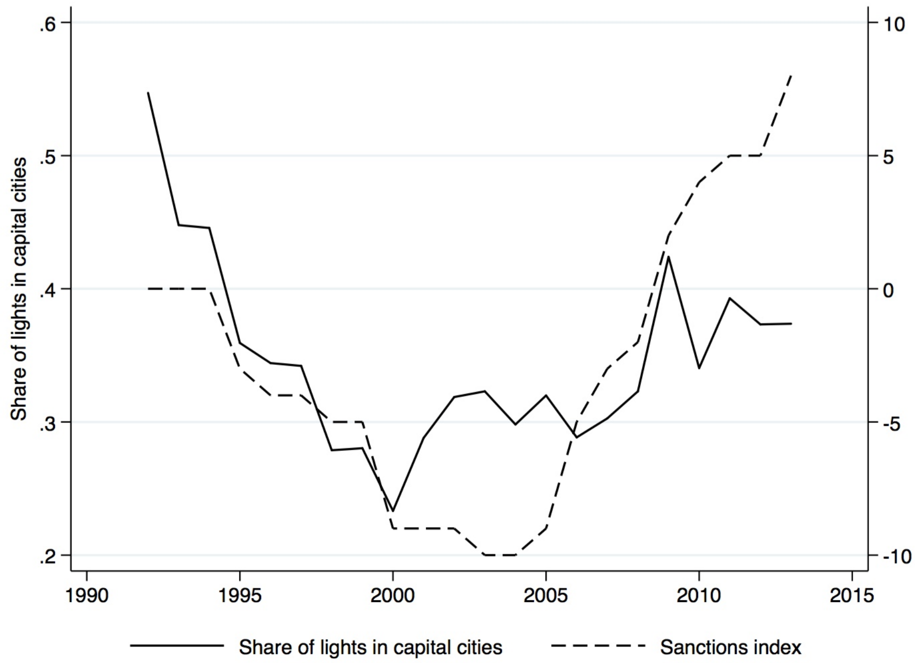
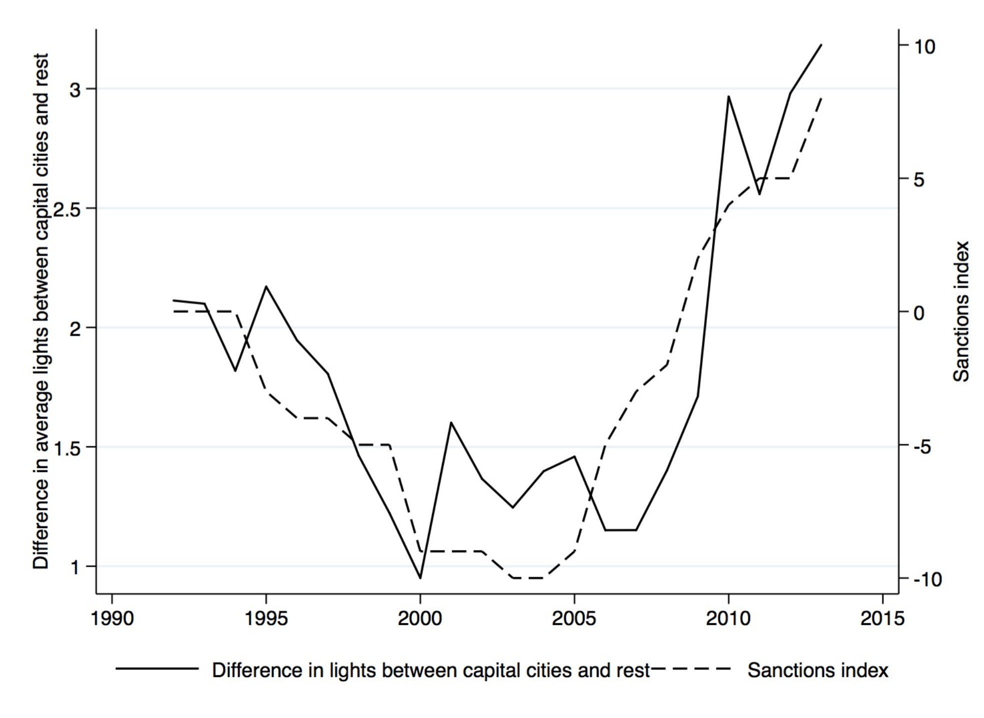


Figure 7. Share of lights in the capital cities and the sanctions index



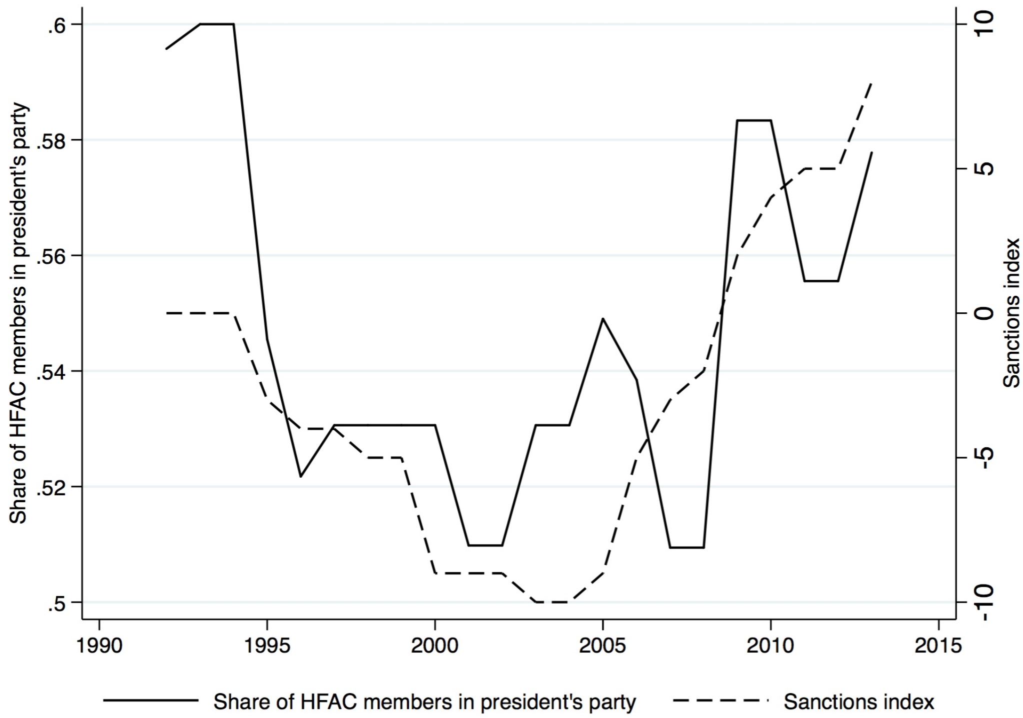
Notes: The solid line represents the sum of all lights (digital numbers) in Pyongyang and province capitals divided by total lights (digital numbers) in North Korea. The dashed line presents the sanctions index from Figure 1.

Figure 8. Difference in average nighttime lights between capital cities and rest of the country



Notes: The solid line is the difference in the average lights (digital numbers) between province capitals and the rest of the country. The dashed line presents the sanctions index from Figure 1.

Figure 9. Share of the US House Foreign Affairs Committee members with the same party affiliation as the president and the sanctions index



Notes: The solid line represents the share of committee members in the US House Foreign Affairs Committee that have the same party affiliation as the president. The dashed line presents the sanctions index from Figure 1.

Figure 10 Scatterplot of the sanctions index and the share of the US House Foreign Affairs Committee members with the same party affiliation as the president

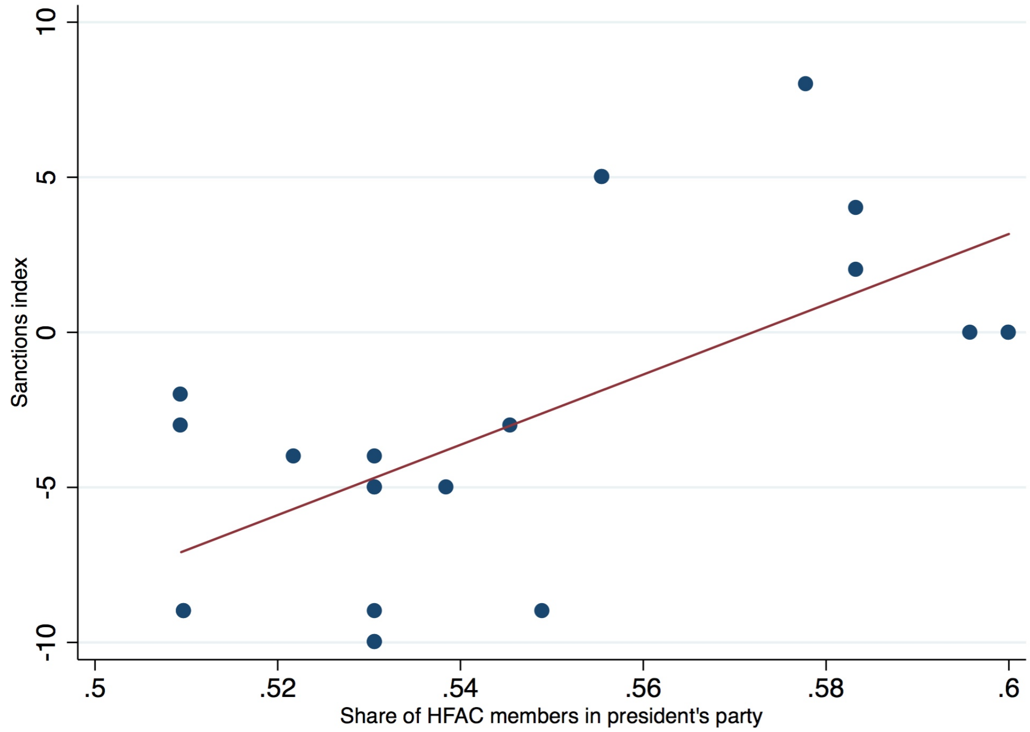


Table 1. Chronology of the sanctions on North Korea

Year	Sender	Content	Trade	Finance	Aid	Travel
1995	US	Multiple economic sanctions eased based on the 1994 Agreed framework. Light water reactor related trade, financial transactions, and travel allowed. Freeze on North Korean assets are relaxed.	-	-		-
1996	US	Humanitarian aid, donation, remittances allowed.			-	
1998	South Korea	South Koreans start travel into Kumkang Mountain.				-
2000	US	Further relaxation on trade, finance, travel, and aid based on President Clinton's 1999 anouncement.	-	-	-	-
2003	South Korea	South Korea invests in Kaesong Industrial Park.		-		
2005	US	North Korea announces end to its missile testing moratorium. Financial sanction imposed on North Korean entities. Banco Delta Asia is designated as institution of "money laundry concern" and Macau voluntarily freezes North Korean accounts.		+		
2006	UN	North Korea's first nuclear test. UN Security Council adopts Resolution 1718, 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 assets of US entities dealing with North Korean entities labeled as Weapons of Mass Destruction proliferator.		+		
2007	US	Impose license requirements for export to North Korea, and travel further regulated.	+			+
2008	South Korea	Terminates travel into Kumkang Mt. after a North Korean soldier shoots and kills one South Korean visitor.				+
2009	UN	North Korea's second nuclear test. UN Security Council adopts Resolution 1874, which further restricts North Korean activities on all dimensions.	+	+	+	+
2010	South Korea	Trade and investment sanctions after North Korea attacks South Korean navy vessel. North Korea attacks South Korean island in November	+	+		
2010	US	Block property of certain persons (US Executive Order 13551)		+		
2011	US	Prohibit additional transactions with North Korea and ensure import restrictions (US Executive Order13570)	+			
2013	UN	UN Security Council adopts Resolution 2094 after North Korea Launches satellite in late 2012. North Korea conducts 3rd nuclear test. UN Security Council adopts Resolution 2087. Increased travel and financial sanctions, including bulk cash.	+	+		+
	China	China shifts attitude toward North Korea and publishes list of sanctioned goods. Instructs local governments to implement the sanctions. Shut down accounts of North Korea Trade Banks	+	+		

Sources: National Committee on North Korea, UN Security Council Resolutions, Office of Foreign Assets Control of the US Department of the Treasury.

Table 2. Summary statistics

Variable	Mean	Std. Dev.	Min	Max	Obs
Panel A: Lights data					
Satellite night lights value	0.235	1.674	0	62.25	1052040
Dummy for ever lit	0.125	0.331	0	1	1052040
Sanction index	-2.864	5.251	-10	8	1052040
Pyongyang	0.009	0.096	0	1	1052040
Province capital	0.032	0.177	0	1	1052040
Manufacturing city	0.087	0.281	0	1	1052040
Mining area	0.008	0.089	0	1	1052040
Port area	0.005	0.071	0	1	1052040
Within 10 km of Chinese border	0.077	0.267	0	1	1052040
Distance to province capital	62.683	33.181	0.0003	182.61	1052040
Within 5 km of city center	0.006	0.079	0	1	1052040
Between 5-10 km of city center	0.017	0.128	0	1	1052040
Between 10-25 km of city center	0.103	0.304	0	1	1052040
Panel B: Trade data					
Annual exports (million USD)	1547.10	849.84	761.15	3621.30	22
Annual imports (million USD)	2320.22	1178.85	1026.25	4360.82	22
Annual number of exporting countries	116.73	26.65	44	141	22
Annual number of importing countries by year	82.18	17.91	34	99	22
Annual number of export commodities by year (HS6 level)	2300.46	246.08	1648	2686	22
Annual number of import commodities by year (HS6 level)	3184.09	311.14	2669	3635	22
Annual share of exports to China	0.32	0.24	0.03	0.81	22
Annual share of imports from China	0.47	0.18	0.20	0.84	22
Annual export by commodity (thousand USD)	176.62	5520.64	0.001	1388197	191903
Annual import by commodity (thousand USD)	326.15	5480.22	0.001	924401	153950
Human capital intensity by commodity	7.59	1.32	0.89	12.26	329942
Capital intensity by commodity	90330	32629	1380.69	209237	329942
Natural resource intensity by commodity	0.63	0.27	0.08	4.62	329942

Table 3. Main results - OLS

Dependent variable	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sanctions index	-0.000417							
	(0.00122)							
Regional Favoritism								
*Urban*Sanctions index*		0.00560	-0.000475					
		(0.00509)	(0.00657)					
Pyongyang Sanctions index*			0.0276***					0.0191***
			(0.00647)					(0.00436)
Province capital Sanctions index*			0.0165*					0.00644
			(0.00941)					(0.00674)
Industrialization								
Manufacturing city Sanctions index*				0.0147***	0.0141***			0.00987**
				(0.00428)	(0.00428)			(0.00449)
*Kaesong*Sanctions index*				-0.0402***	-0.0401***			-0.0389***
				(0.00121)	(0.00120)			(0.00124)
*Mining area*Sanctions index*					0.0266***			0.0269***
					(0.00942)			(0.00934)
Economic Geography								
*Within 10km of Chinese border*Sanctions index*						0.0140***	0.0140***	0.0142***
						(0.00380)	(0.00384)	(0.00367)
*Sinuiju*Sanctions index*						0.118***	0.118***	0.103***
						(0.00363)	(0.00368)	(0.00671)
*Port*Sanctions index*							-0.0166	-0.0168
							(0.0101)	(0.0109)
*Port city*Sanctions index*							0.0131*	
							(0.00677)	
R-squared	0.735	0.736	0.736	0.736	0.737	0.737	0.737	0.737
Year fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country time trends	No	No	No	No	No	No	No	No
Observations	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040

Notes: The sample covers all areas of North Korea from 1992 to 2013. Standard errors are clustered at the county level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 4. Main results – 2SLS

Dependent variable	Sanctions index	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Share of USHFAC members in president's party	113.3***								
	(25.89)								
Sanctions index		-0.00272							
		(0.00217)							
Regional Favoritism									
*Urban*Sanctions index*			0.00357	-0.00886					
			(0.00894)	(0.0103)					
*Pyongyang*Sanctions index*				0.0762***					0.0581***
				(0.0101)					(0.00524)
*Province capital*Sanctions index*				0.0281**					0.00982
				(0.0133)					(0.00934)
Industrialization									
*Manufacturing city*Sanctions index*					0.0220***	0.0211***			0.0126**
					(0.00741)	(0.00754)			(0.00558)
*Kaesong Industrial Region*Sanctions index*					-0.0690***	-0.0687***			-0.0670***
					(0.00222)	(0.00221)			(0.00233)
*Mining area*Sanctions index*						0.0391***			0.0403***
						(0.0118)			(0.0112)
Economic Geography									
*Within 10km of Chinese border*Sanctions index*							0.0209***	0.0209***	0.0214***
							(0.00512)	(0.00513)	(0.00497)
*Sinuiju*Sanctions index*							0.105***	0.105***	0.0840***
							(0.00463)	(0.00467)	(0.00920)
*Port*Sanctions index*								-0.0370***	-0.0315**
								(0.0124)	(0.0147)
*Port city*Sanctions index*								0.0233**	
								(0.0103)	
R-squared	0.416								
First stage F-statistic		19.135	19.135	19.135	19.135	19.135	19.135	19.135	19.135
Year fixed effects	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country time trends	No	No	No	No	No	No	No	No	No
Observations	1,052,040	1,052,040	1,052,041	1,052,042	1,052,043	1,052,044	1,052,045	1,052,046	1,052,040

Notes: The sample covers all areas of North Korea from 1992 to 2013. Kleibergen-Paap first-stage statistics are reported. Each first stage regression in each 2SLS regression returns the same first stage F-statistic. This is because each first stage regresses *sanctions index*region dummy* on *USHFAC member share*region dummy* and *USHFAC member share*other region dummies,* and effectively the other region interaction terms become irrelevant, i.e., return coefficient estimates of zero. Standard errors are clustered at the county level in the OLS regression and the second stage of the 2SLS regression. Since the variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 5. Robustness Checks

	Control for lagged lights		Control for county time trends		Exclude unlit grid cells		Use lagged sanctions index		More aggregated sanctions index		Less aggregated sanctions index	
Dependent variable: ln(lights)	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Regional Favoritism												
*Pyongyang*Sanctions index*	0.0137***	0.0400***	0.0434***	0.0485***	0.00334	0.0543**	0.0241***	0.0519***	0.0588***	0.130***	0.00418	0.0373***
	(0.00348)	(0.00419)	(0.00429)	(0.00500)	(0.0166)	(0.0214)	(0.00441)	(0.00612)	(0.0101)	(0.0117)	(0.00266)	(0.00337)
*Province capital*Sanctions index*	0.00529	0.00882	0.00920	0.00885	0.0199	0.0388	0.00933	0.0116	0.0157	0.0220	0.00309	0.00631
	(0.00558)	(0.00835)	(0.00746)	(0.00878)	(0.0181)	(0.0252)	(0.00737)	(0.0120)	(0.0159)	(0.0209)	(0.00398)	(0.00600)
Industrialization												
*Manufacturing city*Sanctions index*	0.00868**	0.0128***	0.00799*	0.0131**	0.0548***	0.0822***	0.0104**	0.0181***	0.0245**	0.0283**	0.00585**	0.00811**
	(0.00357)	(0.00435)	(0.00451)	(0.00530)	(0.0183)	(0.0256)	(0.00452)	(0.00641)	(0.0104)	(0.0125)	(0.00273)	(0.00359)
*Kaesong Industrial Region*Sanctions index*	-0.0319***	-0.0329***	-0.0767***	-0.0538***	-0.0158	-0.0131	-0.0450***	-0.0594***	-0.0953***	-0.150***	-0.0138***	-0.0431***
	(0.00114)	(0.00285)	(0.00157)	(0.00216)	(0.0111)	(0.0193)	(0.00117)	(0.00233)	(0.00292)	(0.00522)	(0.000652)	(0.00150)
*Mining area*Sanctions index*	0.0217***	0.0397***	0.0266***	0.0404***	0.0551**	0.0950***	0.0279***	0.0552***	0.0662***	0.0903***	0.0159***	0.0259***
	(0.00756)	(0.00948)	(0.00943)	(0.0111)	(0.0215)	(0.0262)	(0.00977)	(0.0134)	(0.0210)	(0.0250)	(0.00551)	(0.00718)
Economic Geography												
*Within 10km of Chinese border*Sanctions index*	0.0111***	0.0192***	0.0130***	0.0216***	0.0809***	0.132***	0.0133***	0.0274***	0.0318***	0.0479***	0.00810***	0.0138***
	(0.00295)	(0.00436)	(0.00324)	(0.00491)	(0.0160)	(0.0230)	(0.00378)	(0.00628)	(0.00814)	(0.0111)	(0.00226)	(0.00319)
*Sinuiju*Sanctions index*	0.0806***	0.0640***	0.0748***	0.0934***	0.00469	-0.0651**	0.0763***	0.105***	0.225***	0.188***	0.0652***	0.0540***
	(0.00671)	(0.00962)	(0.00678)	(0.00880)	(0.0209)	(0.0319)	(0.00748)	(0.0126)	(0.0156)	(0.0206)	(0.00408)	(0.00591)
*Port*Sanctions index*	-0.0117	-0.0191**	-0.0143	-0.0323**	-0.0564***	-0.0905***	-0.0174*	-0.0305**	-0.0409	-0.0705**	-0.00874	-0.0202**
	(0.00794)	(0.00845)	(0.0120)	(0.0140)	(0.0198)	(0.0246)	(0.00935)	(0.0135)	(0.0249)	(0.0329)	(0.00699)	(0.00944)
Lagged ln(lights)	0.209***	0.207***										
	(0.0208)	(0.0208)										
R-squared	0.756		0.981		0.629		0.745		0.737		0.737	
First stage F-statistic		16.325		55.965		19.135		21.517		24.139		10.856
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country time trends	No	No	Yes	Yes	No	No	No	No	No	No	No	No
R-squared	0.756		0.981		0.629		0.745		0.737		0.737	
Observations	1,004,220	1,004,220	1,052,040	1,052,040	131,384	131,384	1,004,220	1,004,220	1,052,040	1,052,040	1,052,040	1,052,040

Notes: Kleibergen-Paap first-stage statistics are reported. Each first stage regression in each 2SLS regression returns the same first stage F-statistic. This is because each first stage regresses *sanctions index*region dummy* on *USHFAC member share*region dummy* and *USHFAC member share*other region dummies,* and effectively the other region interaction terms become irrelevant, i.e., return coefficient estimates of zero. Standard errors are clustered at the county level in the OLS regression and the second stage of the 2SLS regression. Since the variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 6. Alternative hypotheses – China's economic growth and North Korea's nuclear plants

Dependent variable: ln(lights)	Years 1992 to 2003		Years 2004 to 2013		Exclude borders		Control for nuclear plant areas	
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Regional Favoritism								
*Pyongyang*Sanctions index*	0.105***	0.0742***	0.00821**	0.0530***	0.0177***	0.0547***	0.0191***	0.0581***
	(0.00854)	(0.00908)	(0.00379)	(0.00472)	(0.00477)	(0.00585)	(0.00436)	(0.00524)
*Province capital*Sanctions index*	0.0173	0.0186	0.00485	0.000456	0.00307	0.00458	0.00643	0.00982
	(0.0164)	(0.0163)	(0.00521)	(0.00969)	(0.00701)	(0.0101)	(0.00674)	(0.00934)
Industrialization								
*Manufacturing city*Sanctions index*	0.0132	0.0151	0.00487	0.00837*	0.00937*	0.0116*	0.00985**	0.0126**
	(0.00891)	(0.00961)	(0.00388)	(0.00489)	(0.00485)	(0.00597)	(0.00449)	(0.00559)
*Kaesong Industrial Region*Sanctions index*	-0.140***	-0.131***	-0.0498***	-0.0119***	-0.0409***	-0.0714***	-0.0390***	-0.0670***
	(0.00283)	(0.00369)	(0.00102)	(0.00125)	(0.000712)	(0.00101)	(0.00124)	(0.00234)
*Mining area*Sanctions index*	0.0351***	0.0397***	0.0139	0.0389***	0.0230**	0.0290***	0.0269***	0.0403***
	(0.0125)	(0.0136)	(0.0107)	(0.0141)	(0.00955)	(0.00947)	(0.00934)	(0.0112)
Economic Geography								
*Within 10km of Chinese border*Sanctions index*	0.0185***	0.0198***	0.00884**	0.0229***			0.0142***	0.0214***
	(0.00593)	(0.00701)	(0.00349)	(0.00640)			(0.00367)	(0.00498)
*Sinuiju*Sanctions index*	0.0371**	0.0498***	0.0872***	0.107***			0.103***	0.0840***
	(0.0147)	(0.0150)	(0.00565)	(0.0106)			(0.00671)	(0.00921)
*Port*Sanctions index*	-0.0448	-0.0579	-0.00856	-0.00170	-0.0142	-0.0334**	-0.0168	-0.0315**
	(0.0279)	(0.0352)	(0.00593)	(0.0219)	(0.0123)	(0.0166)	(0.0109)	(0.0147)
*Yongbyon(nuclear weapons development site)*Sanctions index*							0.000970	0.000268
							(0.00124)	(0.00234)
*Kumho (light water reactor site)*Sanctions index*							-0.351***	-0.284***
							(0.00124)	(0.00234)
R-squared	0.739		0.797		0.689		0.737	
First stage F-statistic		88.003		8.818		19.135		19.135
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	573,840	573,840	478,200	478,200	952,028	952,028	1,052,040	1,052,040

Notes: Columns (1) and (2) cover the period when sanctions were being relaxed. Columns (3) and (4) cover the period when sanctions were tightening. Columns (5) and (6) exclude all grid cells within 10km of the Chinese border. Columns (7) and (8) additionally control for two regions – Yongbyun, the main nuclear weapons development site in North Korea, and Kumho, the area where the light water reactor was offered in return for halting weapons development. Kleibergen-Paap first-stage statistics are reported. Each first stage regression in each 2SLS regression returns the same first stage F-statistic. This is because each first stage regresses *sanctions index*region dummy* on *USHFAC member share*region dummy* and *USHFAC member share*other region dummies,* and effectively the other region interaction terms become irrelevant, i.e., return coefficient estimates of zero. Standard errors are clustered at the county level in the OLS regression and the second stage of the 2SLS regression. Since the variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 7. Impact of North Korean sanctions on Chinese provinces and counties bordering North Korea

Dependent variable: ln(lights)	All years		Years 1992 to 2003		Years 2004 to 2013	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Chinese provinces bordering North Korea						
City dummy * Sanctions index	0.0122*	-0.00171	-0.0131	-0.0107	0.00561	0.000903
	(0.00663)	(0.00977)	(0.0104)	(0.0102)	(0.00692)	(0.0165)
R-squared	0.769		0.803		0.798	
First stage F-statistic		19.13		87.98		8.82
Observations	1,595,352	1,595,352	870,192	870,192	725,160	725,160
Panel B. Chinese counties bordering North Korea						
City dummy * Sanctions index	0.00146	-0.00672	-0.00363	-0.00790	-0.00532	-0.00978
	(0.0122)	(0.00642)	(0.0129)	(0.0117)	(0.0110)	(0.0111)
R-squared	0.739		0.781		0.791	
First stage F-statistic		19.13		87.98		8.82
Observations	769,890	769,890	419,940	419,940	349,950	349,950
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	769,890	769,890	419,940	419,940	349,950	349,950

Notes: The sample covers the parts of China near North Korea as depicted in Figure 5. Kleibergen-Paap first-stage statistics are reported. Each first stage regression in each 2SLS regression returns the same first stage F-statistic. This is because each first stage regresses *sanctions index*region dummy* on *USHFAC member share*region dummy* and *USHFAC member share*other region dummies,* and effectively the other region interaction terms become irrelevant, i.e., return coefficient estimates of zero. Standard errors are clustered at the county level in the OLS regression and the second stage of the 2SLS regression. Since the variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 8. Alternative hypothesis – World mineral prices

Dependent variable: ln(lights)	Coal		Iron	
	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)
*Pyongyang*Sanctions index*	0.0295***	0.0726***	0.0727**	0.104***
	(0.00304)	(0.00558)	(0.0284)	(0.00772)
*Province capital*Sanctions index*	0.00751	0.0112	0.0144***	0.0152
	(0.00507)	(0.0100)	(0.00449)	(0.0137)
*Manufacturing city*Sanctions index*	0.00663**	0.0120**	0.00596	0.0126
	(0.00331)	(0.00604)	(0.00766)	(0.00828)
*Kaesong Industrial Region*Sanctions index*	-0.0791***	-0.0910***	-0.142***	-0.127***
	(0.00148)	(0.00275)	(0.0404)	(0.00348)
*Mining area*Sanctions index*	0.0142	0.0385***	0.00912	0.0409***
	(0.0108)	(0.0126)	(0.0172)	(0.0151)
*Within 10km of Chinese border*Sanctions index*	0.00955***	0.0214***	0.00742	0.0229***
	(0.00306)	(0.00551)	(0.00612)	(0.00714)
*Sinuiju*Sanctions index*	0.0547***	0.0591***	0.0150	0.0355***
	(0.00503)	(0.0100)	(0.0332)	(0.0136)
*Port*Sanctions index*	-0.0138**	-0.0341**	-0.0294**	-0.0457*
	(0.00681)	(0.0172)	(0.0107)	(0.0247)
*Pyongyang*Ln(mineral price)*	-0.185***	-0.482***	-0.435**	-0.586***
	(0.0477)	(0.0549)	(0.197)	(0.0530)
*Province capital*Ln(mineral price)*	-0.0191	-0.0441	-0.0645*	-0.0685
	(0.0721)	(0.0808)	(0.0344)	(0.0873)
*Manufacturing city*Ln(mineral price)*	0.0577	0.0207	0.0318	-0.000258
	(0.0498)	(0.0580)	(0.0446)	(0.0556)
*Kaesong Industrial Region*Ln(mineral price)*	0.716***	0.798***	0.836***	0.767***
	(0.0112)	(0.0171)	(0.293)	(0.0162)
*Mining area*Ln(mineral price)*	0.227**	0.0592	0.145	-0.00761
	(0.103)	(0.105)	(0.107)	(0.0865)
*Within 10km of Chinese border*Ln(mineral price)*	0.0825*	0.000923	0.0548	-0.0195
	(0.0494)	(0.0538)	(0.0420)	(0.0487)
*Sinuiju*Ln(mineral price)*	0.858***	0.828***	0.713***	0.615***
	(0.0811)	(0.0907)	(0.160)	(0.0922)
*Port*Ln(mineral price)*	-0.0520	0.0879	0.102	0.181
	(0.116)	(0.173)	(0.0831)	(0.154)
R-squared	0.737		0.738	
First stage F-statistic		39.72		44.82
Year fixed effects	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes
Observations	1,052,040	1,052,040	1052040	1,052,040

Notes: The mineral price in columns (1) and (2) is the world coal price and in columns (3) and (4) the world iron ore price. The world mineral price information come from the IMF primary commodity price data. Kleibergen-Paap first-stage statistics are reported. Each first stage regression in each 2SLS regression returns the same first stage F-statistic. This is because each first stage regresses *sanctions index*region dummy* on *USHFAC member share*region dummy* and *USHFAC member share*other region dummies,* and effectively the other region interaction terms become irrelevant, i.e., return coefficient estimates of zero. Standard errors are clustered at the county level in the OLS regression and the second stage of the 2SLS regression. Since the variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 9. Alternative hypothesis – domestic migration

	OLS	2SLS	OLS	2SLS
Dependent variable: ln(lights)	(1)	(2)	(3)	(4)
Ln(distance to province capital)* Sanction index	-0.00680***	-0.00927**		
	(0.00211)	(0.00390)		
Within 5 km from city center* Sanction index			0.0412***	0.0431*
			(0.0137)	(0.0238)
Between 5-10 km from city center* Sanction index			0.0271***	0.0323***
			(0.00818)	(0.0125)
Between 10-25 km from city center* Sanction index			0.00683**	0.0101
			(0.00302)	(0.00694)
R-squared	0.736		0.737	
First stage F-statistic		19.13		19.13
Year fixed effects	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes
Observations	1,052,040	1,052,040	1,052,040	1,052,040

Notes: Distance is the straight line distance from each grid cell to its province capital. Kleibergen-Paap first-stage statistics are reported. Standard errors are clustered at the county level in the OLS regression and the second stage of the 2SLS regression. Since the variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 10. North Korea annual trade

Dependent variable:	Log trade value		Log # of trade partners		Log # of products traded	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Exports						
Sanctions index	0.0235	-0.0645	-0.0275	-0.102*	-0.0147***	-0.0376**
	(0.0150)	(0.0583)	(0.0160)	(0.0532)	(0.00421)	(0.0161)
R-squared	0.534		0.141		0.323	
First-stage F-statistic		7.193		7.005		7.005
Panel B. Imports						
Sanctions index	-0.0178	-0.137**	-0.0259	-0.0893*	-0.0177***	-0.0315***
	(0.0223)	(0.0643)	(0.0154)	(0.0493)	(0.00396)	(0.00981)
R-squared	0.464		0.142		0.528	
First-stage F-statistic		7.358		6.713		7.193
North Korea lights and GDP	Yes	Yes	Yes	Yes	Yes	Yes
Observations	22	22	22	22	22	22

Notes: The share of USHFAC members in president's party is used to instrument for the sanctions index in the 2SLS regressions. Kleibergen-Paap first-stage statistics are reported. Products are at the HS code 6-digit level. Newey-West standard errors are reported to account for auto-correlation. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 11. North Korea bilateral trade diversion to China

Dependent variable:	Log trade value		Log # of products traded	
	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)
Panel A. Exports				
Sanctions index * China	0.107***	0.109***	0.0261**	0.0316***
	(0.0172)	(0.0167)	(0.0103)	(0.0121)
R-squared	0.688		0.644	
First-stage F-statistic		20.446		20.555
Observations	2,456	2,456	2,428	2,428
Panel B. Imports				
Sanctions index * China	0.0970***	0.0723***	0.00902	0.0179*
	(0.0178)	(0.0215)	(0.00912)	(0.0101)
R-squared	0.691		0.9	
First-stage F-statistic		19.965		20.002
Observations	1,758	1,758	1,739	1,739
Partner Country GDP	Yes	Yes	Yes	Yes
Partner Country fixed effects	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: The share of USHFAC members in president's party interacted with the China dummy is the instrumental variable in the 2SLS regressions. Kleibergen-Paap first-stage statistics are reported. Products are at the HS code 6-digit level. Standard errors are clustered at the country level in the OLS regression and the second stage of the 2SLS regression. Since the main variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at the other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 12. Product level trade

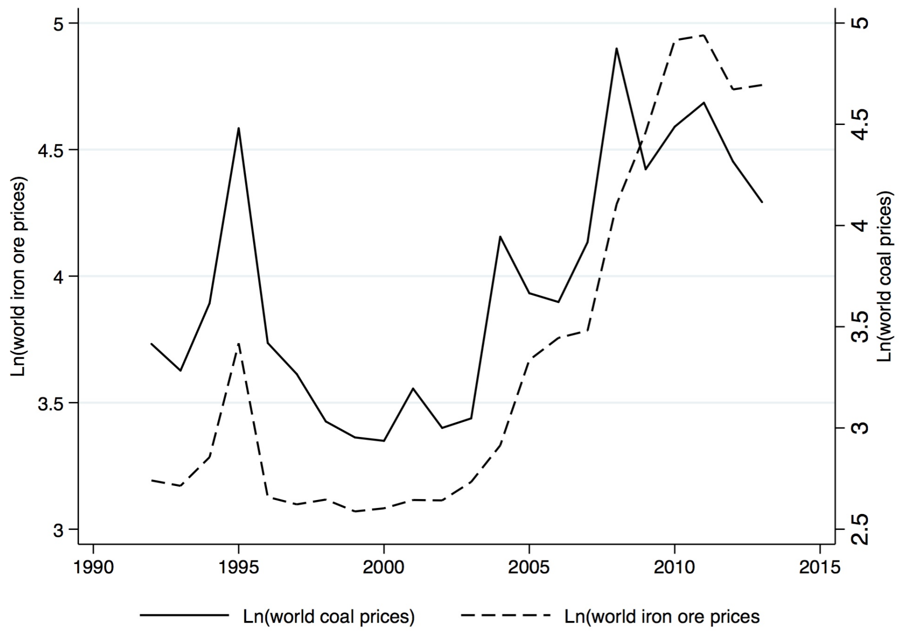
Dependent variable:Log(trade value)	All trade partners		China		Rest of the world	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Exports						
Sanctions index * Log(product capital intensity)	-0.0232***	-0.0291***	-0.0108	0.0231	-0.0132	-0.0252***
	(0.00793)	(0.00859)	(0.0203)	(0.0265)	(0.00861)	(0.00897)
Sanctions index * Log(product human capital intensity)	0.0502***	0.0477**	-0.0122	0.0212	0.0475**	0.0419**
	(0.0187)	(0.0196)	(0.0592)	(0.0774)	(0.0200)	(0.0199)
Sanctions index * Log(product natural resource intensity)	0.0194***	0.0111**	-0.0143	0.00391	0.0211***	0.0114**
	(0.00413)	(0.00436)	(0.0151)	(0.0203)	(0.00426)	(0.00448)
R-squared	0.446		0.699		0.439	
First-stage F-statistics		27.22 26.37 34.76		22.31 25.16 24.13		23.72 26.41 40.99
Observations	191,903	191,903	7,582	7,582	183,620	183,620
Panel B:Imports						
Sanctions index * Log(product capital intensity)	0.00551	0.0106*	0.0338***	0.0133	-0.00430	0.0173**
	(0.00544)	(0.00595)	(0.00775)	(0.00972)	(0.00661)	(0.00801)
Sanctions index * Log(product human capital intensity)	-0.0158	-0.0208	-0.0704***	-0.0596***	0.00808	-0.0213
	(0.0130)	(0.0142)	(0.0185)	(0.0221)	(0.0153)	(0.0189)
Sanctions index * Log(product natural resource intensity)	-0.00671*	-0.00901**	-0.0173***	-0.00772	-0.00419	-0.0111**
	(0.00381)	(0.00425)	(0.00603)	(0.00694)	(0.00433)	(0.00535)
R-squared	0.382		0.61		0.371	
First-stage F-statistics		34.99 23.90 24.93		28.85 31.05 23.60		62.04 54.22 53.14
Observations	153,950	153,950	48,322	48,322	105,125	105,125
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Commodity FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The share of USHFAC members in president's party interacted with the three factor intensity variables are included as instrumental variables in the 2SLS regressions. Sanderson-Windmeijer first-stage F-statistics are reported for each endogenous variables. Products are at the HS code 6-digit level. Standard errors are clustered at the product level in the OLS regression and the second stage of the 2SLS regression. Since the main variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at the other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Appendix Figure 1. North Korea Military Base Locations

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

Appendix Figure 2. World coal and iron ore prices



Note: Above presents the logarithm of Australian coal prices in US dollars per metric ton and the logarithm of China iron ore import prices in US dollars per metric ton. Both are adjusted by North Korea's GDP deflator. The price information comes from the IMF commodity price data.

Appendix Table 1. List of North Korean major 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 the city centers, which were identified by the brightest pixel in each city.

Appendix Table 2. Additional robustness checks

Dependent variable: ln(lights)	US Sanctions		UN Sanctions		South Korea Sanctions		Military base regions	
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Regional Favoritism								
*Pyongyang*Sanctions index*	0.0463***	0.111***	-0.0631***	0.389***	0.254***	0.360***	0.0193***	0.0587***
	(0.00769)	(0.0100)	(0.0125)	(0.0351)	(0.0186)	(0.0325)	(0.00434)	(0.00507)
*Province capital*Sanctions index*	0.0162	0.0188	0.00309	0.0658	0.0375	0.0608	0.00507	0.00397
	(0.0144)	(0.0179)	(0.0194)	(0.0625)	(0.0312)	(0.0578)	(0.00724)	(0.0104)
Industrialization								
*Manufacturing city*Sanctions index*	0.00962	0.0242**	0.0214*	0.0846**	0.0507***	0.0782**	0.00985**	0.0126**
	(0.00811)	(0.0107)	(0.0128)	(0.0374)	(0.0190)	(0.0346)	(0.00447)	(0.00541)
*Kaesong Industrial Region*Sanctions index*	-0.168***	-0.128***	0.0349***	-0.449***	-0.122***	-0.415***	-0.0388***	-0.0665***
	(0.00301)	(0.00447)	(0.00203)	(0.0156)	(0.00483)	(0.0144)	(0.00130)	(0.00246)
*Mining area*Sanctions index*	0.0299*	0.0773***	0.0548**	0.270***	0.137***	0.250***	0.0268***	0.0400***
	(0.0155)	(0.0214)	(0.0242)	(0.0748)	(0.0422)	(0.0692)	(0.00936)	(0.0111)
Economic Geography								
*Within 10km of Chinese border*Sanctions index*	0.0204***	0.0410***	0.0278**	0.143***	0.0567***	0.133***	0.0143***	0.0219***
	(0.00519)	(0.00953)	(0.0115)	(0.0333)	(0.0165)	(0.0308)	(0.00369)	(0.00502)
*Sinuiju*Sanctions index*	0.115***	0.161***	0.299***	0.563***	0.305***	0.520***	0.104***	0.0899***
	(0.0121)	(0.0176)	(0.0211)	(0.0617)	(0.0322)	(0.0570)	(0.00719)	(0.0101)
*Port*Sanctions index*	-0.0456	-0.0604**	-0.0153	-0.211**	-0.0589*	-0.195**	-0.0168	-0.0316**
	(0.0320)	(0.0282)	(0.0336)	(0.0985)	(0.0303)	(0.0910)	(0.0109)	(0.0146)
*Military base region *Sanctions index*							0.00163	0.00698
							(0.00353)	(0.00602)
R-squared	0.737		0.737		0.724		0.737	
First stage F-statistic		16.62		1.03		15.12		19.13
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040

Notes: The sanctions index by country is the cumulative sum of the number of sanction events imposed by the each country every year, with the base year in 1992 normalized to zero. Kleibergen-Paap first-stage statistics are reported. Each first stage regression in each 2SLS regression returns the same first stage F-statistic. This is because each first stage regresses *sanctions index*region dummy* on *USHFAC member share*region dummy* and *USHFAC member share*other region dummies,* and effectively the other region interaction terms become irrelevant, i.e., return coefficient estimates of zero. Standard errors are clustered at the county level in the OLS regression and the second stage of the 2SLS regression. Since the variation in the first-stage of the 2SLS regression is at the year level, standard errors are clustered at the year level in the first-stage regression to present the appropriate first stage F-statistic. Clustering the first-stage at the year level returns substantially smaller, hence, conservative first-stage F-statistics than clustering at other levels. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.