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

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Abstract

This paper examines how regional inequality evolves when a country becomes increasingly isolated from economic sanctions. I hypothesize three channels: regional favoritism by the ruling elites, reallocation of commerce that reflects the change in relative trade costs, and import substitution. Using nighttime lights from North Korea, I find that the capital city, trade hubs near China, and manufacturing cities become relatively brighter when sanctions increase. However, production shifts away from capital-intensive goods, deterring industrial development. The results imply that despite the intention to target the ruling elites, sanctions increase regional inequality at a cost to the already marginalized hinterlands.

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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.

Sanctions could affect regional economic inequality through several channels. One is through regional favoritism whereby the ruling elites allocate limited resources and public goods to regions based on private political and economic gain, rather than aggregate welfare. Regional favoritism by the ruling elites is more prevalent in autocracies (Hodler and Rashcky 2014, Besley and Mueller 2016), which are often the targets of economic sanctions. Another channel by which sanctions could affect regional inequality is the economic geography related to trade. Sanctions alter the relative trade costs between countries, which results in trade diversion (Lee 2015). If trade diversion is substantial, production could move to regions within the country that benefit most from the new trade relations. For example, Mexico's production activities near the US border increased after the Mexico-US Free Trade Agreement (Hanson and Krugman 1993). Another economic geography channel by which sanctions could affect regional inequality is through the location decision of producers. Producers in a closed economy benefit from locating near large cities because of the close linkages producers have with consumers and intermediate

[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.

goods suppliers. On the other hand, the benefits of locating near large cities diminish as producers can sell and buy from abroad in an open economy (Krugman and Livas Elizondo 1996). Since sanctions isolate countries from global trade, sanctions could induce the urban concentration of producers and consumers. Finally, sanctions could also impact regional economic activity via import substitution and industrial development. 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 develop her industries and seek out new trade partners.[2] The argument that economic isolation could result in industrial development is similar to the logic behind protectionism and the import substitution policies pursued by many post-colonial countries in the mid-20th century. If sanctions indeed promote industrial development, manufacturing regions could see a relative increase in economic activity compared to other regions of the country.

In short, regional favoritism predicts that the ruling elites of sanctioned countries would disproportionately distribute resources to areas valued by the elites. The economic geography of trade predicts that the location of commerce would move to regions that benefit from the relative change in international trade costs. The import substitution and industrialization channel hypothesizes that sanctions could trigger countries to divert resources to manufacturing regions. The objective of this paper is to empirically examine whether the above channels are at work, and then to discuss the regional inequality implications and efficacy of sanctions. This paper examines the case of North Korea. The intensity of sanctions against North Korea has fluctuated considerably in recent decades, providing interesting variation for empirical analysis. The North

[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)

Korea case is particularly appealing because internal migration is strictly limited. Hence, the observed changes in the geographic distribution of economic activity 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 several data sets including 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 in the 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. However, the share of trade with China, North Korea's main trading partner and one that did not enforce the sanctions, increases drastically. By 2013 trade with China comprised more than 80 percent of North Korea's trade.

I find that an additional sanction increases the difference in nighttime lights between the capital Pyongyang and the rest of the country by 1.9%, or by 0.6% 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% 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. The difference in nighttime lights between mining areas and the rest of the country increases by 2.7% with an additional sanctions event. However, this effect disappears once I control for world coal prices. 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. On the other hand, traditional port areas become darker when sanctions increase. In short, sanctions caused economic activity to concentrate relatively more in the capital city, manufacturing cities, 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. I also examine two-stage least squares (2SLS) estimates that use the share of US House Foreign Affairs Committee members with the same party affiliation as the ruling president to instrument for the sanctions index. A majority of sanctions in the US are announced as presidential executive orders, and the 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 to the sanctions index and the 2SLS results confirm the OLS results.

The empirical analysis finds strong regional favoritism effects from sanctions - the ruling elites in Pyongyang shield themselves from the effects of sanctions while literally leaving the majority of the country in the dark. Despite the intention to punish the target country's ruling elites, sanctions increase inequality at a cost to the already marginalized hinterlands. Also, the increase in nighttime lights near China and the decrease in traditional port areas indicate that sanctions can trigger substantial economic geography responses, altering the regional distribution of economic activity based on trade costs. Lastly, the relative increase in nighttime lights in manufacturing cities could imply import substitution accompanied with industrial upgrading or the inevitable shift to domestic production using factors available in the economy. I examine how sanctions affect North Korea's product exports and imports by factor intensity. Sanctions reduce the export of capital intensive products but increase the import of capital intensive products. The import substitution induced by sanctions is more likely to have deterred industrial upgrading.[3]

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 efficacy of sanctions (Eaton and Engers 1992; 1999, Dashti-Gibson et al. 1997, Davis and Engerman 2003, Hufbauer et al. 2009)[4],

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[3] Though I do not find that isolation from induces industrial development in this paper, 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. The broad ranged nature of sanctions, including the restriction of capital and intermediate goods, likely results in different results compared to the narrow blockade on textiles back then.

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

and more recently the consequences of sanctions in relation to international trade and finance (Haidar 2014, Lee 2015, Besedes et al. 2016, Crozet and Hinz 2016). However, the economics literature has focused less on how sanctions differentially affect the population 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 blacks and that blacks were often the main victims of mass layoffs. By examining how sanctions differentially affect regions within the target country, this paper contributes to our understanding of what happens on the ground when countries are sanctioned.

The regional inequality results, especially the diversion of resources to the capital city, are closely related to the literature that examines national institutions and regional inequality. Ades and Glaeser (1995) find that urban concentration in the capital city is greater in dictatorships and politically unstable regimes. They argue that this is because dictators exploit the hinterlands at little cost and politically unstable regimes disproportionately cater to the population near the capital city to maintain power. Recently economists have used various datasets to examine regional favoritism and inequality. Hodler and Raschky (2014) find that the nighttime light intensity near the leaders' birthplaces becomes brighter when leaders come into power, especially in autocratic countries. Besley and Mueller (2016) find that group inequality is lower when there are more constraints on executive power. 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. Relatedly, Alesina et al. (2016) and De Luca et al. (2016) use nighttime lights to examine ethnic inequality and favoritism across countries. My paper contributes to this literature by examining a novel determinant of regional inequality, i.e., international isolation due to economic sanctions. Moreover, I utilize the nighttime lights data in a country where hardly any other sub-national data exists, and show that isolation increases regional inequality in an ethnically homogenous country.

The paper's results are also closely related to the literature that examines how access to international markets affects domestic economic activity and welfare. Atkin and Donaldson (2015) examine how falling international trade barrier affects domestic consumers depending on intra-national trade costs. Kovak (2014) examines the effects of trade liberalization on regional labor markets in Brazil. Autor et al. (2013) examine how increased competition from China affect local labor markets in the US. This paper's focus on sanctions is particularly related to works that examine the impact of restricting access to world markets, for example, through trade embargoes or blockades, on the domestic economy (Irwin 2005, Etkes and Zimring 2015, Juhasz 2015).

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. Section 4 presents descriptive patterns from the data and discusses the estimation 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 maintained core features of a centrally planned economy. The communist party dictates production activities and allocates labor directly, restricting migration within the country. The Bank of Korea estimates that North Korea's GDP was about 24 billion in 2010 and that agriculture and fisheries comprised 20.8 %, mining 14.4%, manufacturing 22%, and service 31% of the economy. Despite the popular reference as a hermit kingdom, North Korea has diplomatic and trade relationships with many third world and past communist countries. When communism was declining in the late 20th century, North Korea strengthened its dictatorship and adhered to a home-grown ideology called Juche, which emphasizes self-reliance, and ultimately started developing nuclear weapons.

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

However, 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, including South Korea, Japan, and the US, jointly funded the development of the light water reactor. This was accompanied by the ease of trade, finance, and travel sanctions. During this period, North Korea suffered a famine and humanitarian aid flowed into the country as well. However, the relaxing of economic sanctions was short lived. North Korea admitted that it was enriching uranium 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. Additional sanctions and UN Security Council Resolutions were imposed after North Korea performed nuclear tests in 2006, 2009, 2013, and most recently in 2016. Initially, sanctions focused on trade bans on weapons related materials and goods, but expanded to luxury goods to target the elites. Sanctions further 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.[5]

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/banking, aid/ 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 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. As additional robustness checks to the main sanctions index, I create two other measures, one more aggregated and the other less aggregated. The more aggregated index does not separate the type of sanctions and increases by one if any sanction type was imposed. This index ranges from -5 to 1. The less

[5] 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.

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.

To examine whether the different types of sanctions have differential effects on regional inequality, I also create three sanctions indexes based on whether the sanctions focus on restricting the flow of goods, capital, or people. The goods-based index is the cumulative sum of events related to trade restrictions, the capital-based index is based on finance/banking and aid/remittance restrictions, and the people-based index is based on travel restrictions. Since asset and account freezes and travel restrictions target the elites, the ruling elites may have responded differently by the types of sanctions.

3. The Data

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 a 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 export and import 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.[6] 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 nighttime lights data to examine economic outcomes in various contexts (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 Raschky 2014, Michalopoulos and Papaioannou 2013, 2014). Adding the small constant allows estimation on the full sample, but also accounts for the

[6] 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.

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 northwestern tip of the Korean Peninsula and serves as the main trading hub between North Korea and 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 coastline for each port city.

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

For each grid cell I calculate the linear distance to the center of province capitals, and 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 the UN Comtrade and extract all reported trade with North Korea from 1992 to 2013. Since North Korea does not report any trade statistics, the data is based on what is reported by the countries that trade with North Korea. Some trade information may have not been included, and the trade data may underestimate actual trade. Also, weapons related trade may have not been fully reported in the 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 in the empirical analysis.

4. Descriptive Patterns and the Estimation Strategy

Before specifying the econometric model, I first descriptively examine the nature of isolation North Korea faced under economic sanctions using the aggregate trade data. Figure 2 indicates that both exports and imports were generally increasing. The spikes 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 a decrease in the number of trade partners. The number of countries North Korea exported to peaks at 141 in 2005 and then gradually declines. The number of countries North Korea imported from is smaller but similarly exhibits an inverse U-shape. The number peaks at 99 in 2005. Figure 4 presents the number of export and import products at the HS 6-digit level. The variety of imports is greater than that of exports, and both exhibit an inverse U-shape. Appendix Table 2 examines these patterns in a simple regression framework. The coefficient estimates on the sanctions index for import value, number of trade partners, and number of traded products are all negative. Even with only 22 observations, the negative relationship between the sanctions index and the number of import and export products is statistically significant at the 1 percent level. Overall, the descriptive patterns 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 has been trading with many countries. Second, the isolation faced by North Korea due to sanctions was not towards autarky, but towards fewer trade partners and product varieties. This is natural given that several sanctioning countries severed trade ties when North Korea continued to conduct nuclear tests. Lastly, despite the reduction in the number of trade partners and products, aggregate trade volume has been increasing.

I next descriptively examine 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. 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 in the capital cities (Pyongyang the province capitals) 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. Figure 8 plots the difference in the average nighttime lights between province capitals and the rest of the country. The line again exhibits a U-shape and the pattern is strikingly similar to the sanctions index. Furthermore, it is more evident that the sanctions index is leading the downward and upward trends. The relaxing and tightening of sanctions indeed seem to be driving the difference in nighttime lights between the two regions.

The base regression that formally examines 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 nighttime light value of each grid cell i in year t plus a small constant, 0.01. The light values are coded zero for a large 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 and 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 difference in nighttime lights between a specified region and the rest of the country increases with sanctions, β would be positive. Standard errors are clustered by the county equivalent administrative region to account for correlations between grid cells within region and across time.

The empirical analysis examines how economic sanctions relate to the luminosity gap between regions, and by doing so, tests whether the different channels, i.e., regional favoritism and elite capture, import substitution and industrial upgrading, and economic geography of trade, are at work. After presenting the robustness of the main results, I examine alternative hypotheses that could explain the regional variation in lights due to sanctions. Lastly, to further examine the causal effect of sanctions on regional inequality, I introduce an instrumental variable strategy that generates plausibly exogenous variation in North Korea sanctions.

5. The Empirical Results

5.1 The main results

Table 3 presents the baseline results. Column (1) first examines 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 import substitution and 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 South Korea's cooperation, and 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. When sanctions increase, more resources are diverted to manufacturing cities under the direct control of the ruling elites. This potentially suggests that isolation from international trade might be inducing import substitution and industrial development. 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 sanctions increase. 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 international trade cost with China, then regions with the lowest intra-national trade cost 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 and barely misses significance at the 10 percent level.

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. The 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 1.9 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 0.6%. 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 about 1 percent and Kaesong relatively darker by 3.9 percent. Sanctions are also related to mining activities. Nighttime lights in mining regions become relatively brighter by 2.7 percent. Finally, areas along the Chinese border become relatively brighter by 1.4 percent and Sinuiju an additional 10 percent. On the other hand, port areas become darker by about 1.7 percent relative to the rest of the city, with the estimate just missing the 10 percent significance level. As sanctions increase, 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 of whether such finding reflects a shift towards industrial development or simply to less productive manufacturing or to mining related production activities. 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, moving down the industrial ladder or increased reliance on natural resources as a source of wealth likely reflects economic regress. Hence, understanding whether the isolation from sanctions actually promoted industrial upgrading is important. I later examine the trade data to probe into this question. But first, I examine the robustness of the main results and whether alternative hypotheses, such as, China's economic growth, world coal prices, and internal migration, can explain the main findings in Table 3.

5.2 Results using different measures of sanctions

Rather than lumping all sanctions event together into one index, I examine how the different types of sanctions affect regional inequality in Table 4. I use three sanctions indexes based on whether the sanctions focus on restricting the flow of goods, capital, or people. The goods-based index is based on trade restrictions, the capital-based index on finance/banking and aid/remittance restrictions, and the people-based index on travel bans. The policy world is aware of the potential negative humanitarian consequences of sanctions and is increasingly utilizing sanctions that target the elites, for instance, through asset freezes or travel bans. Columns (1) to (3) reveal that the different sanctions indexes generally exhibit qualitatively similar results. However, the luminosity gap between Pyongyang and the rest of the country increases with the capital- and people- based indexes only. It is difficult to definitively attribute the inequality patterns to a particular type of sanction, since the different types of sanctions are correlated. However, the results on Pyongyang imply that the sanction types that particularly target the ruling elites induce the elites to divert resources to the capital and shield themselves from those sanctions. Finally, in the remaining two columns, I use a less aggregated sanctions index and a more aggregated sanctions index as previously described in Section 2. The results are qualitatively similar to when I use the main sanctions index in Table 3.

As Figure 4 indicated, sanctions significantly reduce the number of traded product varieties. In Appendix 3, I use the number of product varieties as a proxy for the intensity of sanctions. This also allows one to directly examine how the nature of isolation relates to regional inequality. Specifically, I use the number of import and export product varieties instead of the sanctions index. Consistent with the previous results, I find that a reduction in import variety is associated with nighttime lights significantly increasing in Pyongyang and Sinuiju, and decreasing in Kaesong. Export variety results are similar and further find significant effects on the regions bordering China.[7]

5.3 Robustness of the main results

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 column (1) by additionally controlling for one-year lagged lights. The inclusion of lagged lights slightly reduces the magnitudes of the estimates but the estimates exhibit similar patterns and statistical significance as before. The inclusion of the lagged dependent variable in a fixed effects regression introduces bias, but in panels where the time dimension is large the bias becomes relatively small (Nikell 1981, Nunn and Qian 2014). In column (2), 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. In particular, the lit areas within 10km of the Chinese border become substantially brighter relative to the other lit areas. In column (3), I examine the extensive margin by using a dummy variable equal to one if the grid cell is lit as the dependent variable. There is no significant effect on the capital cities, but the other coefficient estimates are all significant. Not only do manufacturing

[7] I also examine country/institution specific sanctions index. I construct each country's sanctions index as the cumulative sum of the number of sanction events imposed by each country every year, with the base year in 1992 normalized to zero. I examine the impacts of South Korea, US, and UN specific sanctions index in Appendix Table 3 columns (3) through (5). The South Korea sanctions index has a substantially stronger effect than the other two sanctions index. The US and UN sanctions generally have qualitatively similar effects as the South Korea sanctions.

cities and areas near China become on average brighter, but more area become lit when sanctions increase. In column (4), I use the previous year sanctions index, since there could be a time lag in how the autocrat responds to sanctions. The magnitude and significance of the estimates are similar to the base result of Table 3 column (8).

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 North Korea 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 go 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 column (5), 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, the site of the new light water reactor. Enrichment of fissile material is substantially more difficult with a light water reactor and several countries including the US and South Korea offered to construct one 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 other 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.

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. I split the sample years and separately examine the first half when sanctions were decreasing in Table 5 column (6), and the latter half when sanctions were increasing in column (7). 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, the estimates in columns (6) and (7) show that this is not the case. For instance, the estimates on the Chinese border interaction term and Sinuiju interaction term are positive and statistically significant in column (6). Since sanctions were decreasing during this period the estimates imply that the Chinese border areas were becoming relatively darker compared to the rest of the country. However, China was consistently growing at a rapid rate during this period. Moreover, the estimates on the other interaction terms are also qualitatively similar to each other in both columns. It seems unlikely that China's economic growth is driving the regional distribution of nighttime lights in North Korea.

Lastly, in column (8), 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.

However, the coefficient estimates on the other variables are again quite similar to that from the main result of Table 3 column (8).[8]

5.4 Alternative hypotheses

In this section I examine alternative hypotheses that could potentially be consistent with the regional inequality patterns presented in the previous tables. I examine three alternative hypotheses. First, is the alternative hypothesis that the satellite sensors might be picking up brightly lit urban and dark rural areas differentially in a manner that is coincidentally correlated with the sanctions. Another hypothesis is that the regional inequality results are due to people voluntarily migrating to cities with better economic prospects and not because of resource allocation by the ruling elites. Lastly, is the hypothesis that world mineral prices, namely coal, were the driving the patterns of regional inequality.

The concern that the regional inequality results are driven by satellite sensors differentially responding to bright urban and dark rural areas seems implausible since the luminosity gaps are not simply between urban and rural areas. A majority of the areas near the Chinese border is not urban, as well as the mining areas. Also, the port area is a narrow strip *within* an urban area. Moreover, if the results were driven by the spurious correlation between the satellite sensors and the sanctions index, similar results could hold in another countries. In Table 6 columns (1) through (3) I examine how North Korea sanctions are related to the urban-rural inequality within Chinese counties that border North Korea. The Chinese counties bordering North Korea are also in a planned economy and have a high concentration of ethnic

[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 column (6) of Appendix Table 3. 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.

Koreans as well as a relatively similar geography to North Korea. As column (1) indicates, sanctions on North Korea have no significant relationship with the urban-rural inequality in China. The results are robust regardless of whether I split the sample periods in columns (2) and (3).

The rural population in developing countries often migrate to urban areas to take advantage of better economic opportunities and public goods. The increasing luminosity gap between regions could reflect internal migration due to the increasing hardships from sanctions. However, migration is unlikely to be the driving force in North Korea. First of all, 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 developing countries urban slums are unseen and unheard of in North Korea. The nighttime lights data can be useful to empirically examine 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 columns (4) and (5), 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 estimate in column (4) indicates that the elasticity of nighttime lights relative to distance to the city center decreases by about 0.007 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. Column (5) further examines 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 4.1 percent for areas within 5 km of the city center and 2.7 percent for areas in between 5 and 10 km. For areas between 10 and 25 km of the city center the magnitude drops considerably to 0.68 percent. These results indicate that sanctions cause nighttime lights to disproportionately increase in the urban core. Urban migration and the formation of slums along the periphery are not the cause of the urban concentration of lights.

North Korea's main export is coal. In 2014, coal exports comprised 33% of North Korea's total exports ($1.03B out of $3.1B). World coal prices fluctuated considerably during this period (Appendix Figure 2) and such fluctuation could have affected North Korea's mining and trade.[9] In Table 6 Panel C, I include the set of region dummies interacted with the world coal price to the base regression. Columns 6(a) and 6(b) are results from that one regression. Now, the estimate on *mining area*sanctions index* is reduced by almost 50% and is no longer statistically significant. On the other hand, the coefficient estimate on *mining area*ln(coal price)* is positive and significant at the 5 percent level. World coal prices were driving the nighttime lights in mining areas, and the relationship between sanctions and nighttime lights in mining areas disappears when coal prices are controlled for. The regional favoritism effect by the ruling elites and the economic geography effects of trade diversion due to sanctions remain strong and significant even when coal prices are controlled for. Also, the luminosity gap between manufacturing cities and the other regions still increases with sanctions.[10]

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[9] World coal prices is based on the Australian coal prices in US dollars per metric ton, and is adjusted using North Korea's GDP deflator. The price information comes from the IMF commodity price data.

[10] Iron ore is also one of North Korea's major export goods, comprising about 6.2% of North Korea's total exports in 2014. However, a regression that include *mining area*ln(iron ore prices)*. do not find iron ore prices to affect

5.5 Additional robustness tests using instrumental variable estimation

The various robustness tests up to know seem to confirm that the regional variation in nighttime lights were driven by external economic sanctions. Nonetheless, there may be concern of endogeneity. To alleviate such concern, I use the share of the US House Foreign Affairs Committee (USHFAC) members that have the same party affiliation as the standing president to instrument for the sanctions index. In the US, economic sanctions are either primarily introduced as a presidential executive order or in some cases through a congressional bill. Within the Congress, the US House Foreign Affairs Committee oversees legislation and performs oversight on issues related to sanctions. Committee members change when congress members win or loss local elections, retire, or become ill. These events are most certainly unrelated to North Korea's nuclear program. Since the introduction of sanctions involves an executive order or a bill, a House Foreign Affairs Committee that is better aligned with the president may be better able to influence the US government (the Senate, the House of Representatives, and the Treasury), the UN, and the US allies to levy and implement sanctions. Figure 9A plots how the USHFAC share variable and the sanctions index evolve over time. The share variable fluctuates over time but exhibits a general U-shaped pattern and as figure 9B indicates two variables are positively correlated.

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

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nighttime lights in mining areas. The annual iron ore prices during this pattern coincidentally exhibit a similar U-shaped pattern as the sanctions index, and coefficient estimates likely suffer from collinearity.

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. 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.[11] The instrumental variable used here varies only by year. Ideally, an instrumental variable that varies annually and regionally would provide better identification. However, it is difficult to find a suitable instrumental variable at that level of variation, and hence I present the following 2SLS results while acknowledging its limitations.

Table 7 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

[11] The 2SLS estimates can also be estimated by using the predicted $\hat{s_t}$ 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.

index and the first-stage Kleibergen-Paap F-statistic is 19.14. 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. Column (3) presents the two-stage least square version of the main regression in Table 3 column (8). The 2SLS estimates are generally larger in magnitude but are qualitatively similar to that of the OLS estimates. The following columns in Table 7 examine the sensitivity of the 2SLS estimates using the same sample restrictions as before. Appendix Table 4 presents the 2SLS results corresponding to the specifications in Table 6. Overall, the 2SLS estimates support the main findings of the OLS estimates and provides additional evidence that sanctions are altering the regional distribution of economic activity.

6. Does isolation induce industrial upgrading? Evidence from the trade data

In this section, I probe into whether the relative increase in nighttime lights in manufacturing implies import substitution accompanied by industrial upgrading. 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 whether sanctions diverted trade to China. Despite UN Security Council resolution, China did not enforce sanctions against North Korea during the sample period. Because of China's non-enforcement, North Korea's trade cost with China relatively declined, which would result in increased trade with China. This is born out econometrically in Table 8 columns (1) and (2). Columns (1) is the regression result 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 estimates on the China interaction terms are positive for both exports and imports and statistically significant at the one percent level. The column (1) 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 10 percent. The estimates for the log number of commodities traded in column (2) are also positive and statistically significant for exports.

I then examine how sanctions affected North Korea's 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,

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

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 the most disaggregated product classification for which the revealed factor intensity indices were constructed, and I run equation (3) at that level. Table 8 columns (3) to (5) present results from the above equation (3) and columns (6) to (8) present results that additionally control for the intensity measures interacted with world coal prices, i.e., $lncap_p lncoalprice_t$, $lnhum_p lncoalprice_t$, and $lnnat_p lncoalprice_t$. As before Panel A presents the results on exports and Panel B imports.

In column (3), an additional sanctions cause North Korea to reduce exports of capital intensive products by 2.3 percent but increase exports of human capital intensive products by 5 percent and natural resource intensive products by 1.9 percent. The estimates are all statistically significant. However, when I control for the world coal price interaction terms in column (6), the coefficient estimate on sanctions interacted with natural resource intensity becomes small and insignificant. This null effect indicates that sanctions did not shift production towards natural resources intensive goods, such as, mining, and is consistent with the null nighttime lights results in mining areas. Controlling for coal prices barely changes the negative coefficient estimate on the capital intensity interaction term. If 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 reduction in the export of capital intensive goods from sanctions does not support this argument. The main effect of sanctions on product trade is the shift to more human capital intensive products. As sanctions inhibit the flow of capital and goods, production shifts to goods that use the factor that is relatively less affected by sanctions. I examine product trade with China in column (7) and with the rest of the world in column (8). The results in column (6) primarily carry through to column (8). However, none of the estimates in column (7) are statistically significant at the 5 percent level. Though sanctions induced North Korea to shift exports to China the export product composition did not change based on factor intensity. The import results in Panel B indicate that sanctions induced North Korea to increase the imports of capital intensive products while reducing imports of human capital or natural resource intensive products. As sanctions inhibit the production of capital intensive goods, North Korea is meeting its demand by importing more. Moreover, columns (7) and (8) indicate that the increased import of capital intensive goods is primarily from China, consistent with China not effectively imposing any sanctions. Overall, the results from the trade data find no evidence of sanctions inducing industrial upgrading. If sanctions induced North Korea to import substitute it was in products relatively more intensive in using human capital, a factor least likely to have been affected by sanctions.

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. Manufacturing cities also become relatively brighter as sanctions increase. However, examination of the trade data find no evidence of industrial upgrading to capital intensive production or shifting towards natural resource intensive goods because of the sanctions. In short, as the country becomes more isolated economic activity shifts towards the capital city, trade hubs with China, and manufacturing regions 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, or trade and manufacturing 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 would 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.

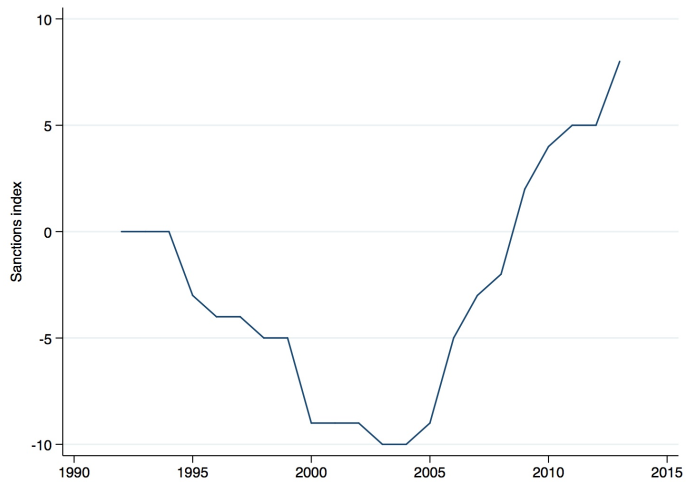


Figure 2. North Korea trade over time

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.

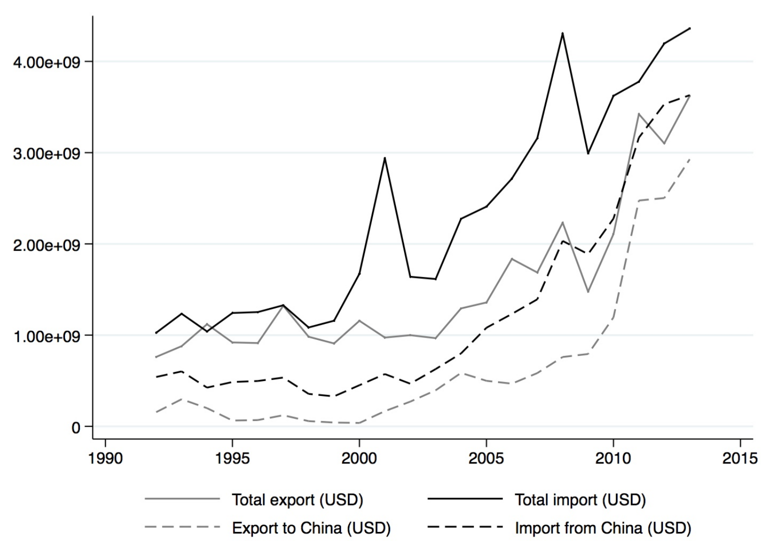


Figure 3. Trade partners over time

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.

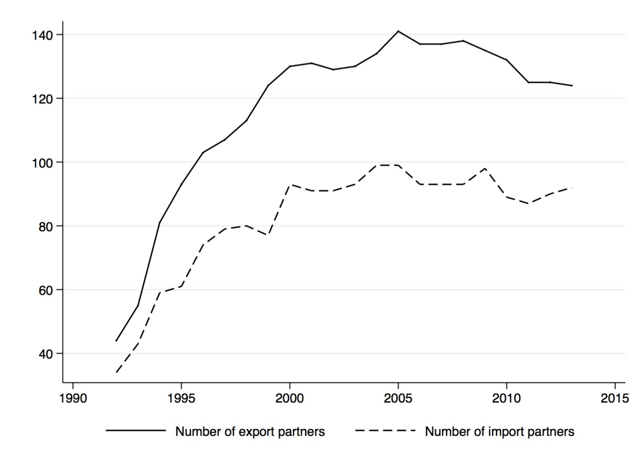


Figure 4. Number of products traded over time

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.

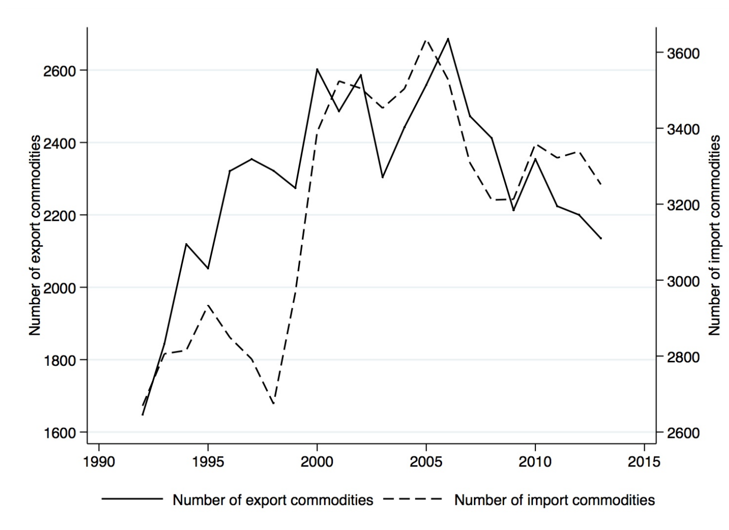


Figure 5. Satellite Image of the Korean Peninsula in 2010.

Notes: The 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.

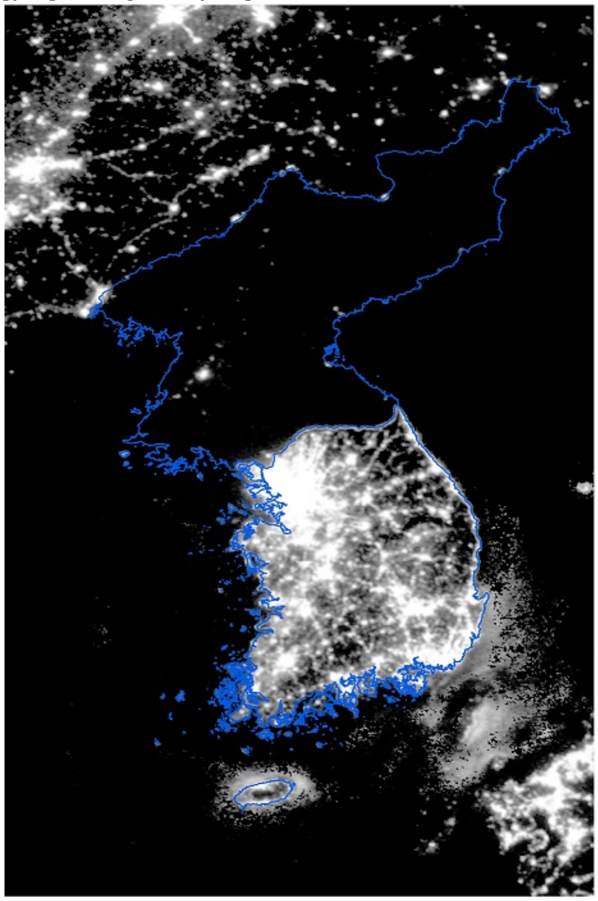


Figure 6. Lights near Pyongyang in 1992, 2002, and 2012.

1992 2002 2012

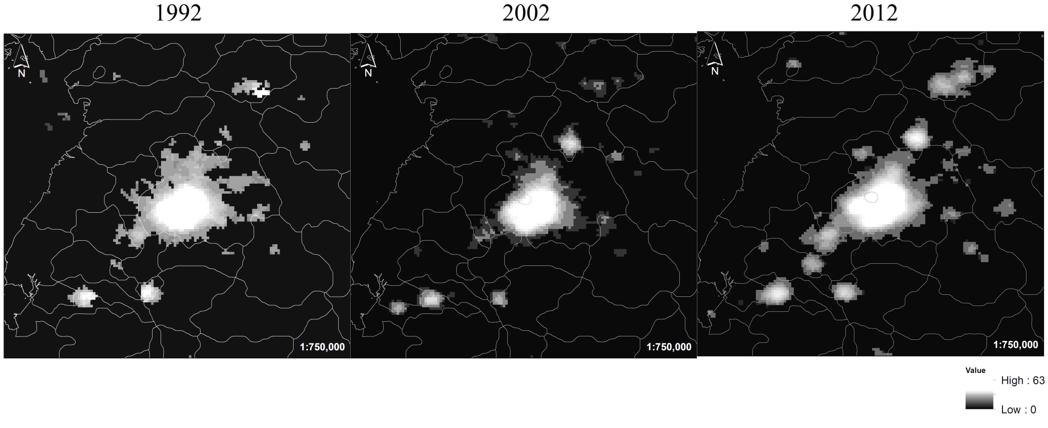


Figure 7. Share of lights in the capital cities and the sanctions index

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 is the sanctions index from Figure 1.

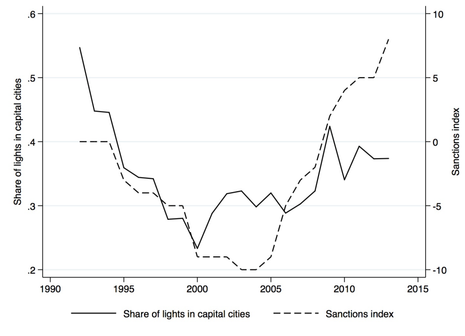


Figure 8. Difference in average nighttime lights between capital cities and rest of the country

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 is the sanctions index from Figure 1.

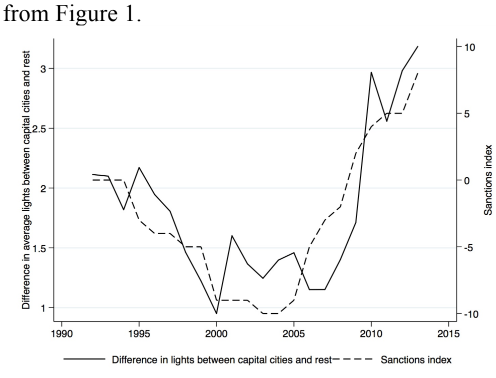


Figure 9A and 9B. Share of the US House Foreign Affairs Committee members with the same party affiliation as the president and the sanctions index

Notes: In 9A, 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 is the sanctions index from Figure 1. Figure 9B presents the scatter plot and linear fit between the two variables.

Figure 9A.

Figure 9B.

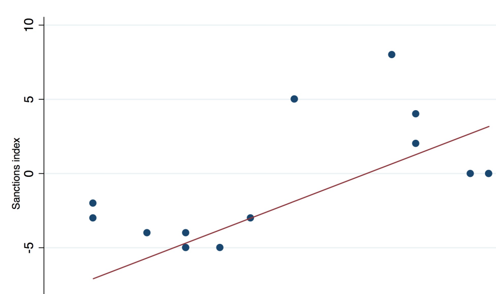


Table 1. Chronology of the sanctions on North Korea

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. The main results

Dependent variable: 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
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: All columns include grid cell and year fixed effects. Standard errors are clustered at the county level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

Table 4. Sanctions by type

Dependent variable: ln(lights)	Index= goods-based sanctions index	Index= capital-based sanctions index	Index= people-based sanctions index	Index= Less aggregate sanctions index	Index= More aggregate sanctions index
	(1)	(2)	(3)	(4)	(5)
Regional Favoritism					
Pyongyang Index*	0.0228	0.0688***	0.0677***	0.00418	0.0588***
	(0.0145)	(0.0102)	(0.0143)	(0.00266)	(0.0101)
*Province capital*Index*	0.0134	0.0181	0.0241	0.00309	0.0157
	(0.0213)	(0.0169)	(0.0228)	(0.00398)	(0.0159)
Industrialization					
*Manufacturing city*Index*	0.0333**	0.0219**	0.0309**	0.00585**	0.0245**
	(0.0148)	(0.0106)	(0.0148)	(0.00273)	(0.0104)
*Kaesong Industrial Region*Index*	-0.0357***	-0.141***	-0.149***	-0.0138***	-0.0953***
	(0.00306)	(0.00330)	(0.00449)	(0.000652)	(0.00292)
*Mining area*Index*	0.0804***	0.0663***	0.0864***	0.0159***	0.0662***
	(0.0286)	(0.0230)	(0.0306)	(0.00551)	(0.0210)
Economic Geography					
*Within 10km of Chinese border*Index*	0.0391***	0.0354***	0.0486***	0.00810***	0.0318***
	(0.0118)	(0.00869)	(0.0121)	(0.00226)	(0.00814)
*Sinuiju*Index*	0.335***	0.222***	0.348***	0.0652***	0.225***
	(0.0220)	(0.0161)	(0.0223)	(0.00408)	(0.0156)
*Port*Index*	-0.0354	-0.0452*	-0.0650	-0.00874	-0.0409
	(0.0309)	(0.0265)	(0.0405)	(0.00699)	(0.0249)
R-squared	0.737	0.737	0.737	0.737	0.737
Observations	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040

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

Table 5. Robustness of the main result

	Control for lagged lights	Exclude unlit grid cells		Use lagged sanctions index	Control for nuclear plant areas	Years 1992 to 2003	Years 2004 to 2013	Exclude borders
Dependent variable	ln(lights)	ln(lights)	Dummy(lit)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Regional Favoritism								
*Pyongyang*Sanctions index*	0.0137***	0.00334	-0.000117	0.0241***	0.0191***	0.105***	0.00821**	0.0177***
	(0.00348)	(0.0166)	(0.000699)	(0.00441)	(0.00436)	(0.00854)	(0.00379)	(0.00477)
*Province capital*Sanctions index*	0.00529	0.0199	0.000447	0.00933	0.00643	0.0173	0.00485	0.00307
	(0.00558)	(0.0181)	(0.00107)	(0.00737)	(0.00674)	(0.0164)	(0.00521)	(0.00701)
Industrialization								
*Manufacturing city*Sanctions index*	0.00868**	0.0548***	0.00124*	0.0104**	0.00985**	0.0132	0.00487	0.00937*
	(0.00357)	(0.0183)	(0.000725)	(0.00452)	(0.00449)	(0.00891)	(0.00388)	(0.00485)
*Kaesong Industrial Region*Sanctions index*	-0.0319***	-0.0158	-0.0103***	-0.0450***	-0.0390***	-0.140***	-0.0498***	-0.0409***
	(0.00114)	(0.0111)	(0.000216)	(0.00117)	(0.00124)	(0.00283)	(0.00102)	(0.000712)
*Mining area*Sanctions index*	0.0217***	0.0551**	0.00356**	0.0279***	0.0269***	0.0351***	0.0139	0.0230**
	(0.00756)	(0.0215)	(0.00157)	(0.00977)	(0.00934)	(0.0125)	(0.0107)	(0.00955)
Economic Geography								
*Within 10km of Chinese border*Sanctions index*	0.0111***	0.0809***	0.00199***	0.0133***	0.0142***	0.0185***	0.00884**	
	(0.00295)	(0.0160)	(0.000535)	(0.00378)	(0.00367)	(0.00593)	(0.00349)	
*Sinuiju*Sanctions index*	0.0806***	0.00469	0.00517***	0.0763***	0.103***	0.0371**	0.0872***	
	(0.00671)	(0.0209)	(0.000978)	(0.00748)	(0.00671)	(0.0147)	(0.00565)	
*Port*Sanctions index*	-0.0117	-0.0564***	-0.00315*	-0.0174*	-0.0168	-0.0448	-0.00856	-0.0142
	(0.00794)	(0.0198)	(0.00188)	(0.00935)	(0.0109)	(0.0279)	(0.00593)	(0.0123)
Lagged ln(lights)	0.209***							
	(0.0208)							
*Yongbyon(nuclear weapons development site)*Sanctions index*					0.000970			
					(0.00124)			
*Kumho (light water reactor site)*Sanctions index*					-0.351***			
					(0.00124)			
R-squared	0.756	0.629	0.686	0.745	0.737	0.739	0.797	0.689
Observations	1,004,220	131,384	1,052,040	1,004,220	1,052,040	573,840	478,200	952,028

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

Table 6. Alternative hypotheses

Dependent variable: ln(lights)	A. Counterfactual effect on bordering Chinese countries			B. Effect by distance from urban center		C. World coal price effect	
	All years	Years 1992 to 2003	Years 2004 to 2013			*VAR*= sanctions index	*VAR*= ln(coal price)
	(1)	(2)	(3)	(4)	(5)	(6a)	(6b)
City dummy * Sanctions index	0.00146	-0.00363	-0.00532				
	(0.0122)	(0.0129)	(0.0110)				
R-squared	0.739	0.781	0.791				
Observations	769,890	419,940	349,950				
Ln(distance to province capital)*Sanction index				-0.00680***			
				(0.00211)			
Within 5 km from city center*Sanction index					0.0412***		
					(0.0137)		
5-10 km from city center*Sanction index					0.0271***		
					(0.00818)		
10-25 km from city center*Sanction index					0.00683**		
					(0.00302)		
R-squared				0.736	0.737		
Observations				1,052,040	1,052,040		
*Pyongyang*VAR*						0.0295***	-0.185***
						(0.00304)	(0.0477)
*Province capital*VAR*						0.00751	-0.0191
						(0.00507)	(0.0721)
*Manufacturing city*VAR*						0.00663**	0.0577
						(0.00331)	(0.0498)
*Kaesong Industrial Region*VAR*						-0.0791***	0.716***
						(0.00148)	(0.0112)
*Mining area*VAR*						0.0142	0.227**
						(0.0108)	(0.103)
*Within 10km of Chinese border*VAR*						0.00955***	0.0825*
						(0.00306)	(0.0494)
*Sinuiju*VAR*						0.0547***	0.858***
						(0.00503)	(0.0811)
*Port*VAR*						-0.0138**	-0.0520
						(0.00681)	(0.116)
R-squared						0.737	
Observations						1,052,040	

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

Table 7. 2SLS results

				Exclude unlit grid cells	Control for nuclear plant areas	Years 1992 to 2003	Years 2004 to 2013	Exclude borders
Dependent variable:	Sanctions index	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)	ln(lights)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Share of US House Foreign Affairs Committee	113.3***							
	(25.89)							
Sanctions index		-0.00272						
		(0.00217)						
Regional Favoritism								
*Pyongyang*Sanctions index*			0.0581***	0.0543**	0.0581***	0.0742***	0.0530***	0.0547***
			(0.00524)	(0.0214)	(0.00524)	(0.00908)	(0.00472)	(0.00585)
*Province capital*Sanctions index*			0.00982	0.0388	0.00982	0.0186	0.000456	0.00458
			(0.00934)	(0.0252)	(0.00934)	(0.0163)	(0.00969)	(0.0101)
Industrialization								
*Manufacturing city*Sanctions index*			0.0126**	0.0822***	0.0126**	0.0151	0.00837*	0.0116*
			(0.00558)	(0.0256)	(0.00559)	(0.00961)	(0.00489)	(0.00597)
*Kaesong Industrial Region*Sanctions index*			-0.0670***	-0.0131	-0.0670***	-0.131***	-0.0119***	-0.0714***
			(0.00233)	(0.0193)	(0.00234)	(0.00369)	(0.00125)	(0.00101)
*Mining area*Sanctions index*			0.0403***	0.0950***	0.0403***	0.0397***	0.0389***	0.0290***
			(0.0112)	(0.0262)	(0.0112)	(0.0136)	(0.0141)	(0.00947)
Economic Geography								
*Within 10km of Chinese border*Sanctions index*			0.0214***	0.132***	0.0214***	0.0198***	0.0229***	
			(0.00497)	(0.0230)	(0.00498)	(0.00701)	(0.00640)	
*Sinuiju*Sanctions index*			0.0840***	-0.0651**	0.0840***	0.0498***	0.107***	
			(0.00920)	(0.0319)	(0.00921)	(0.0150)	(0.0106)	
*Port*Sanctions index*			-0.0315**	-0.0905***	-0.0315**	-0.0579	-0.00170	-0.0334**
			(0.0147)	(0.0246)	(0.0147)	(0.0352)	(0.0219)	(0.0166)
Lagged ln(lights)								
*Yongbyon(nuclear weapons development site)*Sanctions index*					0.000268			
					(0.00234)			
*Kumho (light water reactor site)*Sanctions index*					-0.284***			
					(0.00234)			
R-squared	0.416							
First stage F-statistic		19.135	19.135	19.135	19.135	88.003	8.818	19.135
Observations	1,052,040	1,052,040	1,052,040	131,384	1,052,040	573,840	478,200	952,028

Notes: All columns include grid cell fixed effects. Columns (3) and onward also control for year fixed effects. Kleibergen-Paap first-stage statistics are reported. The first stage regresses *sanctions index*region dummy* on *USHFAC member share*region dummy* and the set of *USHFAC member share*other region dummies*. 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. Bilateral trade diversion and product level trade

	A. Country level trade		*B. Product level trade*					
			Log trade value					
	Log trade value	Log # of products traded	All trade partners	China	Rest of the world	All trade partners	China	Rest of the world
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Exports								
Sanctions index * China	0.107***	0.0261**						
	(0.0172)	(0.0103)						
Sanctions index * Log(product capital intensity)			-0.0232***	-0.0108	-0.0132	-0.0224***	0.0234	-0.0214***
			(0.00793)	(0.0203)	(0.00861)	(0.00754)	(0.0206)	(0.00829)
Sanctions index * Log(product human capital intensity)			0.0502***	-0.0122	0.0475**	0.0384**	-0.0372	0.0448**
			(0.0187)	(0.0592)	(0.0200)	(0.0189)	(0.0635)	(0.0207)
Sanctions index * Log(product natural resource intensity)			0.0194***	-0.0143	0.0211***	0.00345	-0.0308*	0.00530
			(0.00413)	(0.0151)	(0.00426)	(0.00426)	(0.0165)	(0.00442)
R-squared	0.688	0.644	0.446	0.699	0.439	0.446	0.700	0.440
Observations	2,456	2,428	191,903	7,582	183,620	191,903	7,582	183,620
Panel B:Imports								
Sanctions index * China	0.0970***	0.00902						
	(0.0178)	(0.00912)						
Sanctions index * Log(product capital intensity)			0.00551	0.0338***	-0.00430	0.00835	0.0141*	0.00747
			(0.00544)	(0.00775)	(0.00661)	(0.00571)	(0.00792)	(0.00737)
Sanctions index * Log(product human capital intensity)			-0.0158	-0.0704***	0.00808	-0.0285**	-0.0630***	-0.0182
			(0.0130)	(0.0185)	(0.0153)	(0.0136)	(0.0195)	(0.0173)
Sanctions index * Log(product natural resource intensity)			-0.00671*	-0.0173***	-0.00419	-0.0159***	-0.00578	-0.0203***
			(0.00381)	(0.00603)	(0.00433)	(0.00411)	(0.00634)	(0.00496)
R-squared	0.691	0.9	0.382	0.61	0.371	0.383	0.610	0.372
Observations	1,758	1,739	153,950	48,322	105,125	153,950	48,322	105,125
Partner Country GDP	Yes	Yes						
Partner Country fixed effects	Yes	Yes						
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Commodity FE			Yes	Yes	Yes	Yes	Yes	Yes
Country-year FE			Yes	Yes	Yes	Yes	Yes	Yes
ln(coal price)*factor intesities			No	No	No	Yes	Yes	Yes

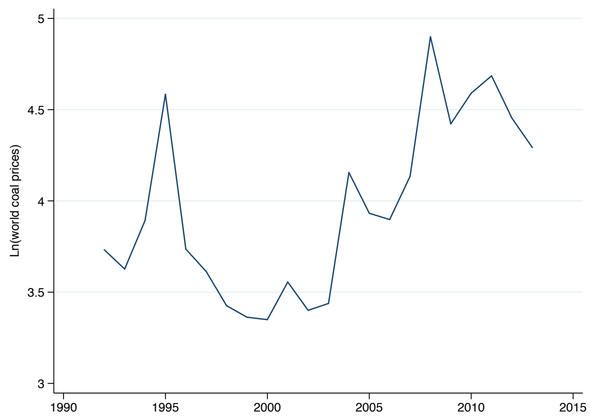
Notes: Products are at the HS code 6-digit level. Notes: All columns include grid cell and year fixed effects. Standard errors are clustered at the county level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level.

APPENDIX

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. Prices 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. The nature of isolation from sanctions

Dependent variable:	Log export value	Log import value	Log # of countries exporting to	Log # of countries importing from	Log # of export products	Log # of import products
	(1)	(2)	(3)	(4)	(5)	(6)
Sanctions index	0.0235	-0.0178	-0.0275	-0.0259	-0.0147***	-0.0177***
	(0.0150)	(0.0223)	(0.0160)	(0.0154)	(0.00421)	(0.00396)
R-squared	0.534	0.464	0.141	0.142	0.323	0.528

Notes: Each column controls for the log of total lights in North Korea and the log GDP values for North Korea as reported by the World Bank. Number of observation is 22 for each column. 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.

Appendix Table 3. The number of product varieties effect and additional robustness tests

Dependent variable: ln(lights)	*Var =* ln(import variety)	*Var =* ln(export variety)	*Var =* South Korea Sanctions	*Var =* US Sanctions	*Var =* UN Sanctions	*Var =* Military base regions
	(1)	(2)	(3)	(4)	(5)	(6)
Regional Favoritism						
*Pyongyang*Var*	-2.205***	-2.456***	0.254***	0.0463***	-0.0631***	0.0193***
	(0.238)	(0.190)	(0.0186)	(0.00769)	(0.0125)	(0.00434)
*Province capital*Var*	-0.378	-0.355	0.0375	0.0162	0.00309	0.00507
	(0.479)	(0.363)	(0.0312)	(0.0144)	(0.0194)	(0.00724)
Industrialization						
*Manufacturing city*Var*	0.178	-0.204	0.0507***	0.00962	0.0214*	0.00985**
	(0.251)	(0.203)	(0.0190)	(0.00811)	(0.0128)	(0.00447)
*Kaesong Industrial Region*Var*	5.567***	3.691***	-0.122***	-0.168***	0.0349***	-0.0388***
	(0.0692)	(0.0767)	(0.00483)	(0.00301)	(0.00203)	(0.00130)
*Mining area*Var*	0.566	-0.450	0.137***	0.0299*	0.0548**	0.0268***
	(0.408)	(0.315)	(0.0422)	(0.0155)	(0.0242)	(0.00936)
Economic Geography						
*Within 10km of Chinese border*Var*	-0.0252	-0.318**	0.0567***	0.0204***	0.0278**	0.0143***
	(0.211)	(0.151)	(0.0165)	(0.00519)	(0.0115)	(0.00369)
*Sinuiju*Var*	2.297***	-1.361***	0.305***	0.115***	0.299***	0.104***
	(0.472)	(0.343)	(0.0322)	(0.0121)	(0.0211)	(0.00719)
*Port*Var*	0.735	1.092*	-0.0589*	-0.0456	-0.0153	-0.0168
	(0.566)	(0.638)	(0.0303)	(0.0320)	(0.0336)	(0.0109)
*Military base region *Var*						0.00163
						(0.00353)
R-squared	0.737	0.737	0.724	0.737	0.737	0.737
Observations	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040	1,052,040

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

Appendix Table 4. Alternative hypothesis – 2SLS results

Dependent variable: ln(lights)	*A. Counterfactual effect on bordering Chinese countries*			*B. Effect by distance from urban center*		*C. World coal price effect*	
	All years	Years 1992 to 2003	Years 2004 to 2013			*VAR*= sanctions index	*VAR*= ln(coal price)
	(1)	(2)	(3)	(4)	(5)	(6a)	(6b)
*City dummy * Sanctions index*	-0.00672	-0.00790	-0.00978				
	(0.00642)	(0.0117)	(0.0111)				
First stage F-statistic	19.13	87.98	8.82				
Observations	769,890	419,940	349,950				
*Ln(distance to province capital)*Sanction index*				-0.00927**			
				(0.00390)			
*Within 5 km from city center*Sanction index*					0.0431*		
					(0.0238)		
*5-10 km from city center*Sanction index*					0.0323***		
					(0.0125)		
*10-25 km from city center*Sanction index*					0.0101		
					(0.00694)		
First stage F-statistic				19.13	19.13		
Observations				1,052,040	1,052,040		
*Pyongyang*VAR*						0.0726***	-0.482***
						(0.00558)	(0.0549)
*Province capital*VAR*						0.0112	-0.0441
						(0.0100)	(0.0808)
*Manufacturing city*VAR*						0.0120**	0.0207
						(0.00604)	(0.0580)
*Kaesong Industrial Region*VAR*						-0.0910***	0.798***
						(0.00275)	(0.0171)
*Mining area*VAR*						0.0385***	0.0592
						(0.0126)	(0.105)
*Within 10km of Chinese border*VAR*						0.0214***	0.000923
						(0.00551)	(0.0538)
*Sinuiju*VAR*						0.0591***	0.828***
						(0.0100)	(0.0907)
*Port*VAR*						-0.0341**	0.0879
						(0.0172)	(0.173)
First stage F-statistic						39.72	
Observations						1,052,040	

Notes: All columns include grid cell and year fixed effects. Kleibergen-Paap first-stage statistics are reported. The first stage regresses *sanctions index*region dummy* on *USHFAC member share*region dummy* and the set of *USHFAC member share*other region dummies*. 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.