Tsukuba Economics Working Papers
No. 2025-001

Exports, Trade Hubs, and Urban-Rural Inequality: Global Evidence from Nighttime Luminosity

by

Shafiqullah Yousafzai

and

Hisahiro Naito

January 2025

UNIVERSITY OF TSUKUBA
Faculty of Humanities and Social Sciences
1-1-1 Tennodai
Tsukuba, Ibaraki 305-8571
JAPAN

Exports, Trade Hubs, and Urban-Rural Inequality: Global Evidence from Nighttime Luminosity

Shafiqullah Yousafzai *†

Graduate School of Humanities and Social Sciences

University of Tsukuba

Hisahiro Naito *‡

Graduate School of Humanities and Social Sciences

University of Tsukuba

January, 2025

*S.Y. appreciates the financial support from MEXT Scholarship. H.N. appreciate financial support from JSPS KAKENHI Grant: Challenging Research (Pioneering:23K17284). The authors appreciate the comments from Taiyo Fukai, Kennnichi Kashiwagi, Yoshinori Kurokawa, Yuko Nakano, Zeng Fei Yu and Fatwa Ramdani. The authors are responsible for all remaining errors.

†Email:shafiqullah1991@gmail.com Address: 1-1-1, Tennodai, Tsukuba City, Ibaraki. Prefecture Postal code 305-8571

‡Email:naito@dpipe.tsukuba.ac.jp. Address: 1-1-1, Tennodai, Tsukuba City, Ibaraki Prefecture. Postal code 305-8571

Abstract

This study examines the effect of exports on subnational income and regional inequality between urban (trade hub) and rural (non–trade hub) areas, using nighttime luminosity as a proxy for economic activity. We construct a country-period panel dataset covering 104 countries, based on five-year average data from 1997 to 2020. Trade hub areas are defined as the union of areas within a 30 km or 50 km radius of each of the three largest ports and three international airports in a country, while all remaining areas are classified as non–trade hub areas.

To address endogeneity, we employ a two-stage least squares (2SLS) approach, using predicted trade as an instrumental variable. Predicted trade is derived from a dynamic gravity equation in which time dummies are interacted with sea and air transport distances. This instrument captures variation in transportation costs driven by technological advances that have shifted trade from sea to air, thereby influencing trade volumes.

Our results show that a 1% increase in exports raises nighttime luminosity by 0.3% in trade hub areas and by 0.06% in non–trade hub areas. Export growth also leads to population increases in trade hub areas, but not in non–trade hub areas. Furthermore, we find that a 1% increase in exports raises nighttime luminosity per capita by 0.18% in trade hub areas and by 0.06% in non–trade hub areas. These findings suggest that while exports stimulate economic activity in trade hubs, population inflows partially offset per capita gains. Nonetheless, exports significantly exacerbate regional inequality.

1 Introduction

Economic activities are unevenly distributed within each country. Nightlight data reveal that brighter areas, indicative of higher economic activity, are often situated near coastlines, rivers, or canals in many nations (Henderson et al., 2018). This observation suggests a strong link between economic activity and international trade and it prompts an important and policy-relevant question —- whether an exogenous increase in exports increases income predominantly in trade-related areas or leads to a more balanced economic improvement across different areas of a country.

Answering this question is crucial for two reasons. First, anti-globalization sentiments are increasingly evident in several countries such as the United States, the United Kingdom, and France (Rodrik, 2021). For example, in the 2024 U.S. presidential election, the Democratic candidate secured the majority of votes in the East and West Coasts—regions that have benefited significantly from globalization—while the Republican candidate dominated inland regions, which are farther from coastlines (The Wall Street Journal, 2024; National Association of Counties, 2024). This divergence underscores the uneven distribution of globalization's benefits. Although the positive relationship between exports and national income is well-documented, the localized impacts of trade on urban and regional development remain underexplored. Understanding whether globalization benefits are widespread or concentrated in specific areas is essential for crafting policies to address its opportunities and challenges effectively.

Second, the UN projection shows that by 2050, 68 percent of the global population will live in urban areas(United Naitons:, 2019). To predict how many individual will live in urban areas precisely, it is vital to understand how globalization affects the income of urban areas and the migration into urban areas.

Investigating the localized effects of exports on income in trade related areas (trade hub area) and trade unrelated areas (non-trade hub area) is challenging for two reasons. First, measuring economic activity at subnational level on global scale is inherently difficult due to the lack of data on global scale. Second, exports are endogenous; for instance, as an area's productivity increase, both export and income might increase. Second, openness itself is endogenous. A country might adopt an export-promoting policy depending on productivity.

To explore how an exogenous increase in exports affects the income of trade hub and non-trade hub areas, we proceed as follows. First, we use night-lights and night-lights per capita data to infer income and income per capita at the subnational level, respectively. Recent economic research shows that night lights can be used to measure economic activity (Henderson et al., 2012; Martinez, 2022). Since night light data can be calculated at a finer resolution, such as 1 km times 1 km, it is possible to grasp the income of trade-related and non-trade-related areas. More specifically, we construct a subnational-level panel dataset using satellite imagery for 104 countries, employing five-year averages for the periods 1997–2020. A trade hub area is defined as the union of areas within a 30 km or 50 km radius of each of the three major ports and three international airports in a country. Using nightlight satellite images, we calculate the five-year average nightlights for trade hub and non-trade hub areas. Our dataset includes over 350 of the world's largest ports and more than 300 inland cities with airports or nearby airports. The non-trade hub area comprises all areas outside these defined hubs.

To address the endogeneity of exports, we use a time-variant instrument based on the gravity equation suggested by Feyrer (2019). This instrument leverages purely geographical characteristics, such as sea and air distances, to account for improvements in transportation technology and the shift from sea to air cargo. These changes have significantly reduced transportation costs over time, redefining the role of distance. For instance, countries with similar sea and air distances may benefit differently depending on their reliance on specific transportation methods, leading to varying impacts across countries.

Our findings reveal that a one percent increase in exports raises the luminosity of nightlights in trade hub areas by 0.3 percent and by 0.06 percent in non-trade hub areas. We used the difference in the natural logarithm of nightlight intensity between trade hub and non-trade hub areas as a proxy for rural-urban inequality. The results show that a one percent increase in exports increases the difference in the natural logarithm of lights between trade hub and non-trade hub areas by 0.24 percent. Additionally, an exogenous one percent increase in exports boosts nightlights per capita, a proxy for income per capita, in trade hub areas by 0.18 percent compared to 0.06 percent in non-trade hub areas. These results indicate that exports predominantly enhance economic performance in trade hub areas, while the effect on non-trade hub areas is less than one-third that of the trade hubs. We also find that an exogenous increase in exports positively affect the population of trade hubs, but do not affect the difference in the natural logarithm of population between trade hub area and non-trade hub area, suggesting that barriers may prevent migration from non-trade hubs to trade hubs. This finding underscores the need to identify and address these obstacles to ensure a more equitable distribution of globalization's benefits.

This paper relates to several strands of the literature. First, it is closely connected to research on the effects of international trade on regional income inequality (Silva and Leichenko, 2004; Meschi and Vivarelli, 2009; Naranpanawa and Arora, 2014; Storeygard, 2016; Hirte et al., 2020). Silva and Leichenko (2004) and Naranpanawa and Arora (2014) analyze this relationship at the state level in the United States and India, respectively. Meschi and Vivarelli (2009) investigates the impact of trade on income inequality in developing countries using cross-sectional data.[1] In a study of Sub-Saharan African cities, Storeygard (2016) examines how a city's distance from a major port affects its income when transportation costs rise. Specifically, Storeygard (2016) find that cities located closer to a large port experience a 7% increase in income compared to cities 500 kilometers farther inland, following a rise in oil prices. Hirte et al. (2020) explores the effects of trade and transport costs on regional inequality in 162 countries, using regional Gini coefficients calculated from nightlight-derived income estimates (Lessmann and Seidel, 2017). To measure international trade costs, they interact trade flows with the distance between each region and other regions within the same country.

Another strand of literature related to our study examines how trade affects economic growth (Rodriguez and Rodrik, 2000; Irwin and Terviö, 2002; Noguer and Siscart, 2005; Frankel and Romer, 1999; Feyrer, 2021). These studies investigate the impact of trade on national-level income using cross-sectional data. In contrast, Feyrer (2019) analyzes the

[1] Meschi and Vivarelli (2009) use inequality data from the University of Texas Inequality Project (UTIP) database, which includes two different inequality measures: the UTIP-UNIDO and EHII indexes. More information is available at http://utip.gov.utexas.edu.

effect of trade on income using panel data and a time-varying instrumental variable derived from fluctuations in transportation costs.

We extend two strands of the literature in the following ways. First, this paper focuses on the impact of exports on inequality between urban (trade hub) and rural (non–trade hub) areas. While Hirte et al. (2020) examines the effect of trade on overall regional inequality, our study specifically investigates how trade influences income in trade-related areas relative to non–trade-related areas. Hirte et al. (2020) finds that trade has no significant effect on the Gini coefficient of income across regions. However, the use of Gini coefficients entails comparisons among all regions, including various rural areas. From a policy standpoint, it is arguably more important to assess whether trade exacerbates disparities between areas directly connected to global trade and those that are not. Accordingly, our paper analyzes whether trade contributes to rural–urban inequality by disproportionately benefiting trade-related areas.

Second, we employ a dynamic gravity equation model and generate a time-varying instrumental variable based on transportation costs, as proposed by Feyrer (2019). This approach enables us to investigate whether an exogenous increase in exports leads to urban expansion in trade-hub areas. Hirte et al. (2020) used an instrumental variable constructed by interacting trade share with GDP growth of trade partners, operating under the identification assumption that a partner's GDP growth is independent of own GDP. In our study, we predict trade flows by exploiting changes in transportation costs and distances for each transportation mode (air or sea) to the trading partner. Because these cost changes are likely exogenous, we believe that Feyrer (2019)'s identification strategy provides more credible estimates.

This paper is organized as follows: Section 2 discusses the relationship between night lights and real GDP. Section 3 outlines the identification strategy. Section 4 presents the results, Section 5 provides the discussion, and Section 6 offers the concluding remarks.

2 Nighttime Lights and Economic Growth

The satellites of the United States Air Force Defense Meteorological Satellite Program (DMSP) recorded data on the intensity of lights generated by human activities using their Operational Linescan System (OLS) sensors.

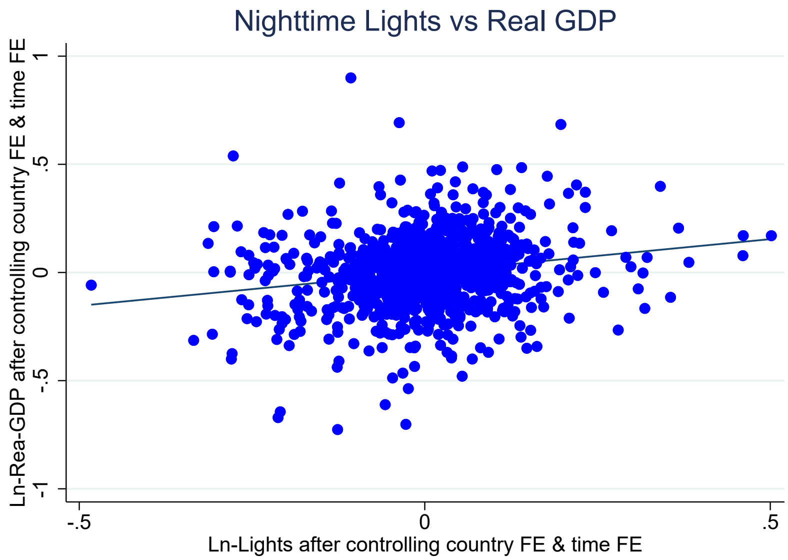
Table 1. The Ordinary Least Squares Estiamted Effects of Lights on Real GDP

	(1)	(2)
A. OLS Estimates		
Dependent Variable	Ln Real GDP	
Ln Lights	0.350***	0.308***
	(0.0934)	(0.0846)
Ln Population		0.529***
		(0.0958)
R-squared	0.998	0.998
B. Specifications		
Country FE	Yes	Yes
Time FE	Yes	Yes
Countries	185	185
N	1,074	1,074

Notes: The nightlights and real GDP data with five-years is used for the regression estimation from 1992 to 2020. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

The satellite data on nighttime luminosity reflect socioeconomic developments in human settlements and serve as a reliable alternative proxy for socioeconomic indicators. A reduction in luminosity suggests a decline in economic activity. As Henderson et al. (2012) demonstrated, nighttime lights data are a strong proxy for gross domestic product (GDP). Similarly, Pérez-Sindín et al. (2021) showed that light data serve as a useful indicator of socioeconomic development at the subnational level in middle- and lower-income countries.

Figure 1: The Association between Nighttime Lights and Real GDP



Notes: The average nighttime lights data from DMSP and VIIRS are used for the period 1997–2020. The data are presented in five-year intervals to plot this graph. We averaged the nighttime lights data for the specific years when both satellites recorded the observations.

Figure 2: Nighttime Lights Map of South America in 2010

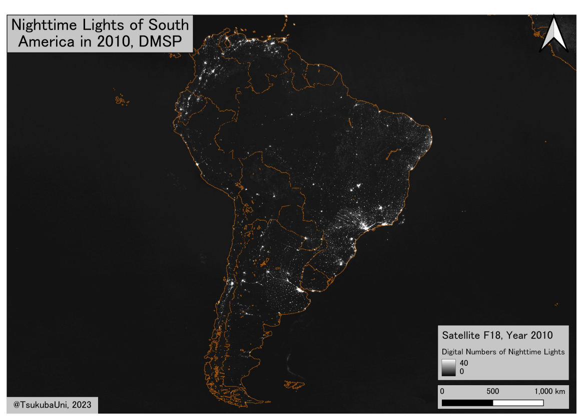


Figure 3: Nighttime Lights Map of Australia in 2010

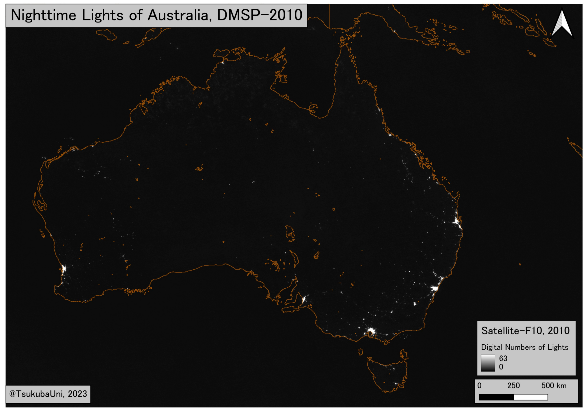


Figure 4: Nighttime Lights Map of Sub-Saharan Africa in 2010

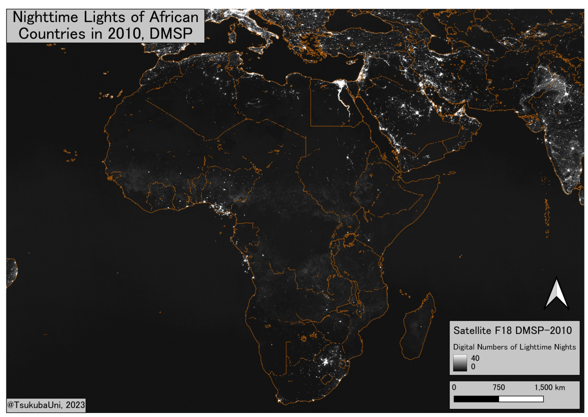


Figure 5: Nighttime Lights Map of South East Asia in 2010

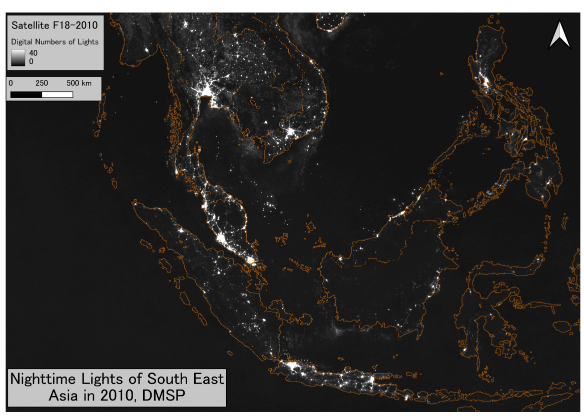


Figure 6: Nighttime Lights Map of East Asia in 2010

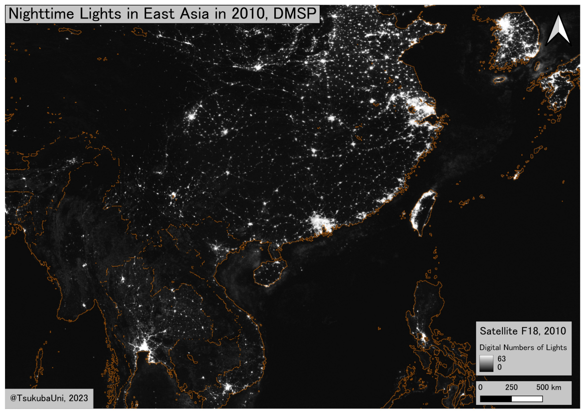


Figure 7: Nighttime Lights Map of Europe in 2010

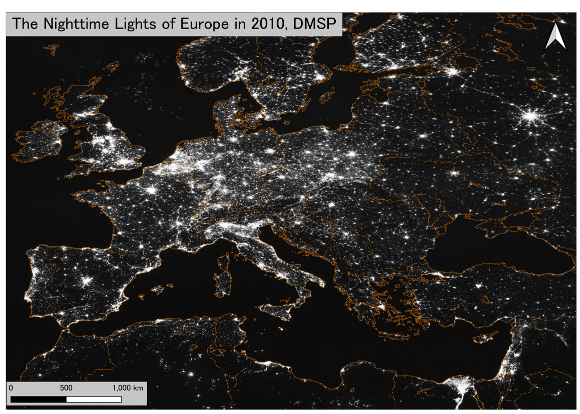


Figure 2-7 show nighttime luminosity across different continents. These figures indicate that in many regions, brighter areas are concentrated along coastlines, large lakes, or canals, suggesting that economic activities are predominantly located in these areas.

Table 1 presents the ordinary least squares (OLS) estimates of the natural logarithm of nighttime lights on the natural logarithm of real GDP. The estimated coefficient of lights is positive and statistically significant, indicating that a one percent increase in nighttime luminosity corresponds to a 0.30 percent increase in real GDP. Figure 1 displays the scatter plot of the estimated effects of nighttime lights on real GDP.[2] The vertical axis represents ln-real GDP after controlling for country fixed effect and time fixed effect, while the horizontal axis represents ln-lights after applying the same controls. The fitted lines depict a positive slope, suggesting a strong positive relationship between nighttime luminosity and real GDP.

3 Estimation Strategy

3.1 Main equation

We hypothesize that exports increase income in trade-related areas (trade hub areas) more than in non-trade-related areas (non-trade hub areas). Thus, we estimate the following equation:

$$\text{Ln Y}^a_{jt} = \alpha 0 + \alpha_1 \text{Ln Exports}_{jt} + \alpha_2 \text{z}_{jt} + \eta_j + \eta_t + \epsilon_{jt} \tag{1}$$

where j is the index of source county and t denotes the time period, measured in five-year intervals. For example, when t is equal to one, it implies that years are from 1997 to 2001. If t is equal to two , it means that years are from 2002 to 2006. The superscript a corresponds to the trade hub area and the non-trade hub area. A trade hub area is defined as the union of areas within a 30 km or 50 km radius of each of the three major ports and three major

[2] In this graph, ln-real GDP is first regressed on control variables, country fixed effects, and time fixed effects. The residuals are then obtained. Similarly, ln-country lights is regressed on control variables, country fixed effects, and time fixed effects, and the residuals are obtained. Finally, the scatter plot of the residuals of nighttime lights and real GDP is plotted.

international airports in a country. We provide a more precise definition of trade hub and non-trade hub areas in Section 3.4.

The outcome variable, $\ln Y_{jt}^{a}$, represents the five-year average of night light intensity, lights per capita, or population in either trade hub or non-trade hub areas. The key explanatory variable, Ln Exports$_{jt}$, is the natural logarithm of five-year averaged exports. z_{jt} represents the set of control variables, including national population and local weather (such as temperature and precipitation).

We include national population as one of the control variables because, in some specifications, the dependent variable is night lights per capita, which is calculated by dividing total night lights by the local (trade hub or non-trade hub) population. We also include weather variables as control variables, as weather conditions may affect both exports and night lights. Country fixed effects account for unobserved country-specific factors influencing economic growth, such as institutional quality, culture, and overall economic development. Time fixed effects control for common time trends that impact economic growth across all countries. The error term is denoted by ξ_{jt}, and we allow for serial correlation in the error terms over time.

3.2 Gravity Equation

To estimate the equation (1), a simple OLS regression does not capture the causal effect since exports is an endogenous variable. For example, a country with higher productivity can enjoy higher income and export more. Additionally, a country's openness can be a policy target due to its competitiveness. Thus, it is necessary to use an instrumental variable approach to address the endogeneity of exports.

In one of the most frequently cited papers on the effect of trade on income, Frankel and Romer (1999) employs geographic factors to predict trade in cross-sectional data and uses this predicted trade as an instrument to examine the effect of trade on income.

The instrument introduced by Frankel and Romer (1999) may not satisfy the exclusion because countries have different geographic characteristics, which can affect their income in various ways. For instance, countries located near the equator are farther from international markets compared to others, and those with unfavorable disease environments or unproductive colonial institutions may engage in less trade.

Feyrer (2019) introduces a time-varying instrumental variable derived from a gravity equation. The instrument is constructed from predicted export values estimated by interacting sea distance and air distance with year dummies in a regression on actual exports. These predicted values capture temporal changes in trade patterns, particularly the shift from sea freight to air cargo. By employing this time-varying instrument in panel regressions, it becomes possible to control for country-specific factors influencing economic growth, thereby mitigating omitted variable bias more effectively than in cross-sectional analyses.

We extend the instrumental variable proposed by Feyrer (2019) and construct our own predicted export values. First, we identify the largest airport in each country and define air distance as the direct point-to-point distance between the largest airports of two countries. Similarly, bilateral sea distance is manually computed using raw geographical data by identifying the largest port in each country and then calculating the sea distance between the two ports in a country pair.[3]

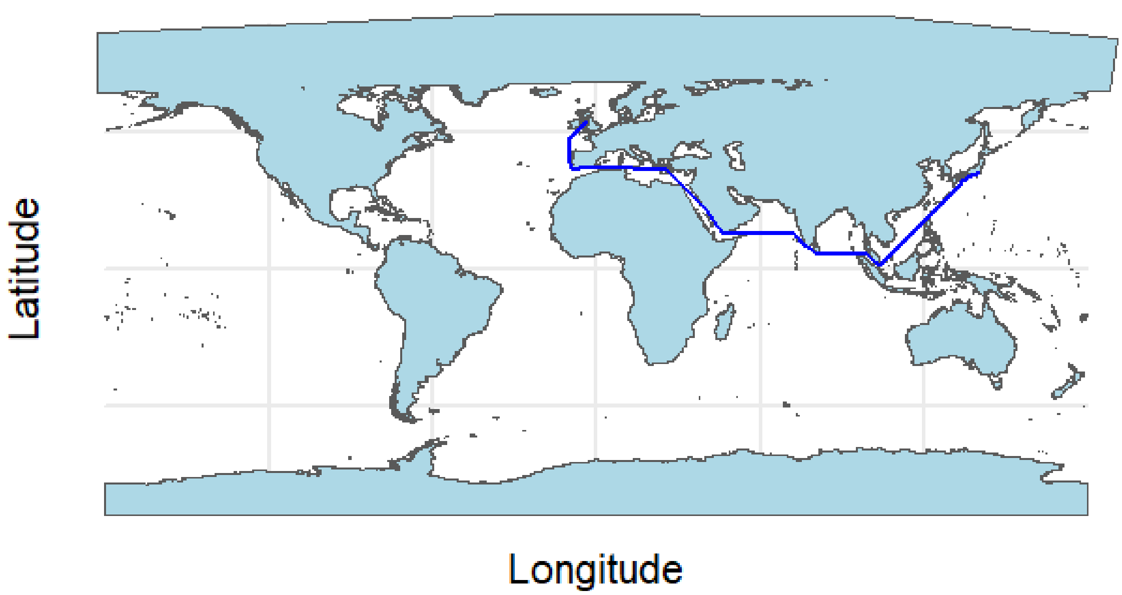
In addition, following the spirit of Feyrer (2019), we include surface distance interacted with year dummies and the number of shared borders interacted with year dummies in the gravity equation. The surface distance is the point-to-point distance between pairs of countries located on the same continent and it is calculated between the capital cities for each source-destination pair. Surface distance is longer for countries with greater distances on landmasses and incurs higher land transportation costs. We assume that Surface distance is infinity for pair of countries that are not located in the same continent. The number of shared borders indicates how many countries a given country shares land borders with.

The sea distance from the United States and Canada to other countries can differ depending on whether it is the west coast or east coast. In the United States and Canada, the west and east coasts serve as independent economic entities, and the sea distances to these coasts are significantly different, which could affect the results in obtaining the instrument. For the

[3] To calculate sea distance, we removed land from a global raster map by assigning a value of 1 to sea and 0 to land, then computed the shortest sea path between the 104 countries. Both air and sea distances are measured in thousands of kilometers.

United States and Canada, the average sea distance to two ports—one from the east coast and one from the west coast—is calculated. In the United States, the Port of New York/New Jersey on the east coast and the Port of Los Angeles on the west coast were selected, while in Canada, the Port of Montreal on the east coast and the Port of Vancouver on the west coast were selected. This may address concerns about differences in sea distances between the east and west coasts of the United States and Canada. In another gravity equation, we used the sea distance from either the east coast or the west coast alone. The results using the sea distance from ports on different coasts in the United States and Canada are consistent with the main findings. Even when we excluded the United States and Canada from the sample, the regression estimations remained consistent with the main results and the results are available on Supplemental Information C.

Figure 8: Shortest Sea Path from Liverpool Port in United Kingdom to Tokyo Port in Japan



Source: Calculated by Authors

Figure 8 describes the calculation of the shortest path from Liverpool port in United Kingdom to Tokyo port in Japan. [4]

[4]We expanded the size of the Suez Canal properly so that the programming algorithm can find the path

We utilize annual export pair data for the gravity equation to obtain the predicted exports. The export pair data contains several zeros across different pairs as well as across years. Zero export values are possible for trade partners, especially in the case of developing countries. In the literature, most previous papers including Frankel and Romer (1999) used a log-linearized model. However, such a model, in the presence of heteroskedasticity, provides biased and inconsistent estimates of parameters Silva and Tenreyro (2006).

Thus, following the suggestion by Silva and Tenreyro (2006), we use the Poisson Pseudo-Maximum Likelihood (PPML) estimation, incorporating exports with zero values. Such a non-linear model appropriately handles the zero values of exports and provides a consistent, unbiased estimates.

To implement PPML, we assume that the following relationship holds:

$$\begin{aligned}\mathbb{E}(\text{Exports}_{jiy}|X_{jiy}) = \exp\Big(&\alpha_0 + \theta_{ji} + \theta_y + \gamma_{sea,y} \times \ln(\text{Sea Distance}_{ji}) \\ &+\gamma_{air,y} \times \ln(\text{Air Distance}_{ji}) + \gamma_{surface,y} \times \ln(1 + 1/\text{Surface Distance}_{ji}) \\ &+\gamma_{sharedborder,y} \times \text{Shared Land Border}_{ji}\Big) \qquad (2)\end{aligned}$$

where j, i and y denote the source country, target country, and year, respectively. Note that in the gravity equation, we use annual data in order to increase the predictive power to predict export through our instrumental variables. The above equation shows that the export is a function of air distance, sea distance, surface distance and sharing border dummy. The presence of $\gamma_{air,y}$, $\gamma_{sea,y}$, $\gamma_{surface,y}$ and $\gamma_{sharedborder,y}$ means that the effect of sea distance and other related variables have different effects at different year. In estimation, this can be handled by interacting distance variables with year dummies. The outcome variable is the annual export of source country j to target country i at year y. X_{ijy} is a set of explanatory variables such as sea distance, air distance, shared Land border dummies, their interaction with year dummies. θ_{ij} is the pair fixed effect, and θ_y is the year fixed effect.

The set of parameters in the above model is obtained by solving the following condition (Motta, 2019).

properly through the Suez Canal if it is the shortest shipping route at sea.

$$\sum_{j,i,y} \left(\text{Exports}_{jiy} - \mathbb{E}(\text{Exports}_{jiy}|X_{jiy})\right) X_{jiy} = 0 \tag{3}$$

where X_{jiy} are the explanatory variables in the gravity equation.

Once the estimated coefficients $\hat{\gamma}$ are obtained, the predicted export values, $\hat{\text{Exports}}_{ijt}$, can be obtained by plugging the estimated coefficients back into the exponential functional form:

$$\widehat{\text{Exports}}_{jiy} = \exp\Big(\hat{\alpha}_0 + \hat{\theta}_{ji} + \hat{\theta}_y + \hat{\gamma}_{sea,y} \times \ln(\text{Sea Distance}_{ji}) + \hat{\gamma}_{air,y} \times \ln(\text{Air Distance}_{ji}) \\ + \hat{\gamma}_{surface,y} \times \ln(1 + 1/\text{Surface Distance}_{ji}) + \hat{\gamma}_{sharedborder,y} \times \text{Shared Land Border}_{ij}\Big) \tag{4}$$

These predicted values represent the expected exports between country pairs given the model's explanatory variables. We then summed the predicted exports to obtain the total predicted exports for each source country and each period:

$$\text{Predicted Exports}_{jt} = \sum_{y \in t} \sum_{i} \widehat{\text{Exports}}_{ijy} \tag{5}$$

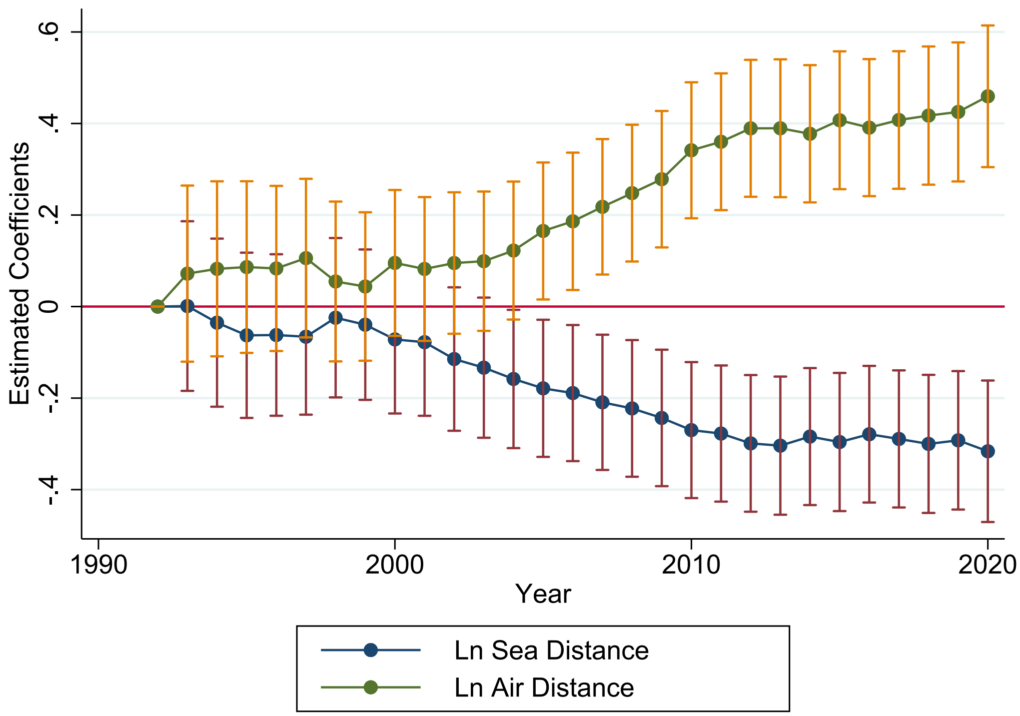
$$\ln \text{E}xports_{jt} = \delta_0 + \delta_1 \ln \text{Predicted Exports}_{jt} + \delta_2 \text{z}_{jt} + \lambda_j + \lambda_t + \varepsilon_{jt} \tag{6}$$

$$\ln Y^a_{jt} = \alpha_0 + \alpha_1 \ln \text{Exports}_{jt} + \alpha_2 \text{z}_{jt} + \eta_j + \eta_t + \xi_{jt} \tag{7}$$

$$j = 1, 2, \ldots, 104,\ t = 1, 2, \ldots, 5.$$

where j denotes the country and t denotes the time period, measured in five-year intervals. $y \in t$ denotes all years included in period t. Equation (6) represents the first-stage estimation. The endogenous explanatory variable is Ln Exports_{jt}, which represents the natural logarithm of the total exports of country j at time t. The instrumental variable for this endogenous variable is Ln Predicted Exports_{jt}, the natural logarithm of predicted exports, which are estimated based on changes in geographic advantages.

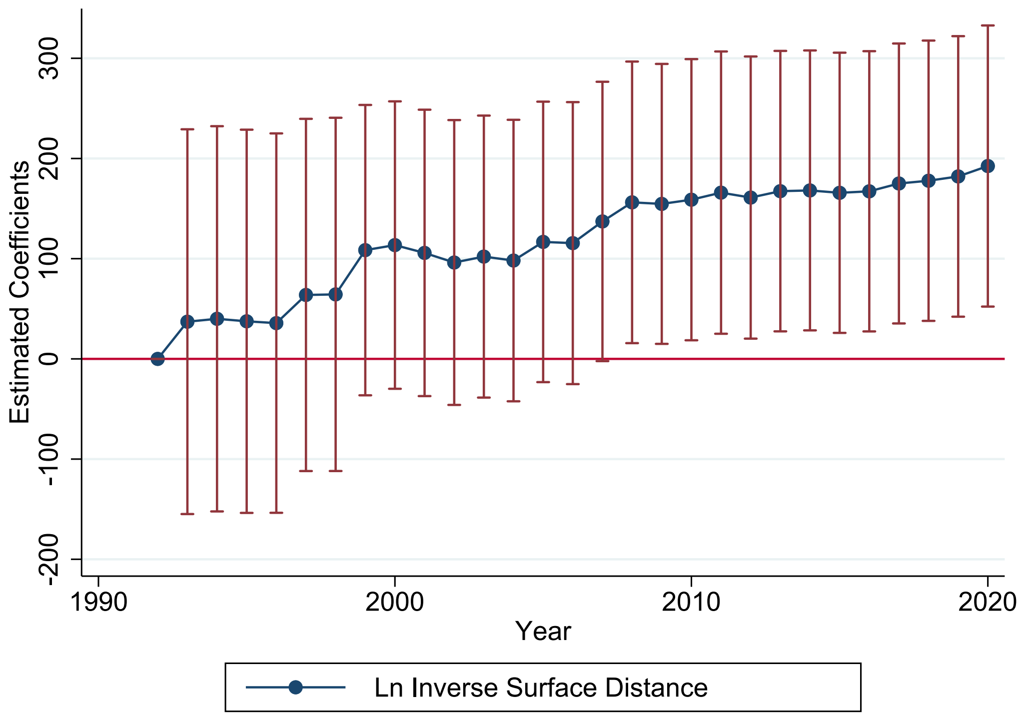
Figure 9: Changing Importance of Different Transportation Mode: The Estimated Coefficients of Sea Distance and Air Distance over Time



Notes: This figure is based on the estimation results from a Poisson Pseudo-Maximum Likelihood (PPML) model using equations (5) and (6). The dependent variable is exports, and the explanatory variables include distance measures, their interactions with year dummies, and fixed effects. To create the graph, the estimated coefficients and standard errors for the natural logarithm of sea distance by year and air distance by year are presented with 95% confidence intervals.

Figure 9 shows the estimated coefficients for natural logarithm of air distance and sea distance by estimating equation (2) for 104 countries over the span of 29 years, from 1992 to 2020. The estimated coefficients of natural logarithm of air distance over time indicate the marginal effect of longer air distance become more positive to export as time passes and the marginal effect of sea distance become more negative as time passes. It shows that shipping through air cargo become more beneficial and shipping through sea became more disadvantageous.

Figure 10: The Change in Export Level with Respect to Surface Distance in the Same Continent Over Time From a Gravity Regression With Pair Fixed Effect

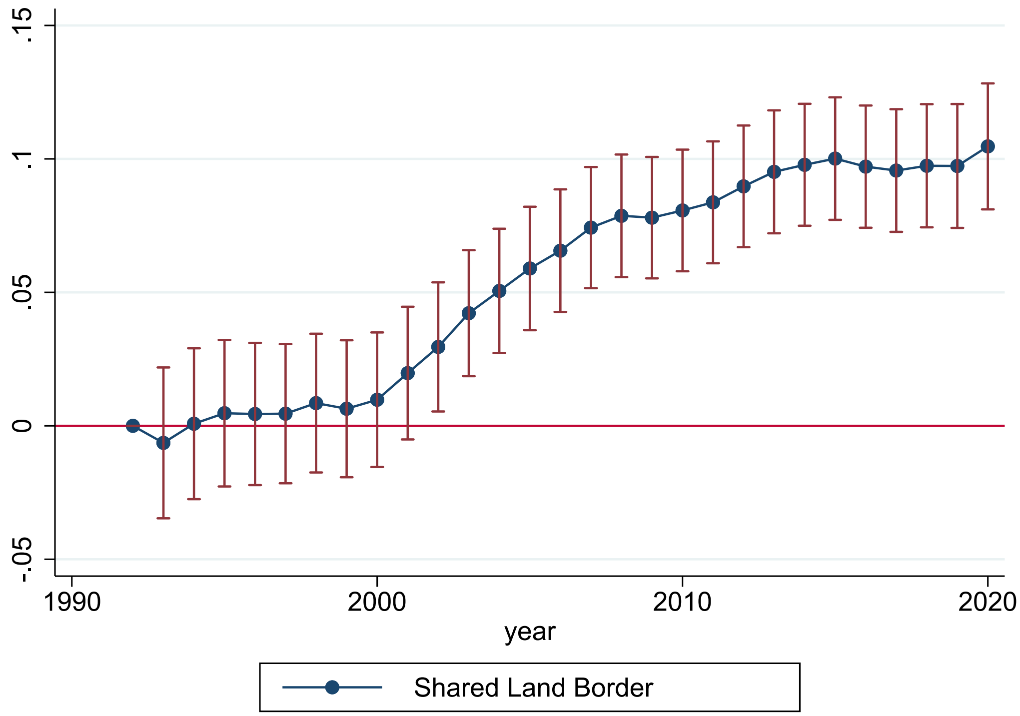


Notes: This figure is based on the estimation results from a Poisson Pseudo-Maximum Likelihood (PPML) model using equations (5) and (6). The dependent variable is exports, and the explanatory variables distance measures, their interaction with year dummies, and fixed effects. To create the graph, the estimated coefficients and standard errors for the $\ln(1+1/\text{Surface Distance}_{ij})$ by year is presented with 95% confidence intervals.

Figure 10 describes the change in export levels with respect to one plus the reciprocity of surface distance. Note that if two countries are on different continents, we assume that surface distance is infinity and $\ln(1+1/\text{surface distance}_{ij}) = 0$. Essentially, Figures 10 and 9 show the same pattern. HOlding air distance and sea distance constant, a shorter surface distance is correlated with an increase in relative exports over time.

Figure 11 shows the change in the marginal effect of having borders with many countries. The explanatory variable is the number of shared borders. Figure 11 indicates that it is more advantageous to share borders with many countries. Due to the very short distances with neighboring countries, conducting exports over land has been much more effective in such

Figure 11: The Change in Export Level with Respect to Shared Land Border Over Time From a Gravity Regression With Pair Fixed Effect



Notes: This figure is based on the estimation results from a Poisson Pseudo-Maximum Likelihood (PPML) model using equations (5) and (6). The dependent variable is exports, and the explanatory variables are distance measures, their interaction with year dummies, and fixed effects. To create the graph, the estimated coefficients and standard errors for the shared land border by year are presented with 95% confidence intervals.

cases, which might be attributed to the construction of highway networks across countries.

3.3 Dataset Construction

This study utilizes data for 104 countries with averaged five years interval from 1997 to 2020.[5] We included countries with ports for international trade and excluded landlocked countries. For the choice of countries, we follow the guideline practiced by Henderson et al. (2012). We do not include Serbia and Montenegro in the sample due to border changes, and we exclude small island countries. Bahrain, Hong Kong, and Qatar are omitted because of

[5] Table A7 in Supplemental Information section presents the list of countries included in the sample.

top-coded lights and the lack of a non-trade hub area. Additionally, we exclude Equatorial Guinea, as most of its lights come from gas flares.

To measure exports, bilateral trade data from 1997 to 2020 were obtained from the Direction of Trade (DoT) database provided by the International Monetary Fund (IMF). Since exports are unlikely to have an immediate effect on nightlight intensity, we use five-year averages of export values in our analysis. Moreover, annual nightlight data can be noisy, and aggregating the data at five-year intervals helps reduce this noise and mitigate distortions.

The fourth version of the Gridded Population of the World (GPWv4) dataset was obtained from the Socioeconomic Data and Applications Center (SEDAC) Center for International Earth Science Information Network–CIESIN–Columbia University (2018). This spatially disaggregated dataset provides population counts at five-year intervals—for the years 2000, 2005, 2010, 2015, and 2020—with a resolution of 30 arc-seconds (approximately one kilometer at the equator). The local population count (number of persons per pixel) for both trade hub and non–trade hub areas is extracted using the same spatial procedure applied to the night lights data.

Temperature and precipitation data are obtained from the Climate Research Unit Time Series (CRU-TS) version 4.06 (Harris et al., 2020). This dataset provides monthly observations from 1901 to 2000 at a spatial resolution of 0.5° × 0.5° (latitude/longitude) grids. For our analysis, the data were aggregated into five-year averages at the local level for both trade hub and non–trade hub areas, as well as at the national level.

3.3.1 Trade Hub and Non-trade hub area

Trade hub areas are defined as the union of areas within a 30 km or 50 km radius of each of the three largest ports (port urban areas) and three international airports (airport urban area) in a country.

To identify the location of ports in our sample, we obtain the geographic coordinates of ports along the coast and in inland cities from Google Earth. Then, a buffer area with a 30 km or 50 km radius is constructed around each port city and inland city. We define the union of all three port urban areas and three airport urban areas in a country as the trade hub area. If a country has fewer than three ports, we account for those two or one ports as a port area—such as Singapore, which has only one main port for international trade. We exclude ports used for purposes other than trade, such as fisheries or tourism.

A total of more than 350 of the largest ports and 300 inland cities in the world were combined to construct trade hub area. To obtain the non-trade hub area, we subtracted the trade hub area from the entire country; the remaining area is the non-trade hub area.

3.3.2 Lights Data

We use nightlight data from two main sources: the United States Air Force Defense Meteorological Satellite Program (DMSP) for the period 1997–2013, and the harmonized version of the Visible Infrared Imaging Radiometer Suite (VIIRS) data produced by the NOAA National Centers for Environmental Information. The combined dataset provides annual observations from 1997 to 2020 at a spatial resolution of 1 km × 1 km. From these data, we extract nightlight intensity for both trade hub and non–trade hub areas within each country, and calculate the total nightlight intensity for each area. For years in which data were available from two satellites, we use the average value. To compute nightlight intensity per capita for trade hub and non–trade hub areas, we divide the total nightlight intensity by the local population in each area, as measured using gridded population data.

Night lights close to North pole and South pole are affected by weather. Thus, We restricted the geographic extent to a latitude range between -65 and 66.63 degrees, which effectively excluded the areas north of the Arctic Circle.

4 Results

4.1 Exports and Lights

Table 2 presents the descriptive statistics of the variables. Panels A, B, and C show the descriptive statistics for the trade hub area, non-trade hub area, and the entire country at five-year intervals, respectively. This is panel data for 104 countries with a sample size of 520.

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
A. Trade Hub Area					
Lights (DN in thousand)	520	213.82	187.267	3.177	769.82
Ln Lights	520	11.845	1.005	8.064	13.554
Lights per Capita (DN per capita)	520	0.061	0.091	0.004	0.956
Ln Lights per Capita	520	-3.323	0.959	-5.612	-0.045
Population (in million)	520	8.258	10.994	0.066	87.917
Temprature (°C)	520	19.643	7.017	2.721	28.478
Precipitation (mm)	520	102.635	63.048	5.826	284.321
B. Non-Trade Hub Area					
Lights (DN in thousand)	520	6276.458	17726.494	0.125	150134.05
Ln Lights	520	13.938	2.105	4.829	18.827
Lights per Capita (DN per capita)	520	0.382	0.976	0.004	13.096
Ln Lights per Capita	520	-1.92	1.227	-5.429	2.572
Population (in million)	520	50.874	170.753	0.001	1391.531
Temprature (°C)	520	19.082	7.949	-3.328	28.936
Precipitation (mm)	520	105.124	70.521	2.175	327.46
C. Country Level Variables					
Ln Export	520	-4.537	2.427	-12.614	0.838
Ln Predicted Exports	520	-4.455	2.323	-10.857	0.756
Difference of ln Lights	520	-2.093	1.477	-5.558	5.284
Difference of ln Lights per Capita	520	-1.403	0.827	-3.98	0.259
Difference of ln Population	520	-0.69	1.215	-3.741	6.198
Lights	520	6493206.7	17828538	3599.906	1.51E+08
Ln Lights	520	14.19	1.752	8.189	18.831
Population (in million)	520	59.132	179.003	0.071	1443.72
Temprature (°C)	520	19.087	7.903	-2.845	28.875
Precipitation (mm)	520	103.581	68.939	2.202	328.134
Number of Countries			104		

Note: Data is in five-years interval from 1997 to 2020.

Table 3 presents the results of the Ordinary Least Squares (OLS) estimations. The dependent variable is the natural logarithm of nightlight intensity in each area (trade hub or non–trade hub), and the main explanatory variable is the natural logarithm of exports. In Columns (2) and (5), we control for national population, as we are interested in the effect of exports on nightlight intensity per capita in an alternative specification. In Columns (3)

Table 3. Ordinary Least Squares Estimated Effects of Exports on Lights in Trade Hub Area and Non-Trade Hub Area

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Areas			Non-Trade Hub Areas		
A. OLS Estimates						
Dependent Variable	Ln Lights			Ln Lights		
ln Exports	0.129***	0.129***	0.130***	0.0449***	0.0453***	0.0435***
	(0.0253)	(0.0256)	(0.0264)	(0.0161)	(0.0160)	(0.0162)
R-Squared	0.990	0.990	0.990	0.998	0.998	0.998
B. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	104	104	104	104	104	104
N	520	520	520	520	520	520

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

and (6), we control for local weather conditions, as weather can directly affect nightlight measurements through its influence on electricity generation and cloud cover.

Table 4 presents the results of the first stage of the Two-Stage Least Squares (2SLS) estimation. Predicted exports are derived from the regression results of our dynamic gravity equation. Column (3) shows a strong relationship between predicted exports and actual exports. The diagnostic tests support the validity of the instrument. The Kleibergen–Paap Wald F-statistic is 18.39, exceeding the conventional threshold of 10, indicating that the instrument is sufficiently strong. Following the guidance of Windmeijer (2025), we also report the effective F-statistic for a single endogenous variable, which is 18.53—again above the standard cutoff—further confirming instrument strength.

Table 5 presents the second-stage and reduced-form regression results from the 2SLS estimation. The estimated coefficients in Columns (3) and (6) indicate that a one percent increase in exports raises nightlight intensity by 0.29 percent in trade hub areas and 0.06

Table 4. First Stage Estimated Effects of Predicted Exports on Actual Exports

	(1)	(2)	(3)
A. OLS Estimates			
Dependent Variable		Ln Exports	
ln Predicted Exports	1.073***	1.074***	1.032***
	(0.218)	(0.211)	(0.215)
Kleibergen–Paap rk Wald F Statistic	19.34	20.78	18.39
Effetive F Statistic	19.49	20.94	18.53
R-Squared	0.975	0.975	0.975
B. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

percent in non–trade hub areas, respectively.

One potential concern is that this study compares highly urbanized areas (trade hub areas) with very remote regions (non–trade hub areas), which may exaggerate the observed disparities. To address this concern, we conduct a 2SLS regression using national-level nightlight intensity per capita as the dependent variable. Table 6 presents the results. The estimated coefficient on $\ln(\text{Export})$ in Table 6 is very similar to the coefficient for non–trade hub areas reported in Table 5. This suggests that the effect of exports on nightlight intensity at the national level largely reflects their impact on non–trade hub areas. In contrast, the effect in trade hub areas is approximately five times larger. Notably, in our dataset, only 36 percent of the population resides in trade hub areas. Therefore, the majority of the population—64 percent—experiences significantly smaller benefits from export growth, as reflected in nightlight intensity.

Table A1 presents the second-stage and reduced-form results of the 2SLS estimation,

Table 5. The Second Stage Estimated Effects of Exports on Lights in Trade Hub Area and Non-Trade Hub Area

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Lights			ln Lights		
ln Exports	0.287***	0.284***	0.293***	0.0599	0.0684	0.0621
	(0.0651)	(0.0637)	(0.0657)	(0.0744)	(0.0730)	(0.0777)
B. Reduced Form Estimates						
ln Predicted Exports	0.308***	0.305***	0.302***	0.0642	0.0735	0.0635
	(0.0720)	(0.0709)	(0.0713)	(0.0838)	(0.0833)	(0.0844)
R-Squared	0.988	0.988	0.988	0.998	0.998	0.998
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	104	104	104	104	104	104
N	520	520	520	520	520	520

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

where the dependent variable is the difference between the natural logarithm of nightlight intensity in trade hub areas and that in non–trade hub areas.[6] The results show that a one percent increase in exports raises the difference in log nightlight intensity between trade hub and non–trade hub areas by 0.23 percentage points. As expected based on the findings in Table 5, Table A1 provides further evidence that export growth widens the income gap between trade hub and non–trade hub areas.

Tables 5 and A1 show that an exogenous increase in exports leads to greater urban–rural inequality in nightlight intensity, which we interpret as a proxy for broader economic inequality between rural and urban areas. This finding naturally raises the question of whether

[6] See Table A1 in the Supplementary Information section.

Table 6. The Second Stage Estimated Effects of Exports on Lights: Regression Estimations at the Country Level

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable		ln Lights	
Ln Exports	0.0536	0.0632	0.0584
	(0.0708)	(0.0697)	(0.0732)
B. Reduced Form Estimates			
Ln Predicted Exports	0.0575	0.0679	0.0600
	(0.0798)	(0.0797)	(0.0801)
R-Squared	0.997	0.997	0.997
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
National Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

the widening gap in nightlight intensity between trade hub and non–trade hub areas induces migration from non–trade hub areas to trade hub areas.

Table 7 examines the impact of export growth on local population using 2SLS estimation, while Table A2 analyzes the effect of trade on the difference in the natural logarithm of population between trade hub and non–trade hub areas.[7] The results in Table 7 indicate that a one percent increase in exports increases the population of trade hub areas by 0.12 percent, compared to just 0.002 percent in non–trade hub areas. Table A2 further shows that a one percent increase in exports widens the population gap between the two areas by 0.13 percent. Although this effect is smaller than the corresponding impact on nightlight intensity, the findings suggest that export growth contributes to population shifts from non–trade hub areas to trade hub areas.

[7] See Table A2 in the Supplementary Information section.

Table 7. The Second Stage Estimated Effects of Exports on Population in Trade Hub Area and Non-Trade Hub Area

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Local Population			ln Local Population		
ln Exports	0.168**	0.112**	0.126**	0.0536	0.00106	0.00250
	(0.0809)	(0.0524)	(0.0541)	(0.0748)	(0.0194)	(0.0232)
B. Reduced Form Estimates						
ln Predicted Exports	0.180**	0.120**	0.130**	0.0575	0.00114	0.00256
	(0.0895)	(0.0540)	(0.0541)	(0.0823)	(0.0211)	(0.0240)
R-Squared	0.994	0.998	0.998	0.998	1.000	1.000
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	104	104	104	104	104	104
N	520	520	520	520	520	520

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 8 presents the second-stage and reduced-form estimates of the effect of exports on nightlight intensity per capita. The coefficients in Columns (3) and (6) indicate that a one percent increase in exports raises lights per capita by 0.17 percent in trade hub areas and 0.06 percent in non–trade hub areas. Table 9 reports the corresponding results at the national level, showing that the estimated coefficient on $\ln(\text{Exports})$ is very similar to that for non–trade hub areas in Table 8. This suggests that the national-level effect primarily reflects the impact on non–trade hub areas, while the effect in trade hub areas is substantially larger. These results imply that individuals in trade hub areas benefit more from export growth, resulting in higher per capita income. Supporting this interpretation, Table A3 shows that a one percent increase in exports raises the difference in the logarithm of lights per capita between trade hub and

Table 8. The Second Stage Estimated Effects of Exports on Lights per Capita in Trade Hub Area and Non-Trade Hub Area

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Lights per Capita			ln Lights per Capita		
ln Exports	0.119	0.172***	0.168***	0.00630	0.0673	0.0596
	(0.0896)	(0.0619)	(0.0644)	(0.112)	(0.0750)	(0.0815)
B. Reduced Form Estimates						
ln Predicted Exports	0.128	0.185**	0.173**	0.00676	0.0735	0.0610
	(0.0962)	(0.0718)	(0.0714)	(0.121)	(0.0833)	(0.0886)
R-Squared	0.978	0.986	0.986	0.987	0.998	0.993
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	104	104	104	104	104	104
N	520	520	520	520	520	520

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

non–trade hub areas by 0.10 percent.[8]

[8]See Table A3 in the Supplementary Information section.

Table 9. The Second Stage Estimated Effects of Exports on Lights per Capita: Regression Estimations at the Country Level

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable		ln Lights per Capita	
Ln Exports	-0.00243	0.0632	0.0584
	(0.112)	(0.0697)	(0.0732)
B. Reduced Form Estimates			
Ln Predicted Exports	-0.00261	0.0679	0.0600
	(0.121)	(0.0797)	(0.0801)
R-Squared	0.985	0.993	0.993
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
National Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

4.2 Does NTL Capture Household Living Standards?

In the previous subsection, we employed night light intensity and night light per capita as proxies for income and income per capita. However, several studies have raised concerns about the validity of using night light as a proxy for income or household living standards at the subnational level in low-income countries (Keola et al., 2015; Gibson et al., 2021). This criticism is particularly pertinent in the context of Sub-Saharan Africa, where many regions exhibit little or no light emissions. To assess whether night light per capita accurately reflects household living standards, this section examines its relationship with data from the Demographic and Health Surveys (DHS). As proxies for household living standards, we use indicators of asset ownership and housing conditions, including access to electricity, use of clean cooking fuel, type of flooring material, and ownership of a radio, television, bicycle, and motorcycle.

Since the Demographic and Health Survey (DHS) is not a panel dataset, we construct a quasi-panel using the GPS coordinates of each cluster (village). Specifically, we designate the earliest available survey as the base wave and match each cluster in subsequent waves to a cluster in the base wave if it is located within 10 kilometers. If multiple clusters in a subsequent wave fall within this distance, we select the one closest to the base cluster. Clusters in the base wave with no corresponding match in later waves are excluded from the analysis. Our sample is limited to Sub-Saharan African countries with at least two DHS survey waves that include GPS data.[9]

After constructing the quasi-panel dataset of clusters, we create a 10-kilometer buffer around each cluster in the base wave and calculate the average night light intensity for each five-year period. The variable period denotes these five-year intervals.

To quantify the effect of night light per capita on household living standards, we estimate the following equation:

[9] Table A9 in the Supplementary Information lists the Sub-Saharan African countries included in the analysis.

$$Y_{cth} = \beta_0 + \beta_1 \ln(\text{Lights per Capita}_{ct}) + \beta_2 \mathbf{z}_{cth} + \lambda_c + \lambda_t + \eta_{cth} \tag{8}$$

In this specification, c and t denote the cluster and time period indices, respectively, with time measured in five-year intervals. The subscript h denotes the household. We compile DHS data from 21 countries and construct a quasi-panel dataset based on GPS coordinates, assigning each cluster a unique index c. The outcome variable, Y_{cth}, is a binary indicator representing asset ownership or housing conditions. The key explanatory variable, $\ln(\text{Lights per Capita}ct)$, is the natural logarithm of the five-year average of night light intensity per capita in each cluster. The vector $\mathbf{z}_{cth}$ includes household-level control variables such as the household head's years of schooling, age, and gender; the mother's years of schooling and age; and household size.

We control for cluster fixed effects, λ_c, which account for unobserved, time-invariant characteristics specific to each cluster, and time fixed effects, λ_t, which capture period-specific shocks common to all clusters. The error term is denoted by η_{cth}. Standard errors are clustered at the cluster level to allow for correlation of error terms within clusters across households and time periods.

Table 10 presents the estimated coefficients, standard errors, and R-squared values. We run the regressions separately for each outcome variable.[10] The results consistently show that lights per capita have a positive and statistically significant effect on household asset ownership and housing conditions.

[10]Descriptive statistics are provided in Table A8 in Supplementary Information A.

Table 10. The Estiamted Effects of Lights per Capita on Household Living Standard
Country-Cluster Analysis of Sub-Saharan African Countries

	(1)	(2)	(3)
	Estimated Coefficient	S. E	R-Squared
List of Dependent Variables			
Electricity Dummy	0.0977***	(0.0103)	0.602
Radio Dummy	0.0668***	(0.00825)	0.207
TV Dummy	0.113***	(0.00777)	0.497
Bicycle Dummy	0.0479***	(0.00750)	0.304
Motorcycle Dummy	0.0180***	(0.00632)	0.301
Floor Dummy	0.0159*	(0.00884)	0.561
Cooking Fuel Dummy	0.0112*	(0.00638)	0.588
Cluster FE	Yes		
Time FE	Yes		
Explanatory Variables	Ln Lights per Capita and Controls		
Countries	21		
Clusters	5,784		
N	211,286		

Notes: We ran separate regressions for each outcome variable. Controls include household head characteristics, respondent's characteristics and household size. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each cluster. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

4.3 Robustness Checks

In the previous subsection, we have shown that an increase in exports leads to an increase in night lights in trade hub areas. However, one might be concerned that defining trade hub areas as the union of areas within a 30 km radius of each of the three major ports and three international airports in a country could primarily capture the lights from the ports or airports themselves, rather than from surrounding economic activity. To address this concern, we redefined trade hub areas as the union of areas within a 30 km radius of each of the three major ports and international airports, but excluded lights within a 3 km radius of each port and airport from the analysis. This adjustment ensures that the lights emitted directly by the ports and airports are excluded, allowing us to better capture the surrounding economic activity within trade hub areas.

Tables 11, 12, and 13 show that even after excluding the lights within a 3 km radius of each port and airport, the results remain consistent with the main findings. The estimated effects of exports on the differences in night lights, population, and lights per capita are provided in the Supplementary Information section (see Tables A4, A5, and A6 on Supplemental Information A).

As a second robustness check, we redefine trade hub areas as the union of areas within a 50-kilometer radius of each of the three major ports and three international airports in a country. The estimated effects of exports on night lights, population, and lights per capita are reported in the Supplementary Information section (see Tables B1–B7 in Supplementary Information B). The results show that a one percent increase in exports raises night light intensity by 0.37 percent in trade hub areas and by 0.10 percent in non–trade hub areas. These findings are consistent with our main results and confirm the robustness of our analysis.

As a third robustness check, we exclude the United States and Canada from the analysis. Measuring sea distance for these two countries is particularly sensitive to port selection, as both border the Atlantic and Pacific Oceans. In our baseline analysis, we assume that countries located near the Atlantic Ocean trade with the U.S. and Canada via the ports of New York and Montreal, while countries near the Pacific Ocean trade via the ports of Los Angeles and Vancouver. To assess the robustness of this assumption, we exclude the United States

Table 11. The Second Stage Estimated Effects of Exports on Lights in Trade Hub Area & Non-Trade Hub Area: Results Within a 30 km Radius Buffer Area After Removing the Central 3 km Radius Around Trade Hubs

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Lights			ln Lights		
ln Exports	0.289***	0.286***	0.295***	0.0599	0.0684	0.0621
	(0.0669)	(0.0655)	(0.0675)	(0.0744)	(0.0730)	(0.0777)
B. Reduced Form Estimates						
ln Predicted Exports	0.310***	0.307***	0.304***	0.0642	0.0735	0.0635
	(0.0733)	(0.0722)	(0.0726)	(0.0838)	(0.0833)	(0.0844)
R-Squared	0.988	0.988	0.988	0.998	0.998	0.998
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	104	104	104	104	104	104
N	520	520	520	520	520	520

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

and Canada entirely and rerun the regression. The results are presented in Supplementary Information C. The estimated effects and their statistical significance remain consistent with our main findings.

Another potential criticism of our main regression is that the results may simply reflect regional differences in economic growth, along with variations in sea and air distances across continents. To address this concern, we conduct a fourth robustness check by excluding countries from one region at a time and re-estimating our model. For example, in one case, we exclude all countries in Central and South America; in another, we exclude all Sub-Saharan African countries. If the estimated coefficients from these robustness checks

Table 12. The Second Stage Estimated Effects of Exports on Population in Trade Hub Area and Non-Trade Hub Area: Results Within a 30 km Radius Buffer Area After Removing the Central 3 km Radius Around Trade Hubs

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Local Population			ln Local Population		
ln Exports	0.163**	0.107**	0.120**	0.0536	0.00106	0.00250
	(0.0806)	(0.0524)	(0.0541)	(0.0748)	(0.0194)	(0.0232)
B. Reduced Form Estimates						
ln Predicted Exports	0.175*	0.115**	0.124**	0.0575	0.00114	0.00256
	(0.0897)	(0.0547)	(0.0549)	(0.0823)	(0.0211)	(0.0240)
R-Squared	0.994	0.998	0.998	0.998	1.000	1.000
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	104	104	104	104	104	104
N	520	520	520	520	520	520

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

are similar to those in the main results, it suggests that concerns about regional differences driving the results are unfounded. Figures D1–D7 present the results of these regressions. The estimates are consistent with the main findings reported in Tables 7, 8, and 9, reinforcing the robustness of our conclusions.

Table 13. The Second Stage Estimated Effects of Exports on Lights per Capita in Trade Hub & Non-Trade Hub Areas: Results Within a 30 km Radius Buffer Area After Removing the Central 3 km Radius Around Trade Hubs

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Lights per Capita			ln Lights per Capita		
ln Exports	0.126	0.179***	0.175***	0.00630	0.0673	0.0596
	(0.0912)	(0.0636)	(0.0661)	(0.112)	(0.0750)	(0.0815)
B. Reduced Form Estimates						
ln Predicted Exports	0.135	0.192***	0.180**	0.00676	0.0735	0.0610
	(0.0974)	(0.0727)	(0.0723)	(0.121)	(0.0833)	(0.0886)
R-Squared	0.978	0.986	0.986	0.987	0.998	0.993
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	104	104	104	104	104	104
N	520	520	520	520	520	520

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

5 Discussion

This study investigates the effects of exports on subnational economic development and rural–urban inequality using night lights data. Trade-hub areas are defined as the union of areas within a 30 km or 50 km radius of each of the three major ports and three international airports in a country. All other areas are classified as non–trade-hub areas.

Using a 30 km radius to define trade-hub areas, we find that a one percent increase in exports raises night light intensity by 0.29 percent in trade-hub areas and by 0.06 percent in non–trade-hub areas, resulting in a 0.23 percent increase in the difference in night light intensity. We also find that a one percent increase in exports increases the local population in trade-hub and non–trade-hub areas by 0.12 percent and 0.002 percent, respectively. As a result, night light per capita rises by 0.16 percent in trade-hub areas and by 0.05 percent in non–trade-hub areas. When we exclude circles with a 3 km radius around ports and airports to remove direct light emissions from these facilities, the results remain robust. When using the union of areas within a 50 km radius instead of a 30 km radius to define trade-hub areas, a one percent increase in exports increases night light intensity by 0.32 percent in trade-hub areas and by 0.06 percent in non–trade-hub areas.

Overall, these findings indicate that a one percent increase in exports raises the difference in nightlight per capita between rural and urban areas by approximately 0.10-0.2 percent. Between 1997 and 2018 (just before the COVID-19 pandemic), exports grew by an average of 380 percent across the countries included in our analysis. Based on our estimation results, night light per capita—a proxy for economic activity—increased by 76 percent in trade hub areas and by 36 percent in non-trade hub areas. Consequently, the gap in night light per capita between trade hub and non-trade hub areas widened by 34 percent. According to our data, in the year 2000, an average of 36 percent of each country's population resided in trade hub areas. Meanwhile, Table 12 shows that increased exports did not lead to a decline in the rural population. Therefore, our estimates suggest that the 64 percent of the population who originally lived in non-trade hub areas did not benefit from the export growth as much as the 36 percent who were already living in trade hub areas.

Our results are consistent with the findings of Storeygard (2016), but stand in sharp contrast to those of Hirte et al. (2020). Storeygard (2016) found that, with rising oil prices, the income of cities located closer to a major port increased by 7% relative to cities located a 500 km further from the port within the same country.

Hirte et al. (2020) find that international trade does not have an unconditional causal effect on inter-regional income inequality, based on their instrumental variable estimation. However, there are several reasons why our estimation results differ. First, while Hirte et al. (2020) use a Bartik-type instrument, we employ a dynamic gravity equation, where the variation is driven by exogenous changes in transportation costs and technology. Different instrumental variables could give different estimates on local average treatment effects. Second, and more importantly, Hirte et al. (2020) focus on inter-regional inequality and use the Gini index to measure it. The use of the Gini index implies that their analysis compares income not only between urban and rural areas, but also among rural areas themselves. In contrast, our study focuses specifically on the comparison between urban (trade hub) areas and rural (non-trade hub) areas.

6 Conclusion

Economic activity is unevenly distributed within countries. Nightlight data reveal that most economic activity is concentrated along coastlines or in inland urban centers, suggesting the presence of distinct urban trade hub areas and rural non-trade hub regions.

This study examines the economic impact of exports on both rural and urban areas within countries. We find that exports have uneven effects on local economic development, with trade hub areas benefiting significantly more than non-trade hub areas. This disparity suggests that export growth can inadvertently contribute to widening rural-urban inequality.

Our results indicate that while exports substantially boost economic performance in trade hub regions, their effects in non-trade hub areas are much more limited. As countries pursue export-led growth strategies, these findings underscore the importance of inclusive policies that ensure the benefits of trade extend beyond urban centers—so that prosperity can truly be shared across the entire landscape of a nation.

References

Center for International Earth Science Information Network–CIESIN–Columbia University (2018) "Gridded Population of the World, Version 4 (GPWv4): Population Count Revision 11 (NASA Socioeconomic Data and Applications Center (SEDAC)."

Feyrer, James (2019) "Trade and income—exploiting time series in geography," *American Economic Journal: Applied Economics*, 11 (4), 1–35.

——— (2021) "Distance, trade, and income—The 1967 to 1975 closing of the Suez Canal as a natural experiment," *Journal of Development Economics*, 153, 102708.

Frankel, Jeffrey and David Romer (1999) "Does trade cause growth?" *American Economic Review*, 83 (3), 379–99.

Gibson, John, Susan Olivia, Geua Boe-Gibson, and Chao Li (2021) "Which night lights data should we use in economics, and where?" *Journal of Development Economics*, 149, 102602.

Harris, Ian, Timothy J Osborn, Phil Jones, and David Lister (2020) "Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset," *Scientific data*, 7 (1), 109.

Henderson, J Vernon, Tim Squires, Adam Storeygard, and David Weil (2018) "The global distribution of economic activity: nature, history, and the role of trade," *The Quarterly Journal of Economics*, 133 (1), 357–406.

Henderson, J Vernon, Adam Storeygard, and David N Weil (2012) "Measuring economic growth from outer space," *American economic review*, 102 (2), 994–1028.

Hirte, Georg, Christian Lessmann, and André Seidel (2020) "International trade, geographic heterogeneity and interregional inequality," *European Economic Review*, 127, 103427.

Irwin, Douglas A and Marko Terviö (2002) "Does trade raise income?: Evidence from the twentieth century," *Journal of international Economics*, 58 (1), 1–18.

Keola, Souknilanh, Magnus Andersson, and Ola Hall (2015) "Monitoring economic development from space: using nighttime light and land cover data to measure economic growth," *World Development*, 66, 322–334.

Lessmann, Christian and André Seidel (2017) "Regional inequality, convergence, and its determinants–A view from outer space," *European Economic Review*, 92, 110–132.

Martinez, Luis R (2022) "How much should we trust the dictator's GDP growth estimates?" *Journal of Political Economy*, 130 (10), 2731–2769.

Meschi, Elena and Marco Vivarelli (2009) "Trade and income inequality in developing countries," *World development*, 37 (2), 287–302.

Motta, Victor (2019) "Estimating Poisson pseudo-maximum-likelihood rather than log-linear model of a log-transformed dependent variable," *RAUSP Management Journal*, 54 (4), 508–518.

Naranpanawa, Athula and Rashmi Arora (2014) "Does trade liberalization promote regional disparities? Evidence from a multiregional CGE model of India," *World Development*, 64, 339–349.

National Association of Counties (2024) "U.S. ELECTIONS 2024:INSIGHTS FOR AMERICA'S COUNTY OF OFFICIALS," *National Association of Counties*, `https://naco.sharefile.com/share/view/s6307e1e1bd78420d9abacf631c3f2786`.

Noguer, Marta and Marc Siscart (2005) "Trade raises income: a precise and robust result," *Journal of international Economics*, 65 (2), 447–460.

Pérez-Sindín, Xaquín S, Tzu-Hsin Karen Chen, and Alexander V Prishchepov (2021) "Are night-time lights a good proxy of economic activity in rural areas in middle and low-income countries? Examining the empirical evidence from Colombia," *Remote Sensing Applications: Society and Environment*, 24, 100647.

Rodriguez, Francisco and Dani Rodrik (2000) "Trade policy and economic growth: a skeptic's guide to the cross-national evidence," *NBER macroeconomics annual*, 15, 261–325.

Rodrik, Dani (2021) “Why does globalization fuel populism? Economics, culture, and the rise of right-wing populism,” *Annual review of economics*, 13 (1), 133–170.

Silva, JMC Santos and Silvana Tenreyro (2006) “The log of gravity,” *The Review of Economics and statistics*, 641–658.

Silva, Julie A and Robin M Leichenko (2004) “Regional income inequality and international trade,” *Economic Geography*, 80 (3), 261–286.

Storeygard, Adam (2016) “Farther on down the road: transport costs, trade and urban growth in sub-Saharan Africa,” *The Review of economic studies*, 83 (3), 1263–1295.

The Wall Street Journal (2024) “Presidential Election 2024: Live Results,” *The Wall Street Journal*, `https://www.wsj.com/election/2024/general`.

United Naitons: (2019) *The 2018 Revision of the World Urbanization Prospects*: United Nations Publications.

Windmeijer, Frank (2025) “The robust F-statistic as a test for weak instruments,” *Journal of Econometrics*, 247, 105951.

Supplemental Information A

Table A1. Second Stage Estimated Effects of Exports on the Difference in ln Lights Between Trade Hub Area and Non-Trade Hub Area

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Lights of Trade Hub & Non-Trade Hub Areas		
Ln Exports	0.227***	0.215***	0.237***
	(0.0606)	(0.0596)	(0.0661)
B. Reduced Form Estimates			
Ln Predicted Exports	0.244***	0.231***	0.244***
	(0.0498)	(0.0479)	(0.0497)
R-Squared	0.997	0.997	0.997
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
National Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table A2. Second Stage Estimated Effects of Exports on the Difference in Population Between Trade Hub Area and Non-Trade Hub Area

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Population of Trade Hub & Non-trade Hub Areas		
Ln Exports	0.114*	0.111*	0.130*
	(0.0643)	(0.0626)	(0.0704)
B. Reduced Form Estimates			
Ln Predicted Exports	0.122*	0.119*	0.133*
	(0.0681)	(0.0668)	(0.0726)
R-Squared	0.995	0.995	0.995
C. Specification			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
National Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variable weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table A3. Second Stage Estimated Effects of Exports on the Difference in Lights per Capita Between Trade Hub Area and Non-Trade Hub Area

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Lights per Capita of Trade Hub & Non-trade Hub Areas		
Ln Exports	0.113	0.105	0.108
	(0.0760)	(0.0747)	(0.0835)
B. Reduced Form Estimates			
Ln Predicted Exports	0.121	0.112	0.111
	(0.0779)	(0.0762)	(0.0813)
R-Squared	0.984	0.984	0.984
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
National Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table A4. Second Stage Estimated Effects of Exports on the Difference in Lights Between Trade Hub & Non-Trade Hub Areas: Results Within a 30 km Radius Buffer Area After Removing the Central 3 km Radius Around Trade Hubs

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Lights of Trade Hub & Non-Trade Hub Areas		
Ln Exports	0.229***	0.217***	0.239***
	(0.0607)	(0.0598)	(0.0662)
B. Reduced Form Estimates			
Ln Predicted Exports	0.246***	0.233***	0.246***
	(0.0490)	(0.0474)	(0.0491)
R-Squared	0.997	0.997	0.997
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table A5. Second Stage Estimated Effects of Exports on the Difference in Population Between Trade Hub & Non-Trade Hub Area: Results Within a 30 km Radius Buffer Area After Removing the Central 3 km Radius Around Trade Hubs

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Population of Trade Hub & Non-trade Hub Areas		
Ln Exports	0.110*	0.106*	0.124*
	(0.0642)	(0.0629)	(0.0707)
B. Reduced Form Estimates			
Ln Predicted Exports	0.118*	0.114*	0.127*
	(0.0685)	(0.0676)	(0.0734)
R-Squared	0.995	0.995	0.995
C. Specification			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variable weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table A6. Second Stage Estimated Effects of Exports on the Difference in Lights per Capita Between Trade Hub & Non-Trade Hub Area: Results Within a 30 km Radius Buffer Area After Removing the Central 3 km Radius Around Trade Hubs

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Lights per Capita of Trade Hub & Non-trade Hub Areas		
Ln Exports	0.119	0.111	0.115
	(0.0768)	(0.0759)	(0.0848)
B. Reduced Form Estimates			
Ln Predicted Exports	0.128	0.120	0.118
	(0.0779)	(0.0767)	(0.0818)
R-Squared	0.984	0.984	0.984
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	104	104	104
N	520	520	520

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table A7: List of Countries included in the Study

1	Albania	28	Dominican Rep	55	Jamaica	82	Poland
2	Algeria	29	Ecuador	56	Japan	83	Portugal
3	Angola	30	Egypt	57	Jordan	84	Romania
4	Argentinia	31	El Salvador	58	Kenya	85	Russian Federation
5	Australia	32	Estonia	59	Korea Rep	86	Senegal
6	Bahamas	33	Fiji	60	Latvia	87	Sierra Leone
7	Bangladesh	34	Finland	61	Lebanon	88	South Africa
8	Belgium	35	France	62	Liberia	89	Spain
9	Belize	36	Gambia	63	Lithuania	90	Sri Lanka
10	Benin	37	Georgia	64	Madagascar	91	Sweden
11	Brazil	38	Germany	65	Malaysia	92	Syria
12	Brunei	39	Ghana	66	Malta	93	Tanzania
13	Bulgaria	40	Greece	67	Mauritania	94	Thailand
14	Cambodia	41	Guatemala	68	Mexico	95	Togo
15	Cameroon	42	Guinea	69	Morocco	96	Trinidad & Tobago
16	Canada	43	Guinea Bassau	70	Mozambique	97	Tunisia
17	Chile	44	Guyana	71	Namibia	98	Turkey
18	China	45	Haiti	72	Netherlands	99	Ukraine
19	Colombia	46	Honduras	73	New Zealand	100	United Kingdom
20	Congo	47	Iceland	74	Nicaragua	101	United States
21	Congo DRC	48	India	75	Nigeria	102	Uruguay
22	Costa Rica	49	Indonesia	76	Norway	103	Vietnam
23	Croatia	50	Iran	77	Papu New Guinea	104	Yemen
24	Cuba	51	Iraq	78	Pakistan		
25	Cyprus	52	Ireland	79	Panama		
26	Denmark	53	Italy	80	Peru		
27	Dominica	54	Ivory Coast	81	Philliphines		

Note: In the sample countries are selected based on availability of data and we excluded landlocked countries from the analysis.

Table A8. Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Summed Lights	211286	2583.028	3430.032	364.066	21135.219
Population (sum)	211286	244204.86	509719.38	55.498	6053485.5
Lights Per Capita	211286	0.054	0.165	0.001	16.704
Ln Lights Per Capita	211286	-3.812	1.19	-6.847	2.816
Electricity Dummy	211286	0.327	0.468	0	1
Radio Dummy	211286	0.6	0.489	0	1
TV Dummy	211286	0.279	0.447	0	1
Motorcycle Dummy	211286	0.119	0.321	0	1
Bicycle Dummy	211286	0.266	0.44	0	1
Floor Dummy	211286	0.467	0.499	0	1
Cooking Fuel Dummy	211286	0.124	0.33	0	1
HH Head Age	211286	41.256	12.126	13	80
HH Head Gender	211286	0.73	0.444	0	1
HH Years of Schooling	211286	5.391	4.892	0	25
HH Size	211286	5.748	2.754	1	45
Respondent Age	211286	32.798	7.875	15	49
Respondent Years of Schooling	211286	4.764	4.458	0	26

Note: Lights are calculated for each cluster with a radius of 10 kilometers.

Table A9: List of Sub-Saharan African Countries Used for Analysis Investigating the Effects of Lights per Capita on Household Welfare

1	Benin	8	Ivory Coast	15	Rwanda
2	Burkina Faso	9	Kenya	16	Sierra Leone
3	Burundi	10	Lesotho	17	Tanzania
4	Cameroon	11	Malawi	18	Togo
5	Ethiopia	12	Mali	19	Uganda
6	Ghana	13	Namibia	20	Zambia
7	Guinea	14	Nigeria	21	Zimbabwe

Note: In the sample Sub-Saharan African countries are selected based on availability of DHS data with GPS information for at least two waves.

Online Supplemental Information

Table B1. First Stage Estimated Effects of Predicted Exports on Actual Exports
Results for the Trade Hubs with a 50 KM Radius Buffer Area

	(1)	(2)	(3)
A. OLS Estimates			
Dependent Variable		Ln Exports	
ln Predicted Exports	0.911***	0.915***	0.883***
	(0.178)	(0.175)	(0.187)
Kleibergen–Paap rk Wald F Statistic	21.03	21.89	17.80
Effetive F Statistic	21.19	22.06	17.94
R-Squared	0.974	0.974	0.974
B. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	102	102	102
N	510	510	510

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table B2. The Second Stage Estimated Effects of Exports on Lights in Trade Hub Area & Non-Trade Hub Area: : Results for the Trade Hubs with a 50 KM Radius Buffer Area

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Lights			ln Lights		
ln Exports	0.321***	0.321***	0.329***	0.0675	0.0730	0.0664
	(0.0751)	(0.0736)	(0.0769)	(0.0862)	(0.0852)	(0.0909)
B. Reduced Form Estimates						
ln Predicted Exports	0.293***	0.294***	0.291***	0.0615	0.0668	0.0580
	(0.0808)	(0.0798)	(0.0805)	(0.0842)	(0.0843)	(0.0855)
R-Squared	0.986	0.986	0.986	0.998	0.998	0.998
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	102	102	102	102	102	102
N	510	510	510	510	510	510

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table B3. The Second Stage Estimated Effects of Exports on Population in Trade Hub Area and Non-Trade Hub Area: Results for the Trade Hubs with a 50 KM Radius Buffer Area

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Local Population			ln Local Population		
ln Exports	0.153	0.115**	0.125**	0.0562	0.0218	0.0257
	(0.0936)	(0.0554)	(0.0578)	(0.0937)	(0.0360)	(0.0436)
B. Reduced Form Estimates						
ln Predicted Exports	0.139	0.105**	0.110**	0.0512	0.0199	0.0225
	(0.0860)	(0.0505)	(0.0511)	(0.0860)	(0.0329)	(0.0380)
R-Squared	0.994	0.998	0.998	0.998	1.000	1.000
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	102	102	102	102	102	102
N	510	510	510	510	510	510

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table B4. The Second Stage Estimated Effects of Exports on Lights per Capita in Trade Hub & Non-Trade Hub Areas: Results for the Trade Hubs with 50 KM Radius Buffer Area

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Lights per Capita			ln Lights per Capita		
ln Exports	0.169	0.207***	0.205***	0.0113	0.0512	0.0407
	(0.116)	(0.0729)	(0.0766)	(0.132)	(0.0918)	(0.101)
B. Reduced Form Estimates						
ln Predicted Exports	0.154	0.189**	0.181**	0.0103	0.0668	0.0355
	(0.111)	(0.0762)	(0.0766)	(0.122)	(0.0843)	(0.0930)
R-Squared	0.977	0.986	0.986	0.988	0.988	0.993
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	102	102	102	102	102	102
N	510	510	510	510	510	510

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table B5. Second Stage Estimated Effects of Exports on the Difference in Lights Between Trade Hub & Non-Trade Hub Areas: Results for the Trade Hubs with a 50 KM Radius Buffer

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Lights of Trade Hub & Non-Trade Hub Areas		
Ln Exports	0.254***	0.248***	0.270***
	(0.0608)	(0.0625)	(0.0687)
B. Reduced Form Estimates			
Ln Predicted Exports	0.231***	0.227***	0.237***
	(0.0383)	(0.0405)	(0.0403)
R-Squared	0.998	0.998	0.998
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	102	102	102
N	510	510	510

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table B6. Second Stage Estimated Effects of Exports on the Difference in Population Between Trade Hub & Non-Trade Hub Area: Results for the Trade Hubs with a 50 KM Radius Buffer Area

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Population of Trade Hub & Non-trade Hub Areas		
Ln Exports	0.0965	0.0927	0.106
	(0.0783)	(0.0785)	(0.0889)
B. Reduced Form Estimates			
Ln Predicted Exports	0.0879	0.0849	0.0932
	(0.0723)	(0.0729)	(0.0799)
R-Squared	0.995	0.995	0.995
C. Specification			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	102	102	102
N	510	510	510

Notes: The control variable weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table B7. Second Stage Estimated Effects of Exports on the Difference in Lights per Capita Between Trade Hub & Non-Trade Hub Area: Results for the Trade Hubs with a 50 KM Radius

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Lights per Capita of Trade Hub & Non-trade Hub Areas		
Ln Exports	0.157*	0.156*	0.164*
	(0.0851)	(0.0853)	(0.0977)
B. Reduced Form Estimates			
Ln Predicted Exports	0.143**	0.143**	0.144*
	(0.0709)	(0.0714)	(0.0780)
R-Squared	0.984	0.984	0.984
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	102	102	102
N	510	510	510

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table C1. First Stage Estimated Effects of Predicted Exports on Actual Exports
Results Within a 30 km Radius of Trade Hubs After Excluding the US and Canada

	(1)	(2)	(3)
A. OLS Estimates			
Dependent Variable	Ln Exports		
ln Predicted Exports	1.078***	1.081***	1.039***
	(0.233)	(0.225)	(0.228)
Kleibergen–Paap rk Wald F Statistic	17.07	18.51	16.54
Effetive F Statistic	17.21	18.66	16.67
R-Squared	0.973	0.973	0.973
B. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	102	102	102
N	510	510	510

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table C2. The Second Stage Estimated Effects of Exports on Lights in Trade Hub Area & Non-Trade Hub Area: Results Within a 30 km Radius of Trade Hubs After Excluding the US and Canada

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Lights			ln Lights		
ln Exports	0.288***	0.285***	0.293***	0.0394	0.0496	0.0460
	(0.0697)	(0.0678)	(0.0698)	(0.0783)	(0.0762)	(0.0804)
B. Reduced Form Estimates						
ln Predicted Exports	0.311***	0.308***	0.305***	0.0424	0.0536	0.0477
	(0.0753)	(0.0740)	(0.0746)	(0.0875)	(0.0865)	(0.0877)
R-Squared	0.988	0.988	0.988	0.998	0.998	0.998
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	102	102	102	102	102	102
N	510	510	510	510	510	510

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table C3. The Second Stage Estimated Effects of Exports on Population in Trade Hub Area and Non-Trade Hub Area: Results Within a 30 km Radius of Trade Hubs After Excluding the US and Canada

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Local Population			ln Local Population		
ln Exports	0.185**	0.118**	0.131**	0.0639	0.00132	0.00243
	(0.0866)	(0.0558)	(0.0576)	(0.0782)	(0.0210)	(0.0240)
B. Reduced Form Estimates						
ln Predicted Exports	0.199**	0.128**	0.136**	0.0689	0.00142	0.00252
	(0.0953)	(0.0574)	(0.0577)	(0.0864)	(0.0228)	(0.0252)
R-Squared	0.994	0.998	0.998	0.998	1.000	1.000
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	102	102	102	102	102	102
N	510	510	510	510	510	510

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table C4. The Second Stage Estimated Effects of Exports on Lights per Capita in Trade Hub & Non-Trade Hub Areas: Results Within a 30 km Radius of Trade Hubs After Excluding the US and Canada

	(1)	(2)	(3)	(4)	(5)	(6)
Area	Trade Hub Area			Non-Trade Hub Area		
A. Second-Stage Estimates						
Dependent Variable	ln Lights per Capita			ln Lights per Capita		
ln Exports	0.104	0.166**	0.163**	-0.0246	0.0483	0.0435
	(0.0945)	(0.0647)	(0.0675)	(0.119)	(0.0789)	(0.0846)
B. Reduced Form Estimates						
ln Predicted Exports	0.112	0.180**	0.169**	-0.0265	0.0536	0.0452
	(0.102)	(0.0747)	(0.0747)	(0.129)	(0.0865)	(0.0922)
R-Squared	0.978	0.986	0.986	0.986	0.998	0.992
C. Specifications						
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
National Population		Yes	Yes		Yes	Yes
Local Weather			Yes			Yes
Countries	102	102	102	102	102	102
N	510	510	510	510	510	510

Notes: The control variables include country-level population and local weather for trade hub and non-trade hub areas. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table C5. Second Stage Estimated Effects of Exports on the Difference in Lights Between Trade Hub & Non-Trade Hub Areas: Results Within a 30 km Radius of Trade Hubs After Excluding the US and Canada

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Lights of Trade Hub & Non-Trade Hub Areas		
Ln Exports	0.249***	0.235***	0.251***
	(0.0668)	(0.0646)	(0.0706)
B. Reduced Form Estimates			
Ln Predicted Exports	0.268***	0.254***	0.262***
	(0.0518)	(0.0490)	(0.0512)
R-Squared	0.997	0.997	0.997
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	102	102	102
N	510	510	510

Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table C6. Second Stage Estimated Effects of Exports on the Difference in Population Between Trade Hub & Non-Trade Hub Area: Results Within a 30 km Radius of Trade Hubs After Excluding the US and Canada

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Population of Trade Hub & Non-trade Hub Areas		
Ln Exports	0.121*	0.117*	0.132*
	(0.0694)	(0.0668)	(0.0730)
B. Reduced Form Estimates			
Ln Predicted Exports	0.130*	0.127*	0.137*
	(0.0735)	(0.0716)	(0.0762)
R-Squared	0.995	0.995	0.995
C. Specification			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	102	102	102
N	510	510	510

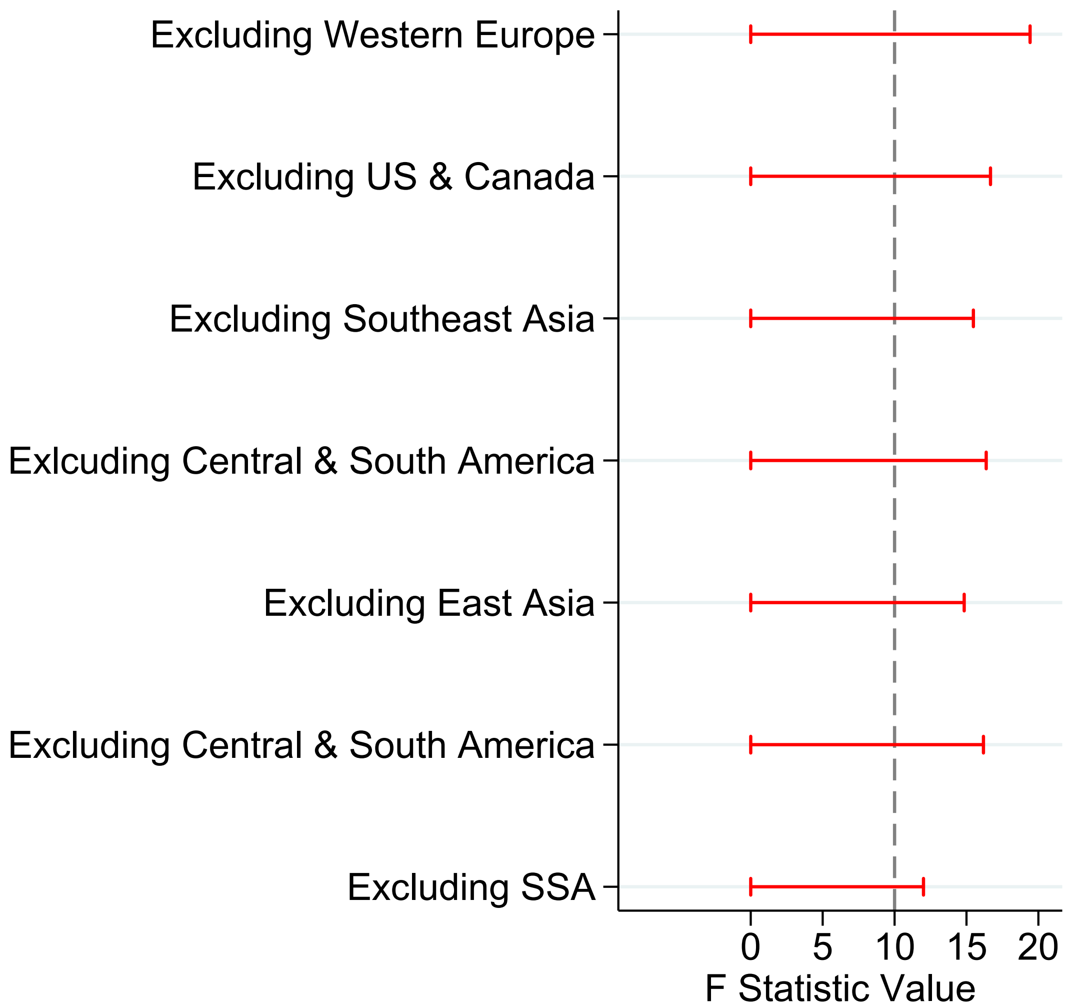
Notes: The control variable weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table C7. Second Stage Estimated Effects of Exports on the Difference in Lights per Capita Between Trade Hub & Non-Trade Hub Area: Results Within a 30 km Radius of Trade Hubs After Excluding the US and Canada

	(1)	(2)	(3)
A. Second-Stage Estimates			
Dependent Variable	Difference of ln Lights per Capita of Trade Hub & Non-trade Hub Areas		
Ln Exports	0.128	0.118	0.120
	(0.0817)	(0.0803)	(0.0876)
B. Reduced Form Estimates			
Ln Predicted Exports	0.138*	0.127	0.125
	(0.0830)	(0.0813)	(0.0854)
R-Squared	0.982	0.983	0.983
C. Specifications			
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
National Population		Yes	Yes
Local Weather			Yes
Countries	102	102	102
N	510	510	510

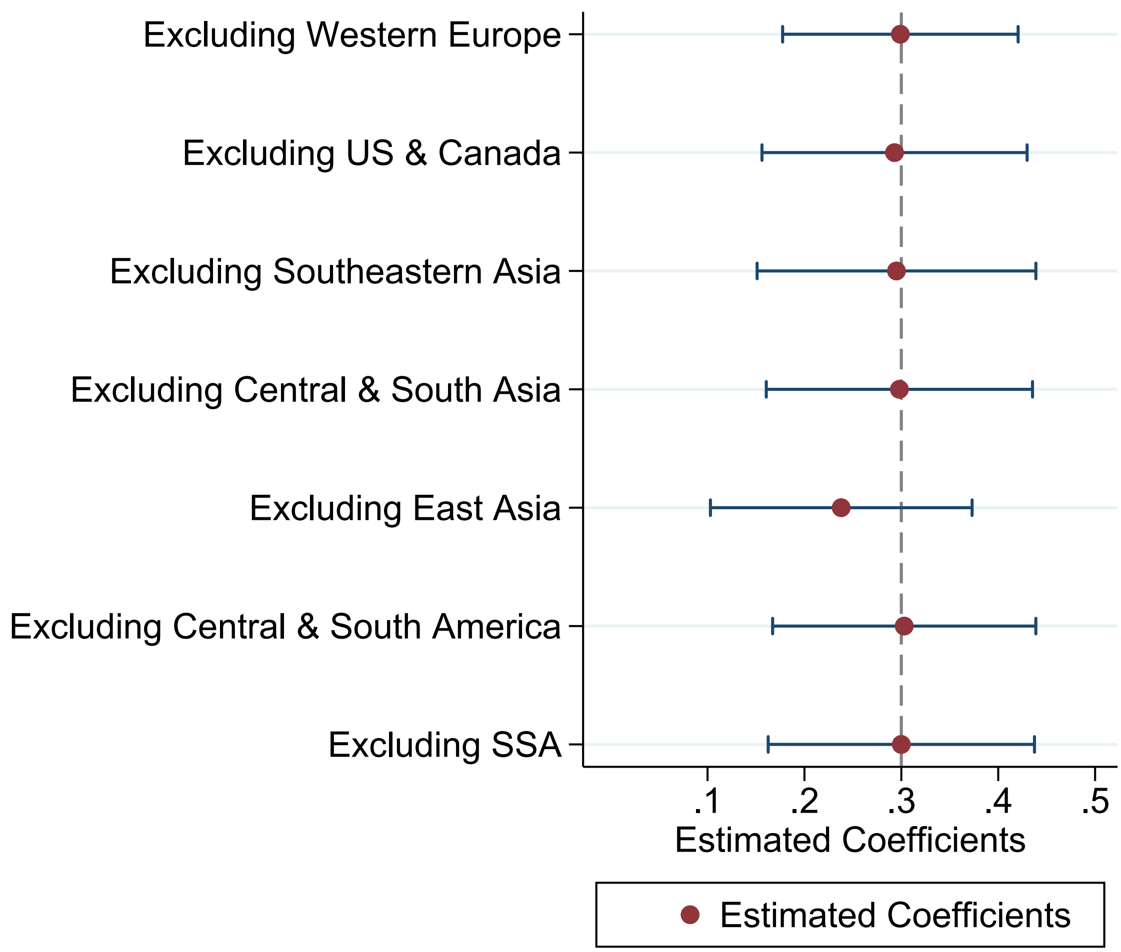
Notes: The control variables include country-level population and weather. Weather includes precipitation and temperature. Clustered robust standard errors are reported in parentheses, assuming that the error terms are correlated within each country. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Figure D1: First-Stage Effective F Statistics by Region Exclusion



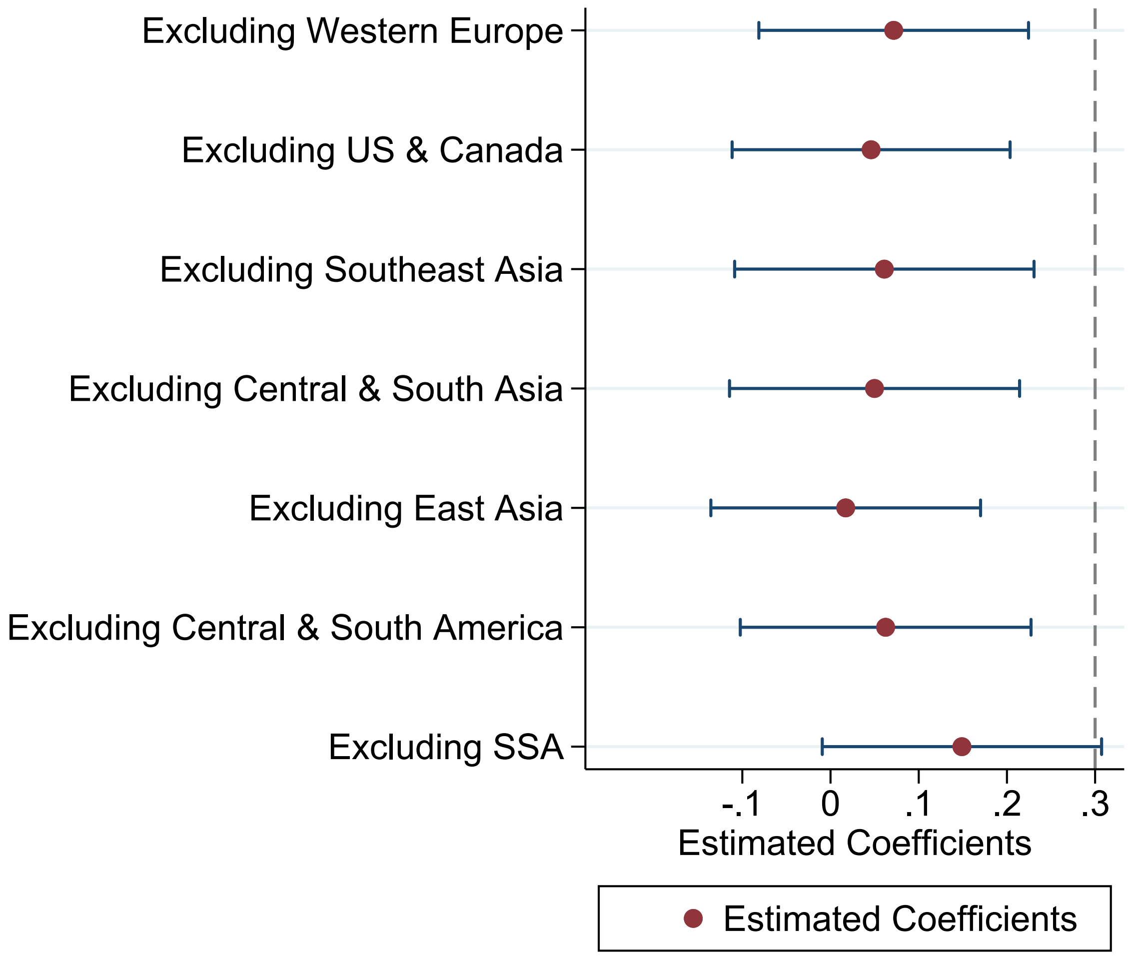
This graph was generated by excluding one region from the sample and running gravity equation regressions. For each regression, we estimated the first-stage and obtained the corresponding Effective F statistic.

Figure D2: Effects of Exports on Night Lights of Trade Hub Area



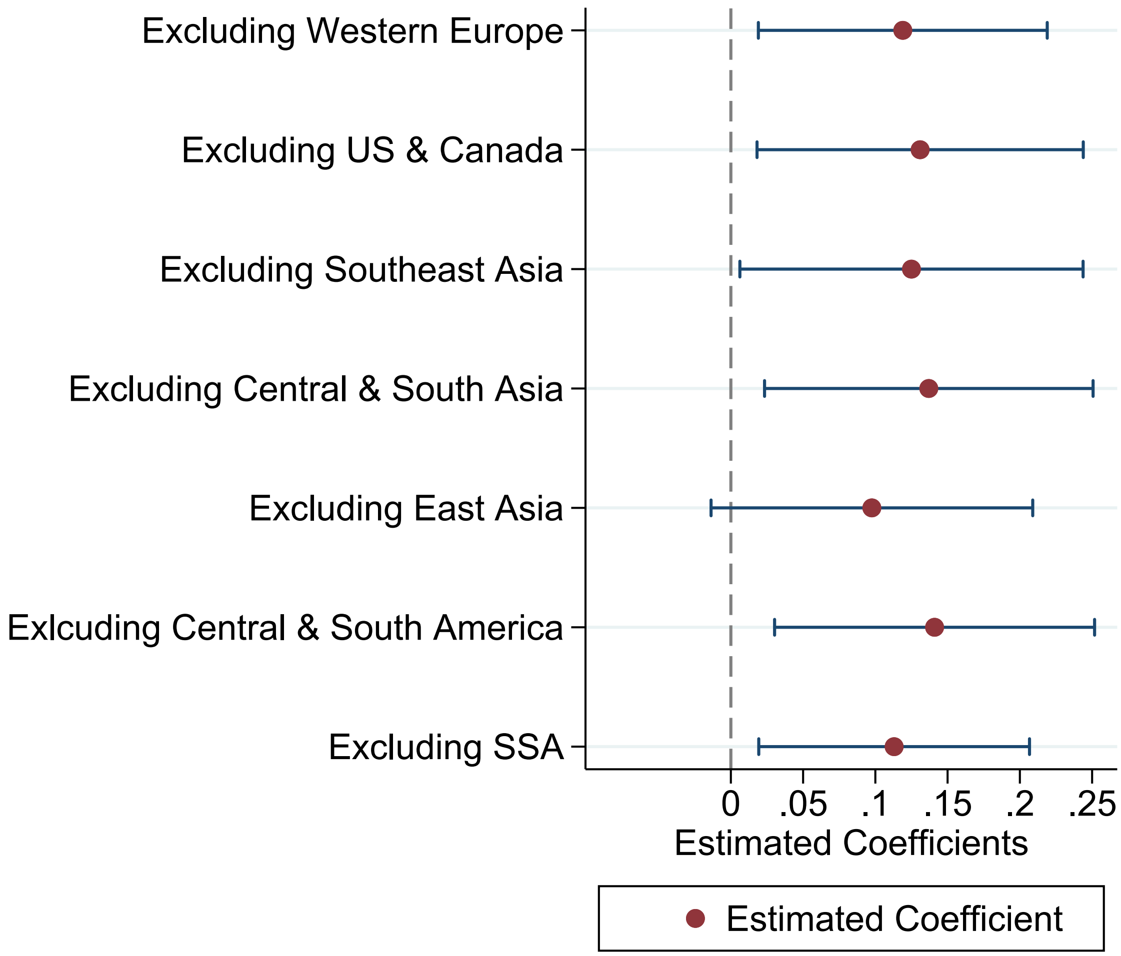
This graph shows the second-stage estimated effects of exports on night lights in trade hub areas. We conducted several regression analyses, each time excluding a specific region and running the gravity equation. For each sample, we obtained the second-stage estimate along with a 95% confidence interval.

Figure D3: Effects of Exports on Night Lights of Non-Trade Hub Area



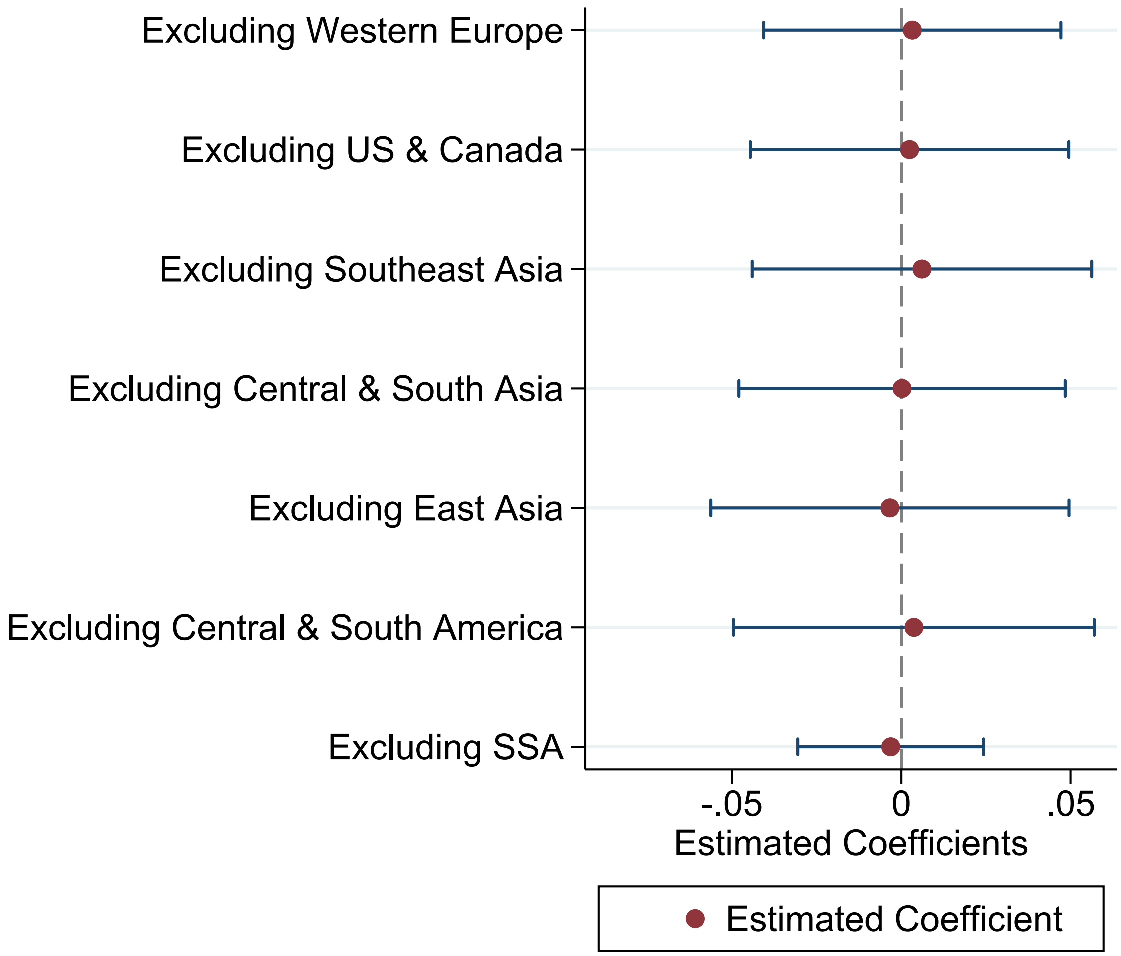
This graph shows the second-stage estimated effects of exports on night lights in non-trade hub areas. We conducted several regression analyses, each time excluding a specific region and running the gravity equation. For each sample, we obtained the second-stage estimate along with a 95% confidence interval.

Figure D4: Effects of Exports on Local Population of Trade Hub Area



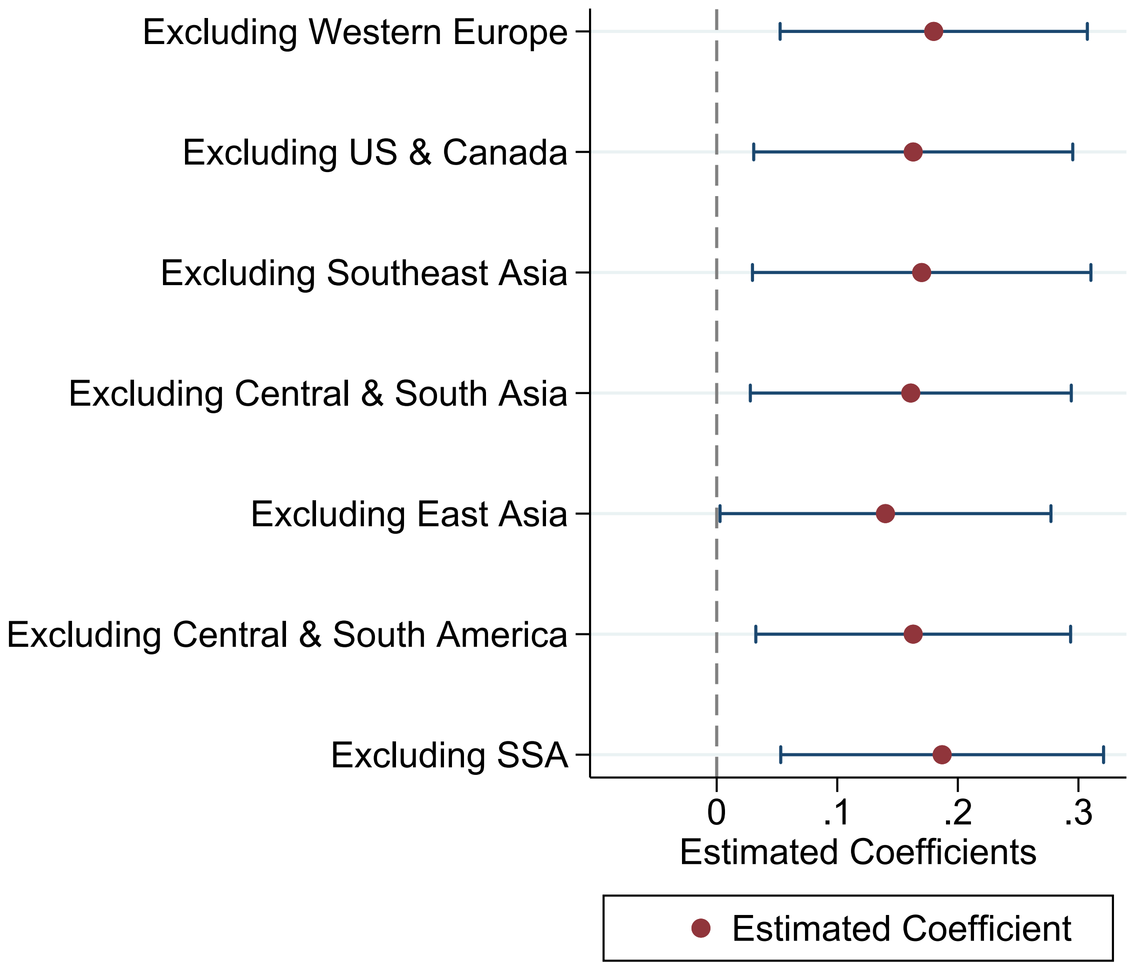
This graph shows the second-stage estimated effects of exports on local population in trade hub areas. We conducted several regression analyses, each time excluding a specific region and running the gravity equation. For each sample, we obtained the second-stage estimate along with a 95% confidence interval.

Figure D5: Effects of Exports on Local Population of Non-Trade Hub Area



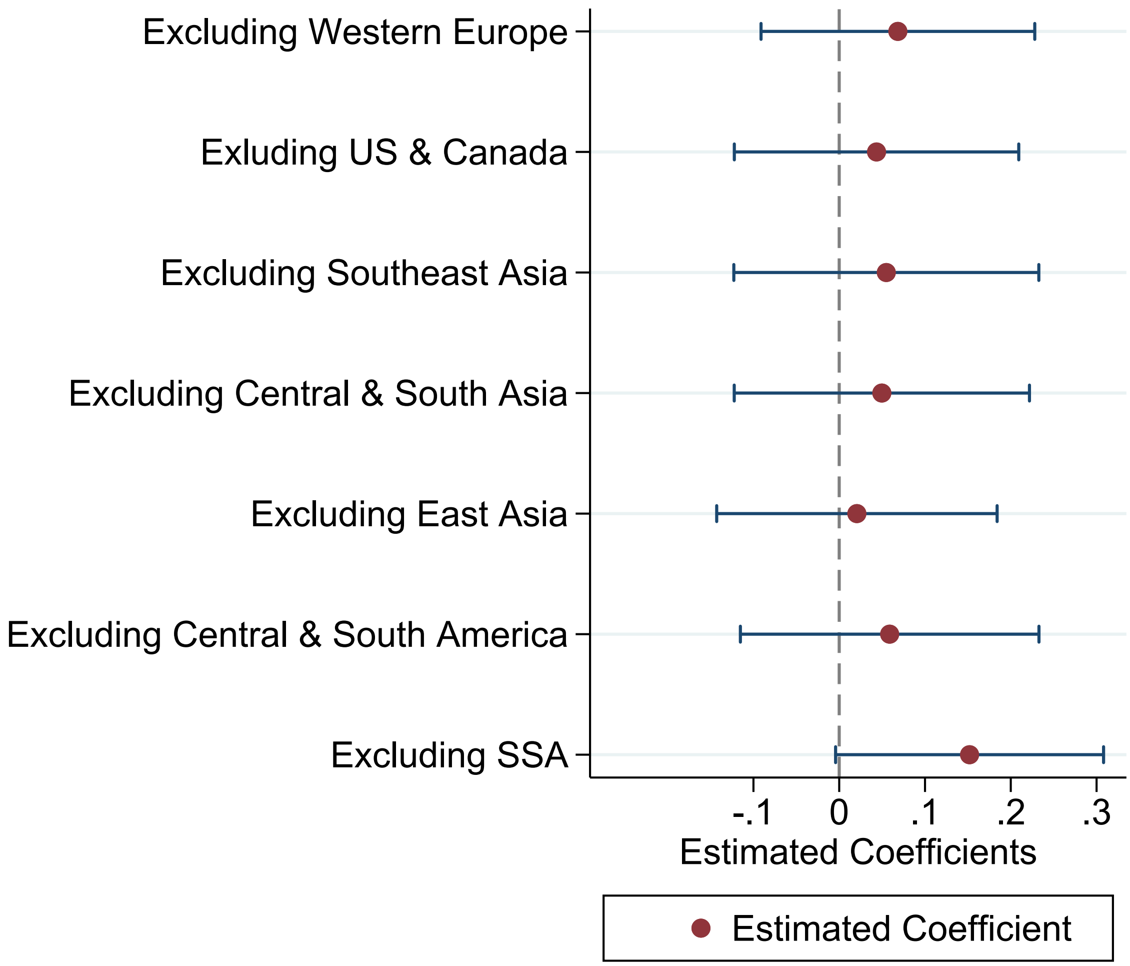
This graph shows the second-stage estimated effects of exports on local population in non-trade hub areas. We conducted several regression analyses, each time excluding a specific region and running the gravity equation. For each sample, we obtained the second-stage estimate along with a 95% confidence interval.

Figure D6: Effects of Exports on Lights per Capita of Trade Hub Area



This graph shows the second-stage estimated effects of exports on lights per capita in trade hub areas. We conducted several regression analyses, each time excluding a specific region and running the gravity equation. For each sample, we obtained the second-stage estimate along with a 95% confidence interval.

Figure D7: Effects of Exports on Lights per Capita of Non-Trade Hub Area



This graph shows the second-stage estimated effects of exports on lights per capita in non-trade hub areas. We conducted several regression analyses, each time excluding a specific region and running the gravity equation. For each sample, we obtained the second-stage estimate along with a 95% confidence interval.