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EFFECT OF TYPHOONS ON ECONOMIC ACTIVITIES IN VIETNAM: EVIDENCE USING SATELLITE IMAGERY*

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Abstract: This paper investigates the effect of typhoons on economic activities in Vietnam. During the period covered by our analysis, 1992-2013, we observed 63 typhoons affecting different locations of the country in different years with varying intensity. Using measures of the intensity of nightlight from satellite imagery as a proxy for the level of economic activity, we study how the nighttime light brightness varies across locations that were variably affected by the tropical cyclones. The results suggest that typhoons have on average dimmed nighttime luminosity of the places hit by 5 ± 5.8 % or 8 ± 7.8 % depending on the specifications we made.

Keywords: Natural disasters, economic growth, Vietnam

JEL Classification: Q54, Q52, C21, O53

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1 Introduction

Global damages caused by natural disasters have steadily increased in the recent decades due to a combination of accelerated economic development and climate change (see EM-DAT, 2010; Stocker, 2014; Takagi, 2019). As coastal regions around the world attract economic activities and foster population growth, assessing their resilience to natural disasters is key to identifying the places which are most vulnerable, and to devising and testing the efficiency of the most adequate public policies. With a rapidly developing economy and projected positive population growth, Vietnam epitomizes the challenges and opportunities posed by natural disasters in a warming climate. The country has an extensive coastline located in the Northwestern Pacific Basin, where most tropical cyclone activities worldwide are located. Between 1992 and 2013, we have counted that intense storms with wind speeds above 64 knots struck the country 63 times. When making landfall in coastal regions, where a large share of the population concentrates, the storms are usually accompanied with heavy rainfall, and cause landslides and severe flooding. They leave in their wake deaths, loss of livelihoods and infrastructures, population displacements, and disruption of economic activities (see Elliott *et al.*, 2015; EM-DAT, 2010; Gröger and Zylberberg, 2016; Nguyen *et al.*, 2019).

To lay the ground for identifying public policies that may help Vietnam, and hopefully other countries in similar contexts, adapt to increased cyclones activities in a warming climate, this paper sets out to document how economic activities at the local and country level react to local shocks induced by tropical cyclones. Existing studies documenting the effect of typhoons in Vietnam have found large negative impacts of tropical cyclones on household welfare measured by income and expenditure (Arouri *et al.*, 2015; Thomas *et al.*, 2010; Trung, 2015), whereas firms experience a short-term reduction in retail sales, and an increase in investment in large cities, which can be due to a short-term boost in demand for reconstruction (Vu and Noy, 2018). Noy and Vu (2010) find that disasters that result in higher deaths lead to lower output growth, while ones with higher infrastructural destruction lead to higher economic growth in the short run.

This paper contributes to this growing literature by providing estimates of the aggregate effect of typhoon on economic activities at the local level. We innovate in two central directions (see Felbermayr and Gröschl, 2014, for detailed accounts of the limitations of studies that used self reported outcomes or ex-post data collected on damages to characterize exposure to natural disasters).

First, we use satellite imagery that documents the vicinity of impact of typhoons to identify the locations affected, which we define as any area located within the radius of 30-kt winds (see Knapp *et al.*, 2018). This approach allows us to overcome the selection bias of ex-post data collected in locations with damages due to natural disasters. Alternative approaches have relied on wind field models to estimate the intensity of typhoon exposure at any distance in a given time, using various climate parameters (Geiger *et al.*, 2018; Strobl, 2019). The estimates are used as inputs to an impact function to produce percentage of damage to infrastructure. However, there are several concerns when it comes to Vietnam. Wind field models do not account for topography. This leads to large measurement errors when we compare three different wind field models to weather station observations. In addition, the impact function that is commonly used relies on parameters calibrated using data observed in high-income countries where local infrastructure can sustain high-level of wind speeds (see Emanuel, 2011). In all likelihood, the resulting threshold will underestimate the damage caused by typhoons in Vietnam where there are numerous cases of "relatively weak" storms that caused severe damages. For instance, Koni is a category-one typhoon that made landfall in Vietnam in 2003. Two hours prior to impact, it reached 1-minute maximum sustained wind speed of 55 knots and weakened afterwards. However, while Rana *et al.* (2022) used a wind field model and impact function that assigned minimal impact of the typhoon Koni on housing, EM-DAT (2010) reported that the typhoon made five thousands people homeless.

Second, we use average nighttime light intensity per year available at 1 kilometer squared resolution to proxy the intensity of economic activities at the local level. Night-time light intensity have been widely examined and shown a strong correlation with economic activity both at the country level (Chen and Nordhaus, 2011; Henderson *et al.*, 2012), and sub-national levels (Donaldson and Storeygard, 2016; Hodler and Raschky, 2014). With a growing number of studies documenting the consequences of extreme events using nighttime light luminosity (see Bertinelli and Strobl, 2013; Elliott *et al.*, 2015; Felbermayr *et al.*, 2018; Strobl, 2012), proxying economic activities at the local level in Vietnam with nighttime light intensity provides a benchmark against which the results in Vietnam can be interpreted.

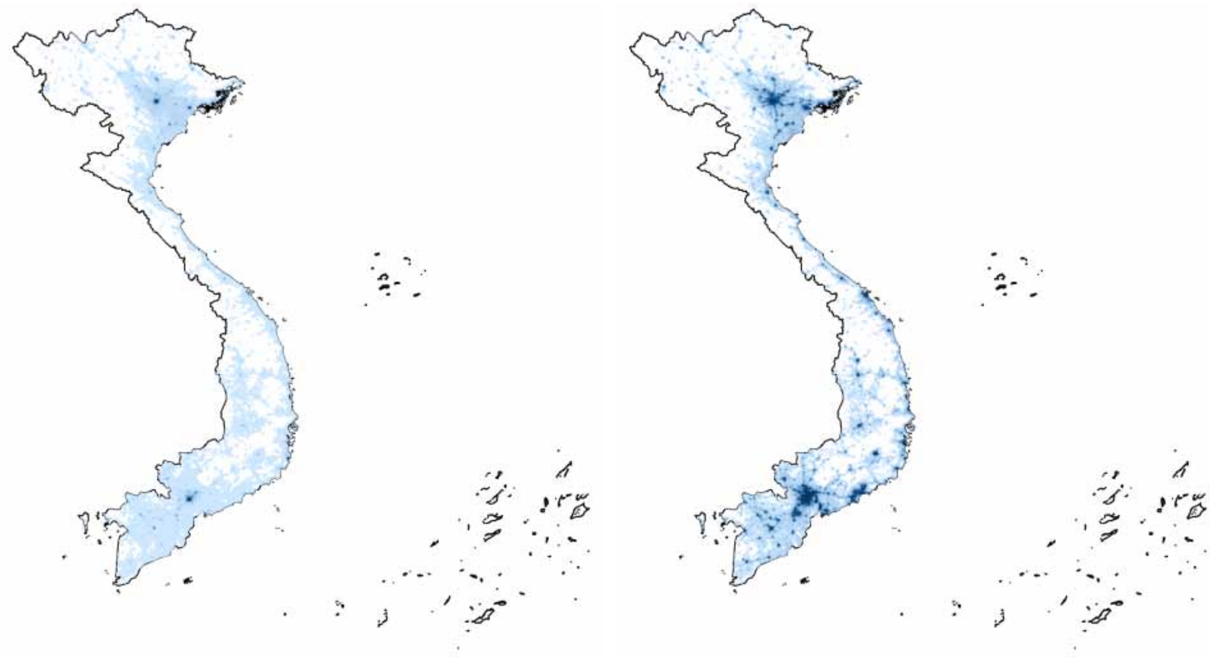
Combining detailed tracking of typhoons and average level of nighttime light intensity, we used a two-way fixed effects regression framework (see de Chaisemartin and D'Haultfœuille, 2020) to estimate how nighttime light intensity has varied at the location hit by typhoons between 1992 and 2013. Comparing the relative changes in nighttime light over time across locations that experienced a typhoon, we find that nighttime light intensity at locations hit by typhoon(s) reduced on average by 8% the year when the typhoon(s) made landfall. We find weak evidence that the typhoon(s) have lasting effects two years later. However, these results are limited to the locations that had stable nighttime light for at least one year between 1992 and 2013 and cannot be extrapolated at the country level.

The remaining of the paper proceeds as follows. In Section 2 we describe the main data and the research design used to estimate the local effect of typhoon in Vietnam. Section 3 presents the main results of the study and Section 4 concludes.

2 Data and methods

2.1 Night-time luminosity

This paper uses measures of annual nighttime light intensity produced using satellite imagery from the Defense Meteorological Satellite Program (DMSP). The images acquired have been processed for the general public by the National Oceanic and Atmospheric Administration (NOAA) with records dating from 1992 up to 2013. The available information contains annual average nightlight intensity with normalized values ranging from 0 indicating no light to 63 digital number (DN). They capture nocturnal lighting from human activity for grid pixels of around 30 arc second size, approximately 1 kilometer squared at the equator (see Elvidge *et al.*, 2022, for details). Aggregating the measures of nighttime light intensity at the local level throughout the country and comparing it to official estimates of yearly GDP, we find that nighttime light intensity is strongly correlated with the national GDP of Vietnam between 1992 and 2013 (see Figure A-1). With 402,852 pixels covered, 174,960 have displayed stable nighttime over at least one year between 1992 and 2013 (see Figure 1 for a map of pixels lit in 1992 and 2013).[1]



(a) Nighttime light in 1992 **(b)** Nighttime light in 2013

Fig. 1: Nighttime light intensity throughout Vietnam as measured in 1992 and 2013. This figure describes the variation of nighttime light intensity throughout Vietnam in 1992 and 2013. The color intensifies as nighttime light luminosity moves from 0 (no color) to 63 (dark blue). Source: Authors' own elaboration using data on nighttime light from the DMSP-OLS program.

[1]As new satellites are launched approximately every five years, they produce overlapping observations. Whenever needed, we choose the satellite that has the higher number of cloud-free observations being used to produce the annual average.

2.2 Typhoon Data

To detect the places hit by a typhoon in a given year, this paper uses data provided by the International Best Track Archive for Climate Stewardship (IBTrACS) program which reports information on 3-hourly central locations of the Western North Pacifics storms with their respective maximum sustained wind speed in conjunction with details such as direction, forward velocity, central pressure, etc. Out of 754 storms recorded in the Western North Pacific during 1992 to 2013, we restrict the analysis to typhoon-level events that reach 1-minute sustained wind speed of 64 knots according to international standards. Using that definition, we find that Vietnam was exposed to 63 typhoons that have crossed regions of the country over the period covered by the analysis. Then, we combined the data produced by IBTraCS with auxiliary information provided by the Japan Meteorological Agency (JMA) – one of the main agencies that monitor storms in the western North Pacific (WNP) and the South China Sea – to identify the radius covered by wind with speed greater or equal to 30 knots. This allows us to identify a pixel being hit when it is located within a radius of 30-knots wind (see Figure 2 for a graphical representation of spatial distribution of places visited by typhoons between 1992 and 2013).

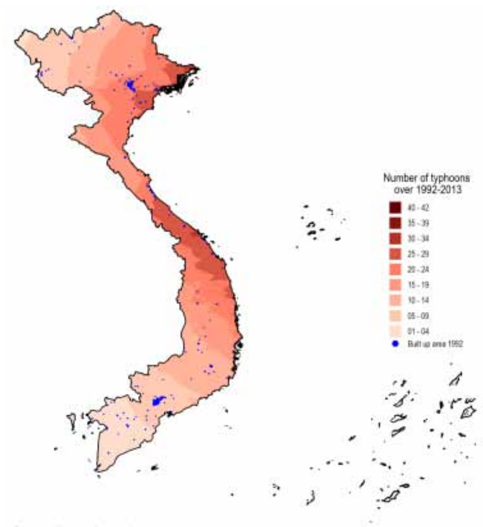


Fig. 2: Number of typhoons making landfall throughout Vietnam between 1992 and 2013. This figure represents how the number of typhoons that made landfall at the local level throughout Vietnam between 1992 and 2013. The color intensifies as the number of typhoons detected moves from 0 (no color) to 35 (red). Source: Authors' own elaboration using data on typhoons collected by IBTrACS.

2.3 Estimating the effect of typhoons on night-time light luminosity

To estimate the effect of typhoon at the local level, we consider the following specification:

$$\text{IHS}\left(\mathbf{N}_{it}\right) = \beta \times \mathbf{S}_{it} + \pi_t + \mu_i + \epsilon_{it} \;\text{ with }\; \text{IHS}\left(\mathbf{N}_{it}\right) = \log\left(\mathbf{N}_{it} + \sqrt{\mathbf{N}_{it}^2 + 1}\right). \qquad (1)$$

IHS$\,(.)$ stands for inverse hyperbolic sinus function. The primary variable of interest is, $\mathbf{N}_{it}$, the average nighttime light intensity at the location of pixel i in year t. Since nighttime light intensity remains at 0 throughout the period for a large number of pixels, we consider as unit of analysis the pixels that showed stable light over at least one year between 1992 and 2013. Hence, our estimates are only valid for the location that had stable light during the period 1992-2013. Nonetheless, a large fraction of pixel-times had 0 as value of nighttime light intensity at different points of time, and we use the inverse hyperbolic sinus function to account for the skewed distribution of nighttime light intensity.

We seek to estimate the impact of the incidence of at least one typhoon, $\mathbf{S}_{it}$, for pixel i in year t. The specification includes location fixed effect, μ_i, to account for unobserved pixel-specific time-invariant effects that can be correlated with typhoon damage and economic activity levels such as forms of resilience or investment in adaptation to typhoons effects. Years fixed effects, π_t, are also included to account for correlated effects commonly shared across location in a given year. The unobserved heterogeneity, ϵ_i, is assumed to be correlated across pixels located in the same province.

We assume that the path followed by typhoons are exogenous and use a two-way fixed effects regression framework to estimate the parameter β. We note $\mathbf{N}_{it}\,(1)$ the level of night time light intensity when a typhoon makes a landfall at the location of pixel i in year t and $\mathbf{N}_{it}\,(0)$ the level of night time light intensity had no typhoon made a landfall at the location of pixel i in year t. Our parameter of interest is the relative expected change in nighttime lights in the year when a pixel is hit by at least one typhoon, or the semi-elasticity:

$$\xi_{ns} \equiv \frac{\mathbb{E}\left[\mathbf{N}_{it}\left(1\right)\right] - \mathbb{E}\left[\mathbf{N}_{it}\left(0\right)\right]}{\mathbb{E}\left[\mathbf{N}_{it}\left(0\right)\right]} \tag{2}$$

Since $\mathbf{S}_{it}$ is a binary variable, the semi-elasticity of night-time light intensity to incidence of at least on typhoon in a year can also be expressed as follows $\xi_{ns} = \exp\left(\beta\right) - 1$ (see Bellemare and Wichman, 2020). Recent advances in econometrics show that the fixed effect estimator of β will likely produce misleading estimates of the average effect of typhoons (see deăChaisemartin and DHaultfuille, 2022).[2] To produce robust estimate of the effects of typhoons, we consider alternative approaches and used the estimator suggested by de Chaisemartin and D'Haultfœuille (2020) and report estimates of the dynamic effects of incidence of typhoon(s) at the local level. We account for auto-correlation of observations (location×year) located in the same province. Likewise, we report how the estimate vary when we account for spatial auto-correlation of unobservable heterogeneity across neighboring locations and restrict the estimates to the locations that displayed stable night light over at least one year and were at least 10 km apart from one another.

3 Results

We find that expected night light intensity at the local level dimmed on average by $5 \pm 5.8\,\%$ or $8 \pm 7.8\,\%$ when a location is affected by a typhoon (see Fig. 3). Moreover, the estimates suggest that the effect is dynamic and may persist up to two years at the locations hit by typhoon(s). Though the estimates are not comparable, previous studies that documented the economic costs of extreme weather have found negative and short-lived macroeconomic impact of tropical cyclones. More specifically, Bertinelli and Strobl (2013) find that an average hurricane leads to a reduction in growth of nightlights by 3.4% in the Caribbean. Regarding the neighboring country of Vietnam, Del Valle *et al.* (2018) shows that in Guangdong province of China, the impact is neg-

[2] In our case, the two-way fixed effects regressions is likely to produce biased estimates because locations switch on and off from being hit by typhoons and the effects of typhoon(s) incidence in a given year is likely to vary across locations and over time. Incidentally, we observed that the estimates produced by the two-way fixed effects estimator is the average of several average treatment effects with positive and negative weights.

ative and significant only within the month of the event. On average, nightlights is reduced by 1% as a result of typhoon damage. The authors also emphasize how institutional context can play an important role.

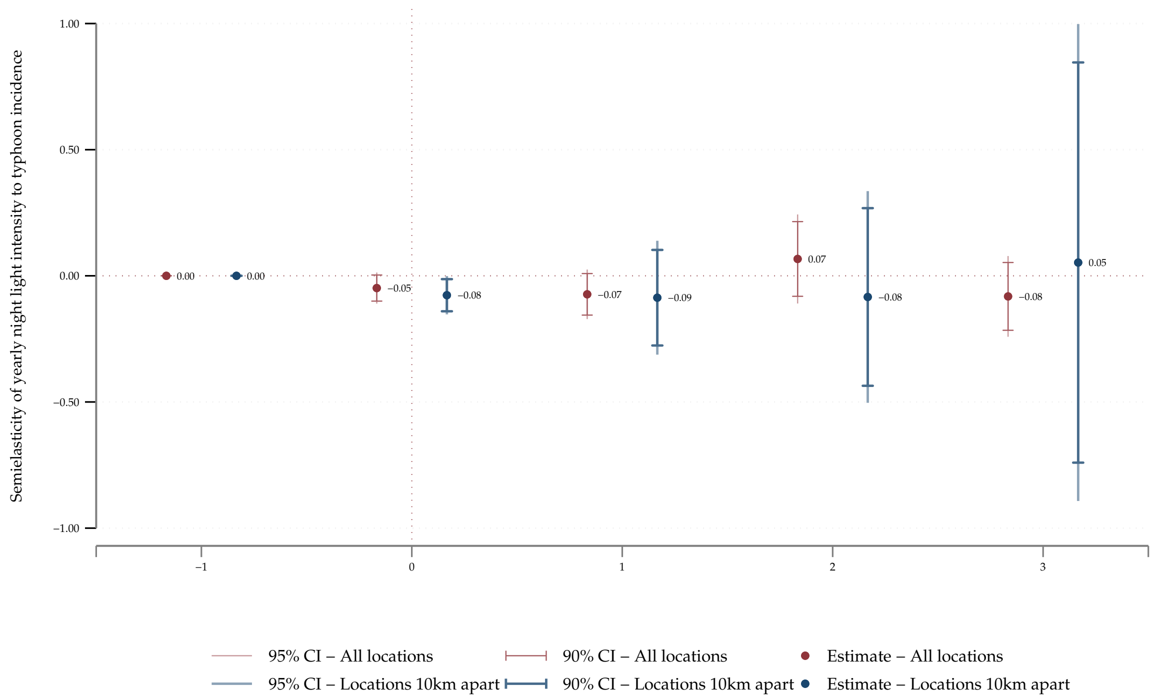


Fig. 3: Expected dynamic change of night light intensity associated to typhoon at local level. The figure represents the percentage variation of night light intensity over time in the locations that were hit by at least one typhoon in a given year (in comparison to the locations that were not hit). The point estimates are reported along with the 95 and the 90% confidence intervals. The estimates reported in red with a thin confidence intervals lines are produced using a sample that includes all the pixels with stable night light over at least one year between 1992 and 2013. The estimates reported in blue with thicker confidence intervals lines are produced with a sample of locations with stable night light that are at least 10 km apart from one another. Source: Authors' calculation.

To explore the difference of policies across countries that may help reduce the cost of typhoons, future studies should report how the point estimates compare when the same methodological approach is used across countries. In the meantime, our approach may underestimate the level of night light intensity in the absence of typhoons at the locations where typhoons made landfalls in Vietnam. Indeed, detailed analyses (see the placebo estimates reported in Table A-1) indicate that local level of night light intensity is on average relatively higher two years prior to the incidence of typhoon compared to the counterfactual levels predicted. This suggests that the parallel trend assumption that underlie the causal interpretation of the results might not hold and leads to underestimate the relative loss of night light intensity experienced in the aftermath of typhoons in Vietnam.

4 Conclusions

This study uses data from satellite observations of typhoons and recent advances in econometrics of two-way fixed effects models to estimate the impacts of typhoon at the local level in the context of Vietnam. The results suggest that expected yearly night light intensity at the locations hit by typhoons dimmed by 8 ± 7.8 % when the typhoons made landfall. The effects are likely to linger the following year or more depending on the methodological approaches. However, we also find that the variation of night light intensity over time differs across the locations that experienced typhoons landfall and the counterfactual suggested by the modelling approach. The direction of the discrepancy suggests that our approach underestimates night light intensity had the locations hit not experienced a typhoon in a given year. Thereby, the estimates reported are likely underestimating the effect of typhoons and invite caution.

Since all the locations with stable night light were affected by typhoons at least once over the period of analysis, and the effect of typhoons persisted over at least one year, alternative estimators that are more parsimonious when creating the counterfactual could help provide better estimates of the effect of typhoons. To account for the lasting effects of typhoon, these estimators will likely require longer time series. Future studies should also expand the analyses to other countries. This will help document how the effect of typhoons vary across countries and investigate the potential role of the cross-country variation of public policies related to natural disaster management.

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Supplementary materials

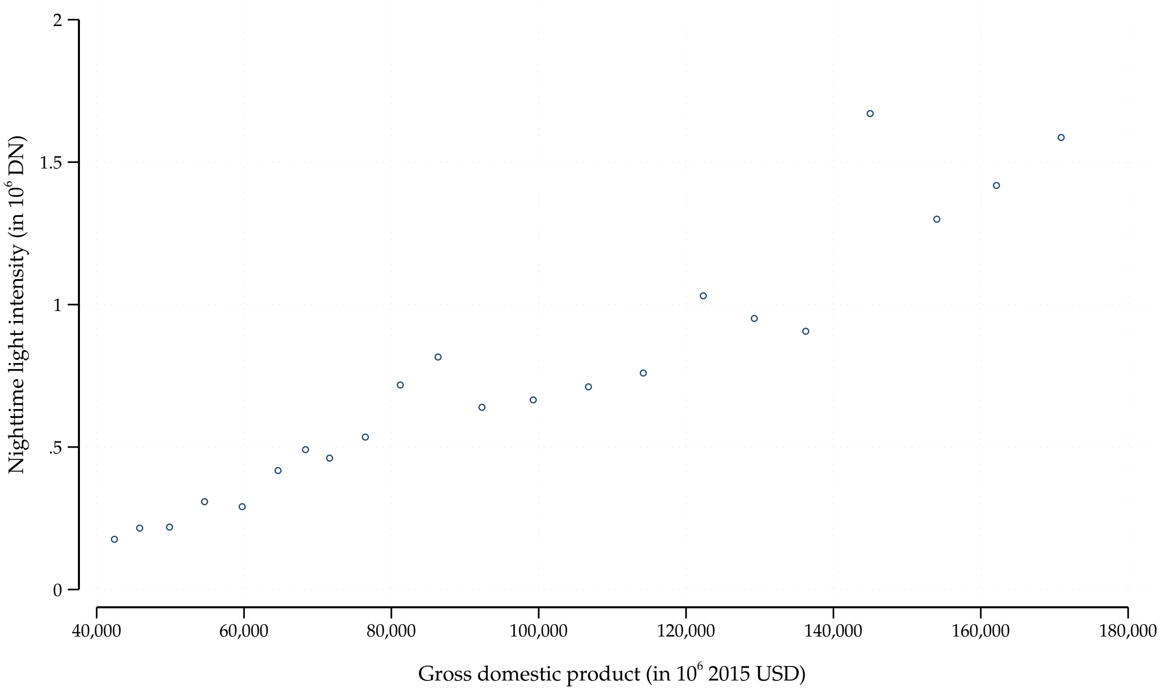
S1 Supplementary tables

Table A-1: Expected change of night light intensity associated to typhoons

	Coefficient β		Semi-elasticity ξ_{ns}	
	(1)	(2)	(3)	(4)
Dynamic change :				
- one year before (reference)	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)
- year when typhoon(s) hit	-0.080	-0.050	-0.077	-0.048
	(0.04)	(0.03)	(0.04)	(0.03)
- one year after	-0.091	-0.076	-0.087	-0.073
	(0.13)	(0.05)	(0.12)	(0.05)
- two years after	-0.088	0.065	-0.084	0.067
	(0.23)	(0.08)	(0.21)	(0.09)
- three years after	0.051	-0.085	0.053	-0.082
	(0.46)	(0.09)	(0.48)	(0.08)
- two years before (placebo)	0.131	0.124	0.140	0.132
	(0.05)	(0.03)	(0.06)	(0.03)
Number of observations	30,976	3,849,120	30,976	3,849,120
Number of pixels with stable light	1,408	174,960	1,408	174,960
Number of clusters	63	63	63	63
Mean $\mathbf{N}_{it}$ before typhoon	3.7	3.5	3.7	3.5
Location F.E.	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes

Note: The table shows estimates of β and ξ_{ns} from Eq. (1) and Eq. (2). Column "(1)" reports the estimates of β using a sample of pixels with stable light that are at least 11 km apart from one another. Column "(2)" reports the estimates of β when the sample includes all the pixels with stable light. Column "(3)" and "(4)" report estimates of ξ_{ns}: the expected change over time of relative night light intensity across locations affected by typhoon(s) compared to locations with no typhoon in a given year t. In column "(3)", the estimation is restricted to pixels with stable light that are 11 km apart. Column "(4)" reports the estimates using all the pixels with stable light.

The standard errors are clustered at the province level and are reported in parentheses.



Source: Authors' illustration using Word Development Indicators and DMSP−OLS datasets.

Fig. A-1: Correlation between GDP in 2015 USD and Nighttime luminosity