Defending the Coasts: Seawalls, Typhoons, and Adapting to Sea-Level Rise

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Abstract

Constructed primarily to defend coastal economies from severe storms and sea surges, seawalls have served as an effective protective measure across the world for thousands of years. In the past decade, as climate change has intensified projections of stronger, more frequent cyclones as well as significantly rising sea levels, seawalls have become even more critical for sustaining coastal economies. Many countries are already planning expansions of seawall infrastructure in preparation for future sea level rise. This study examines the current role of seawalls in protecting China's coastal economies from typhoon impacts during 2015-2024. Our results have shown that increasing the share of coastlines protected by seawalls has significantly reduced the negative impacts of typhoons, high waves, and rising sea levels on coastal economies, as reflected by changes in nightlight intensity and housing price. These impacts mostly arise from reduced disruptions to industrial, residential, and transportation activities, and are concentrated in districts that are not directly coastal but are the most economically active within each coastal city, implying that the defensive effects of seawalls spillover beyond directly protected coastal districts. We also find that seawall maintenance significantly improves protective effectiveness, while co-location with offshore mangroves can reduce the protective benefits. Overall, our findings highlight the importance of seawalls in strengthening coastal resilience to extreme climate events and underscore their relevance under future climate change.

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1 Introduction

As climate change causes increasing frequency and intensity of natural disasters worldwide, the urgency of climate adaptation has grown substantially entering the second quarter of the twenty-first century. With global temperatures increasingly likely to exceed the $1.5°C$ threshold by the end of this century, adaptation has shifted from a long-run concern to an immediate policy priority[1]. Among the most consequential climate risks, coastal cyclones and sea level rise have drawn sustained attention in both scientific and policy communities for decades. Billions of people living in low-lying coastal regions are projected to be affected, with potentially enormous economic losses and widening economic inequalities when low-income economies may lack the capacity to effectively facilitate sufficient adaptation to the extreme weather events (Mendelsohn et al. 2012, Hsiao 2025).

Urban adaptation strategies play a central role in responding to climate risks (Carter et al. 2015, Birkmann et al. 2010). Among available adaptation measures, seawalls stand out as one of the most common, yet most costly, forms of hard coastal defense. Historically, seawalls have served as protection against storm surges, high waves, inundation, and at times military threats. Their long-standing role is illustrated by China's Fangong Di, constructed nearly a millennium ago under the leadership of the statesman Zhongyan Fan still commemorated today. In the contemporary era, large-scale seawall projects continue to attract policy attention, particularly in rapidly urbanizing and climate-vulnerable regions such as Indonesia, where massive coastal barriers costing billions of dollars and decades of constructions have been proposed to protect densely populated cities and national capitals from rising seas[2].

A growing literature evaluates seawalls and related coastal infrastructure in the context of climate risk reduction and public investment. As a form of adaptation capital, the impact of seawalls in climate adaptation and associated investment-returns have been studied theoretically (Fried 2022). Hsiao (2023) documents the conflicting effect of seawall construction and inland migration as adaptation responses, highlighting policy challenges faced by developing

[1]Source: https://wmo.int/media/news/global-temperature-likely-exceed-15degc-above-pre-industrial-level-temporarily-next-5-years-0.

[2]Source: https://www.straitstimes.com/asia/se-asia/indonesias-seawall-project-set-to-expand-good-for-some-but-gloomy-for-others.

countries with long coastlines exposed to climate change. Concerns have been drawn upon continuous investment in regions facing greater sea level rises, as economic perspective is decreased indicated by housing price (Agarwal et al. 2025), and dynamic modeling has suggested substantial long-run costs of investing in coastal infrastructures that sustain high-risk developments (Balboni 2025). Locally, the long-run cost and benefits of seawall buildings have been studied for specific regions (Chow et al. 2017, Davlasheridze & Fan 2019). Outside of economic literature, there have been vast engineering studies on the interactions between climate change and seawalls, assessing their effectiveness and the increasing challenges posed by evolving environmental conditions Mase et al. (2015). However, these engineering studies primarily focus on physical performance and technical feasibility, and cannot directly inform the economic impacts that are central to policy analyses.

Despite their prominence, the economic effectiveness of seawalls as a climate adaptation tool remains an open empirical question due to limited data on seawall infrastructure. Systematic evidence on their real-time performance and welfare impacts during extreme weather events, especially using high-frequency data and robust identification strategies, remains limited. In particular, it is unclear under what conditions seawalls meaningfully mitigate economic disruptions from typhoons, sea level rise, and extreme waves, and how their design interacts with natural coastal ecosystems such as mangroves. This paper will fill in the gap in the seawall literature, providing the first empirical analysis combining a newly constructed, detailed data on seawall location and coverage with high-frequency typhoon exposure, sea level anomalies (SLA), and significant wave height (SWH) to quantify the economic impacts of seawalls during natural disasters. In addition, our paper will also adds to the broader empirical literature on adaptation to coastal flooding and similar land-protecting infrastructures such as levees (Ostriker & Russo 2022, Ziff & Vinnakota 2022, Fan 2024).

Coastal southern and eastern provinces of China account for over 40% of population, over 40% of national GDP, and over 60% of total trade volume, being the strong driver of economic growth since the economic opening up in 1990s[3]. Meanwhile, coastal cities of China also directly face the threats from sea due to tropical cyclones (typhoons) every year's summer-fall season. As a result, these regions have the long history of seawall construction

[3]Source: State Bureau of Statistics, Xinhua News.

and maintenance funded by local and central governments, where defenses were initially designed for typhoon protection. More recently, more reinforcement and extension of seawalls have been proposed as part of national and local climate adaptation strategies against sea level rise[4]. Our study then focus on 391 districts of 53 coastal cities in mainland China over the recent decade of 2015-2024. Merging daily nightlight observations, realized typhoon tracks, and documented seawall spatial distribution of 2020 matched to Baidu map, we use a difference-in-differences-in-differences research design to estimate the impact of typhoons with defense of seawalls on local economies. From the regressions, we show that a larger share of seawall coverage along the coastline substantially and statistically significantly mitigates the negative economic shocks induced by typhoons, as measured by coastal city nightlight intensity. In particular, achieving approximately 85% coastline coverage nearly eliminates the adverse economic effects of typhoons. Besides typhoon, we further document that seawalls also reduce economic disruptions associated with elevated sea levels and extreme waves, proxied by sea level anomalies and significant wave height. These findings provide strong evidence that seawalls are an effective form of urban defense for current and future climate risks.

However, the effectiveness of seawalls depends critically on maintenance quality and their interaction with nature-based coastal adaptation features. We find that seawall maintenance investments (measured by number of maintenance counts and average investment amount) that strengthen the structures rather than increase wall height would significantly enhance protection against typhoon shocks. By contrast, while nature-based solutions such as offshore mangroves along southern China coastlines also provide effective protection against typhoons, seawall construction that overlaps with mangrove ecosystems yields null or even negative additional protective effects. These results highlight the important trade-offs between gray and green infrastructure in coastal adaptation.

To shed light on underlying mechanisms, we examine sectoral and spatial responses to typhoon shocks. Seawalls have limited effects on marine-based activities such as fishing and port operations, but significantly improve post-disaster recovery in land-based economic sectors, including industry, residential activity, and transportation. The strongest protective

[4]Source: https://sswj.zhuhai.gov.cn/gkmlpt/content/3/3133/mpost_3133605.html#6023.

effects occur in economically active, high-nightlight districts located farther inland within coastal cities, suggesting spillover impacts through transportation networks and within-city population movements. Moreover, we find that seawall effectiveness becomes pronounced after 2019, following the completion of the reinforcement project that unified previously fragmented defenses[5]. Importantly, increases in seawall height alone do not appear to drive these gains, implying that investments aimed at improving structural integrity or expanding coastline coverage may be more cost-effective than vertical expansion for reducing current climate impacts.

The remainder of the paper proceeds as follows. Section 2 describes the data. Section 3 outlines the empirical strategy. Section 4 presents the main results. Section 5 discusses mechanisms and policy implications. Section 6 concludes.

2 Data

2.1 Nightlight

We obtain daily (UTC time)-grid (500m) level VIIRS gap filled BRDF corrected DNB NTL from *Google Earth Engine*, sourced from NASA. The unit of nightlight measure is $nWcm^{-2}sr^{-1}$. Using the 2017 district/county level (by 6-digit GB code) shapefile of China sourced from State Bureau of Surveying and Mapping and obtained from National Geomatics Center of China (NGCC), we use overlaping area weighting to aggregate daily nightlight measurement to district-daily level for China across 2015-2024. Due to missing satellite images, there are daily observations missing for all districts for some days in July 2022, August 2022, May 2024, June 2024, July 2024, September 2024, November 2024.

2.2 Typhoon Exposure

We define a district of day in China to be exposed to typhoon influence if its jurisdiction has overlaps with the 34-knot (about Level 8) wind ring of western Pacific typhoons. This observations are classified as hazardous wind speed, legally required for local governments in China to issue typhoon warnings. We use the hourly data for the location of the ty-

[5]Source: https://www.gov.cn/xinwen/2017-08/21/5219341/files/ca80da2e6b404a788a6c0f47ccc8ca8e.pdf.

phoon center (latitude, longitude) and four-quadrant radii (NE, SE, SW, NW) from the U.S. observations of Joint Typhoon Warning Center (JTWC), source compiled by NOAA. For robustness checks, we also use the Level 7 hourly wind ring observations from China Meteorological Center, scraped from *Shenzhen Typhoon Net* or *Wenzhou Typhoon Net*. For all typhoons tracks and rings from 2015 to 2024, we compute the hourly record of each district's area overlapping with the 34-knot wind ring over coastal China. We than take the maximum overlapped area proportion for each day (UTC time), and define a district being with typhoon impact of the day if that daily maximum exposure level is strictly greater than zero.

2.3 Sea Level and Sea Wave Variable

We obtain reanalysis data of grid (0.25 degrees) level sea level anomalies (SLA, defined as sea surface at given time period normalized by deducting long-run historical sea level average) from DUACS, sourced Copernicus Data Center. Data is available until 2023, so we obtain daily observations for the period 2015-2023. We also download significant wave height (SWH, defined as the average of highest one-third wave heights across the given time period) from ERA-5 sourced Climate Data Store. We obtain these sea wave data for 2015-2024. We assign the sea level and sea wave variables to coastal districts of China through matching them with the closest sea grid to the administrative regions' centroids. Both sea level indicators are measured in meters (m).

2.4 Seawall and Seawall Maintenance

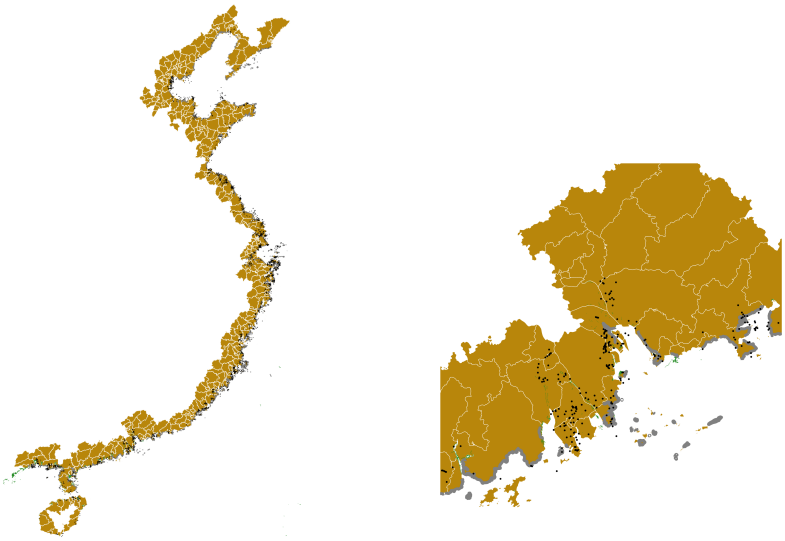
We obtain the satellite-based measurements of seawalls along coastal China from National Earth System Science Data Center, author dated 2020. Since the panel data only records starting and ending point coordinates (latitude, longitude), length and administrative region of each seawall segment, we apply nearest-matching algorithm and manually adjustment (especially for seawalls on and around small islands) to locate the seawall starting and ending points to nearest coastlines on Baidu Map. For robustness, we also do this mapping to the other coastline options, including Open Street Map, Gaode Map (Country and City Levels both). After mapping, seawall lengths recalculated are on average $2.67km$ smaller than the

original panel data records, and their differences are statistically significantly different at 1% T-test. We also computed city-level coastline length in kilometers from the same shapefile, then compute proportion of coastline covered by seawalls accordingly. The average is 45.8% across 53 coastal cities of China[6]. We also generate alternative measure of share of typhoon exposure defensed by seawalls, as the proportion of the length of seawall overlapping with 34-knot typhoon ring, over the length of coastlines overlapping with 34-knot typhoon ring, for each coastal city. This metric will be used for robustness checks.

To capture the state of seawalls along the coast, we also manually collected the maintenance records of seawalls from *Zhaobiao* website, with cross-checking to local government announcements and news reports. All together filtering maintenance since 2010 and dated before 2025, we collect 2054 maintenance records including posting dates, location, project name, construction company, planned budget, and sometimes budget sources (mostly from local governments), predicted project finished time across 52 coastal cities of China. On average across the 15 years period of the records, each city has on average 39.5 counts of maintenance records, and over the 82.4% records with projected investment, the average investment per maintenance construction of seawalls is about 120 million Yuan (nominal values, not discounting by inflation).

We plot the seawalls along 391 coastal city's districts of China together with maintenance points approximated by AI-reading addresses, and mangrove polygons in Figure 1. Overall, seawall distributions are broad across all coastal provinces except for Hainan (due to tourism and nature boundaries, the island is not with longer human-made seawalls). In correlation estimates, seawall coverage share of coastline is little correlated with local GDP per capita, but much positively correlated with share of secondary industry and negatively correlated with tertiary industries. This is consistent with the analysis that industrial development provide lower costs for seawall construction and maintenance, while local tourism must consider the disadvantages brought by seawall instead of keeping the beaches.

[6]Due to measurement errors for complicated coastlines, there are two cities with seawall coverage calculated to be greater than 100%. We winsorize their coverage measurement by one in later analysis for robustness, and our main results do not change.



(a) Coastal Cities **(b) Pearl River Delta**

Figure 1: Coastal Districts, Seawalls, and Mangroves

2.5 Mangrove Exposure

To capture the exposures of coastal areas to mangroves which are natural defense to sea waves and typhoons, we obtain the satellite-based mapping of mangrove polygon allocations from National Earth System Science Data Center, project dated 2020. We compute mangrove exposure as the inverse-distance weighted sum of mangrove area (kilometer squares) for all mangrove polygons within $50km$ of the coastal city boundaries. For robustness, we also compute these within $50km$ of seawall segments as the exposure to both seawall and mangroves. These exposure values are then normalized dividing coastline lengths for each coastal cities.

2.6 Carbon Emissions

We collect high-resolution daily grid-level ($0.1° \times 0.1°$) carbon emissions from Graced Carbon Monitor (https://carbonmonitor-graced.com/datasets.html) (Liu et al. 2020, Dou et al. 2023). All daily emissions by total and selected segregated sectors (industrial, transportation, residential, power) are aggregated to district level, unit kgC/h (kilogram of carbon per hour). These high-resolution carbon emission metrics will represent the economic activities of each sector by district by day in the mechanism exploration section of this paper. The

sample period is 2019-2024.

2.7 Port and Sea Activities

To assess port and near-coastal sea activities, we collect data on nightlight activity indicator VIIR Boat Detection from Colorado School of Mines (https://eogdata.mines.edu/products/vbd/), 2015-2024. We calculate the average nightlight measures of boats within $50km$ of each coastal districts. We also collected summary of daily fishing hours from Global Fishing Watch (https://globalfishingwatch.org), 2015-2024. We sum fishing hours to sea grid activities only within $50km$ of each coastal districts. For port activities, we obtain daily number of port calls and total trade volume (unit: metric tons) from IMF Port Watch (https://portwatch.imf.org/), 2019-2024. Ports are matched to China's coastal cities by their latitude and longitude coordinates.

2.8 Grid-Level Elevations

Since we do not obtain direct measurement of the height of seawalls, which will be crucial to their abilities to defend high waves and sea rises, we obtain high-resolution land elevation data from 2011-2015 Copernicus DEM as a proximate[7]. The Copernicus DEM is a Digital Surface Model (DSM) that derives heights of land relative to water bodies (normalized to zero elevations) comparing the reflective surfaces of land, including buildings, vegetation, infrastructures. To approximate the heights of seawalls, we take the land grid measurement of DEM within 50 meters of each seawall and average across all grid, or top 1% and 5% of the highest grids, as proxy measures of seawall or the land of seawall building's heights.

2.9 Floods

We collect satellite based grid-level daily flood plain observations covering coastal China from Corpernicus Global Flood Monitoring (GFM), data downloaded from EODC Data Catalogue (https://services.eodc.eu/). Geospatial grid files are compiled at district levels and summarized to calculate the share of each district's area being flooded according to

[7]We are still working to gather more information of seawalls from individual local water conservancy bureaus.

GFM observations per day. Data coverage is 2015-2024[8].

2.10 Control Variables

As linear control variables, we take daily average temperature and total precipitations from ERA-5, sourced *Google Earth Engine* and aggregated to district-day levels with overlapping area weighting from China's district shapefile. We also use annual city-level GDP per capita and primary, secondary, tertiary industry shares from China City Statistical Yearbook, 2016-2024. The data for year 2024, due by Yearbook 2025, is approximated at this point because it is not yet released.

3 Empirical Strategy

3.1 Summary Trends and Location Maps

We summarize the yearly trends of typhoon exposure, sea level anomalies, and sea wave height in Figure 2. In addition, we also add the trend of ERA-5 precipitations as a reference. On yearly average, typhoon exposures and precipitation levels are roughly correlated, and neither exhibits a monotonic trend over the study period of 2015-2024. Typhoon exposure peaks around 2018-2019, falls to lowest point after 2020, and, despite a gradual increase through 2024, does not return to pre-2020 levels. Meanwhile, precipitation levels are rising during that period exceeding pre-2020 levels. On sea levels, the yearly trend is more monotonic, featuring both rising sea levels (by SLA) and sea wave heights (by SWH) during the 10-year period. By 2024, wave height has risen by up to 4%, and sea level anomaly by 2022 is almost 70% higher than it is in 2015. These effectively features sea level rise in this period over coastal China.

Monthly trends of these variables in Figure 3 show that all variables are not correlated in months. Typhoon exposure typically peaks about one month after peak precipitation, and is absent in the region during the early part of the year, prior to May. Typhoon exposures usually comes one month after peak precipitation, and there are usual earlier half of the year before May when there are zero typhoon exposures in the region. Unlike precipitation and

[8]Data collection and compilation is ongoing, and results for this subsection in Mechanism is TBD.

typhoons that peaks at summer to autumn months, sea level peaks around autumn period of September to October, in correlation with Typhoon. However, sea waves on average is highest during winter time (December-January), and though typhoons increase local sea wave heights during typhoons, seasonally waves are the lowest during the summer typhoon months.

Geospatial distribution map of Figure 4 further illustrates the differences between these sea and wind exposure variables to coastal China. Over 391 districts of all coastal cities of China, consistent with meteorological rules, typhoon exposures is greatest to the south of the country, and significantly decreasing to zero to the northern part of the coasts around Tianjin. Cities enclosed by bays are less exposed to typhoons than those on peninsula, including Shanghai and Guangzhou. Meanwhile, sea waves and sea levels are more evenly distributed spatially. There are no clear patterns of north-south trends for these variables, and we can see that sea waves seems highest around the east coast of Hainan Province,, part of Guangdong Province, and Fujian Province. Even so, northern coasts also have comparable sea wave heights to the south, up to Liaoning Province. Sea level anomalies is even higher around the north, near Shandong Peninsula, and part of Fujian Province.

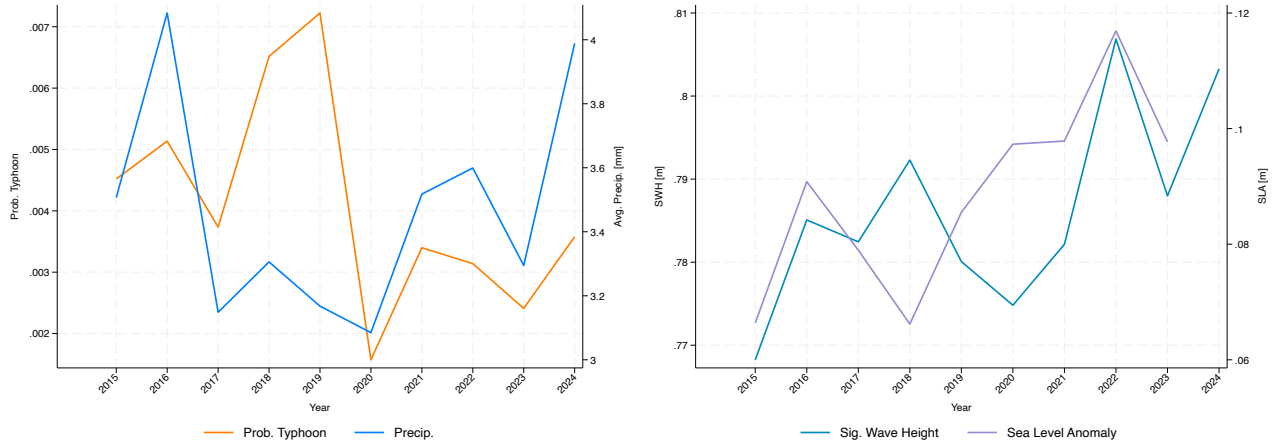


Figure 2: Yearly Trends of Typhoon, Sea Level, and Sea Wave

3.2 Baseline Difference-in-Difference-in-Difference Regression

To explore the impact of seawall defense on local economies under disaster events related to sea, we run the following triple-difference regression:

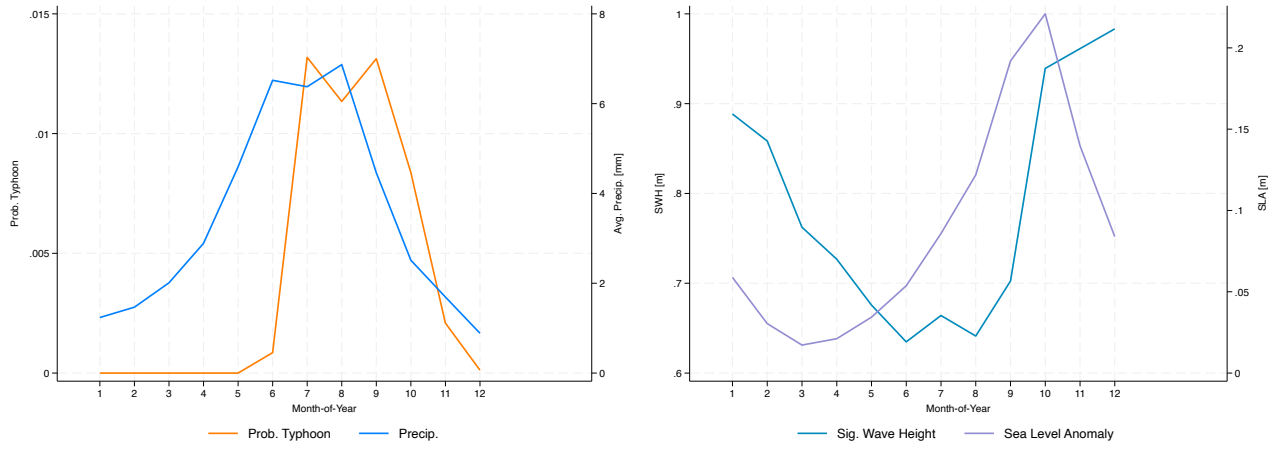
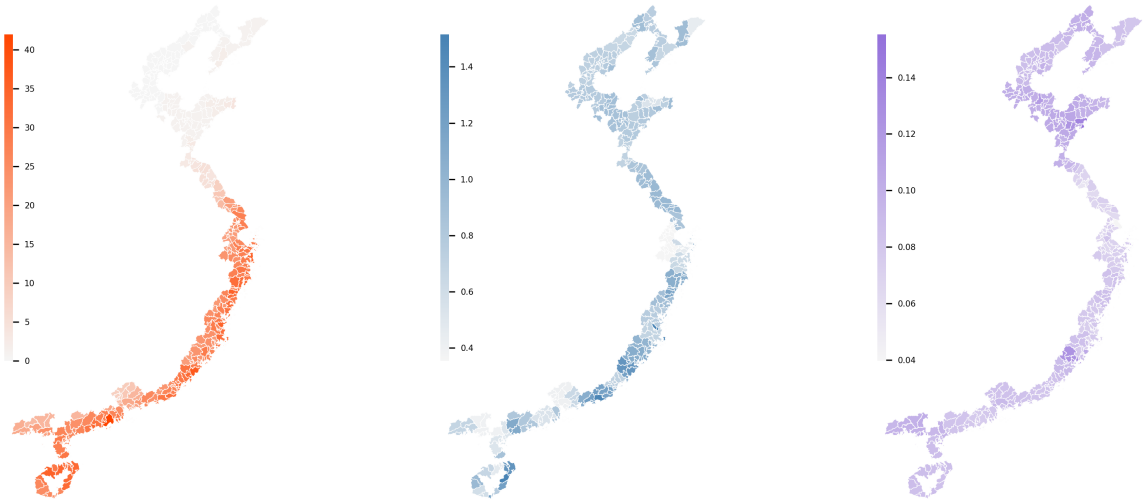


Figure 3: Monthly Trends of Typhoon, Sea Level, and Sea Wave



(a) Number of Days in 34kt Typhoon Ring, 2015-2024

(b) Average Significant Wave Height [m], 2015-2024

(c) Average Sea Level Anomaly [m], 2015-2023

Figure 4: Spatial Distribution of Typhoon, Sea Level, and Sea Wave

$$\log(Nightlight_{ict}) = \alpha + \beta_1 Tyhoon_{ict} + \beta_2 Typhoon_{ict} \times Seawall_c + \gamma \mathbf{X}_{ict} + \epsilon_{ict} \quad (1)$$

Here sea disaster impact variable $Typhoon_{ict}$ indicates whether district i of city c overlaps with the 34kt wind ring of any typhoon in date t. For robustness, in later analysis we also use this variable as the maximum share of district area overlapping with any typhoon 34kt wind ring over the date t. In later analysis, we will also replace $Typhoon$ with SLA and SWH to measure the direct impacts of sea rise and sea waves. Our sample will cover 338 over 391 districts in coastal cities of mainland China, dropping any coastal cities in provinces that never come across any typhoons during 2015-2024. $Seawall_c$ indicates how much the city c has defense against sea rise impacts. In our baseline analysis, this is the share of coastlines covered by seawalls. $\mathbf{X}_{ict}$ controls include date fixed effects, district fixed effects, city-by-month of year fixed effects to capture seasonal fixed effects at city levels (e.g. seasonal trends or policies), temperature, precipitations and their polynomials, city-year level GDP per capita, primary and secondary industry shares. Standard errors are clustered by districts.

By this DDD regression, estimator β_1 indicates the impact of typhoon on nightlight of the district of a coastal city without any seawall along the city's coastline. Estimator on the interactive term β_2 indicates the change in nightlight during any typhoon events if the city's coastline is 100% covered by seawall. Hypothesis on seawall defense against economic loss of typhoons will match with regression results of β_1 being negative, and β_2 being positive.

3.3 Event Study of Typhoon Impacts on Nightlight

To guarantee the parallel trend assumption of difference-in-differences design, we first run the event study analysis for exposures to typhoon only:

$$\log(Nightlight_{ict}) = \alpha + \sum_k \beta^k \mathbf{1}\{Typhoon_{ict+k} = 1\} + \gamma \mathbf{X}_{ict} + \epsilon_{ict} \quad (2)$$

Here $Typhoon$ indicates whether there is a typhoon crossing path of district i of city c at day $t+k$, for the window of $k = \leq -7, \ldots -1$ up to seven days before typhoon events (excluding instances when there are double typhoons), $k = 0, \geq 1$ up to one days when typhoon hits the district (maximum number of days a typhoon stays continuously on a district is three in

this sample, and 66.1% of district-days are typhoon impacts lasting no more than one day), $k = 1, ..., \geq 7$ up to a week after typhoon left the region.

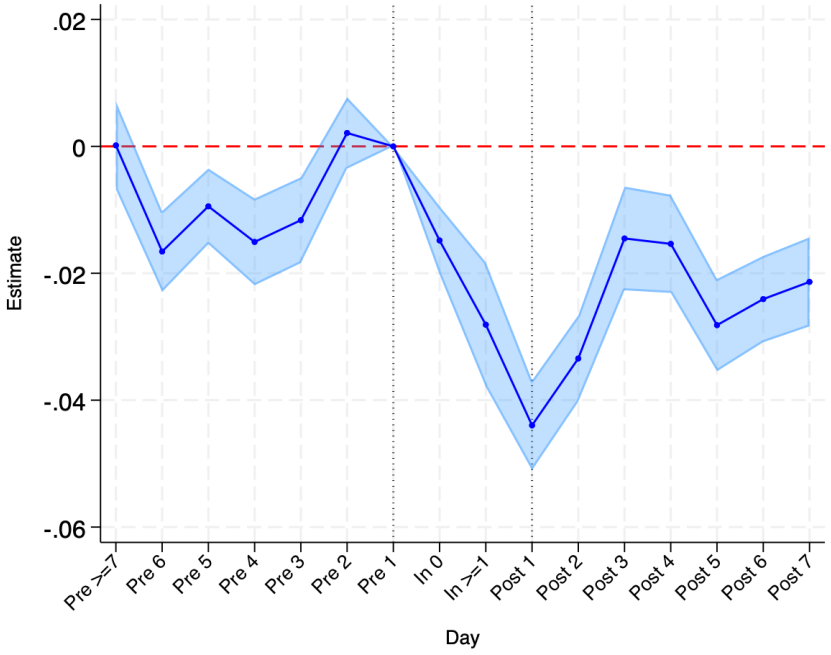


Figure 5: Event Study of Typhoon Impacts on Coastal Nightlight

Event study plot Figure 5 shows the β_k estimates in show roughly parallel pre-trend (or some immediate increasing trend two days before typhoon exposures), immediate and continuous decrease in nightlight after typhoon exposures (the greater time periods typhoon exposures last, the greater the drop of nightlight), and slow recovery of economic activities represented by nightlight up to a week after the typhoon leaves. These results then confirm the negative impact of typhoon on local economics in coastal cities of China, which is consistent with previous literature and intuition.

3.4 Multiple Defense Regression and Heterogeneity Analysis

In our main analysis, seawalls are not time-varying, therefore endogeneity problem can bias our regression estimators as long as there are omitted variables correlated with seawall presence in the DDD baseline regression Eq. 1. To resolve those issues, we will conduct regressions adding interactions of typhoon exposures with other defense besides seawalls:

$$\log(Nightlight_{ict}) = \alpha + \beta_1 Tyhoon_{ict} + \beta_2 Typhoon_{ict} \times Seawall_c + \beta_3 Typhoon_{ict} \times Defense_c + \gamma \mathbf{X}_{ict} + \epsilon_{ict} \quad (3)$$

In later results sections, we will include additional defense measures as $Defense$, including seawall maintenance count and investment, mangrove exposures, and approximated height of seawalls. β_3 in this regression represents the impact of additional defense metric against typhoons besides seawalls, and in some cases (for example, mangroves) we will also include interactions of the defense with seawalls to conduct analysis on whether their combining effects are significant on nightlight improvement when encountering typhoons.

Based on the baseline DDD regression Eq. 1, we will also run heterogeneity analysis for mechanism explorations:

$$\log(Nightlight_{ict}) = \alpha + \sum_g \mathbf{1}_g [\beta_1^g Tyhoon_{ict} + \beta_2^g Typhoon_{ict} \times Seawall_c] + \gamma \mathbf{X}_{ict} + \epsilon_{ict} \quad (4)$$

Where $g \in G$ separate the sample by location, time or both dimensions, so β_1^g, β_2^g of typhoon and seawall impacts on nightlights are separately estimated for each group g. In later mechanism sections, we segregate the sample by coastal versus non-coastal districts, years, and provincial level renewable energy standard shares.

4 Results

4.1 Seawall Defense on Typhoon Impacts of Nightlight

Our main estimated results of typhoon impacts on nightlight with seawall defense with Eq. 1 are presented in Table 1. From this regression, encountering $\geq 34kt$ typhoon wind during a day would reduce China's coastal city's district's nightlight by 1.6%, comparing with those not crossing the path with any typhoons. Adding seawall defense interaction with typhoons, districts belonging to coastal cities with zero seawall defense will experience up to 3.4% decrease in nightlight when hit by typhoon. Those reduction will be recovered

by the increase of 4%, if instead the city's coastline is 100% protected by seawalls. On these point estimates, approximately 85.0% coverage of seawalls of coastlines of a coastal city in mainland China would completely eliminate the negative impact of typhoons on coastal city's district nightlights. These then verify the significant role of seawalls in protecting coastal economics during typhoon events.

When relaxing the typhoon indicators to the continuous measure of maximum area of districts overlap with any typhoon's 34kt wind ring, results remain robust in Column (3) and (4) of Table 1. Negative impacts of typhoons on coastal city nightlight is on average 1.5% of decrease, and zero coastal seawall defense can result in up to 3.2% decrease of nightlight. With seawall defense, zero impacts by typhoons will be reached if the coast is covered 89.9% by seawalls. We also run a series of robustness checks with alternative seawall and coastline measurement, and typhoon season sample restrictions in Table A.1. The main results of Table 1 remain robust by signs, magnitudes, and statistical significance throughout.

Though seawall defense against typhoon is verified with our regression analysis, it does not mean that government investment to seawalls will be cost-effective. On welfare analysis, we use the city of Zhuhai for an example, which has a detailed proposed plan of seawall reinforcement in defense of typhoons, floods and sea level rise over the construction period of 15 years, 2021-2035. Proposed budget for such construction is total 12.6 billion Yuan. The current seawall cover share of coastline from our data is 0.531[9]. Zhuhai over 2015-2024 has an average 3.23 days of typhoon exposure to $\geq$ 34kt wind per year, negatively impacting the local economy by 0.0112% as measured by nightlights with our regression estimates in Table 1. Taking the city's 2024 GDP (447.9 billion Yuan), the economic loss by typhoon is approximately 50.6 million Yuan per year. If the city's seawall extends the share of coastline defended to 0.850 (increase by 60%), economic loss from typhoon will be completely avoided, and the net economic gain over 100 years will add up to 5.06 billion Yuan without discounting. Therefore for the local investment to have positive NPV in 100 years, our estimates need to be a much lower bound, even with the expectation of higher typhoon exposures under climate change.

[9]The total seawall length in our data is calculated as 331.48km for Zhuhai, 9% shorter than the city government's measurement of 364.33km.

Table 1: Typhoon Impacts on Coastal City Nightlight with Seawall Defense

	(1) $\log(NTL)$	(2) $\log(NTL)$	(3) $\log(NTL)$	(4) $\log(NTL)$
Typhoon	-0.016***	-0.034***	-0.015***	-0.032***
	(0.004)	(0.008)	(0.004)	(0.009)
Typhoon x Shr. Seawall		0.040***		0.036**
		(0.013)		(0.015)
N	1139599	1139599	1139599	1139599
Adj. R-sq	0.977	0.977	0.977	0.977
Typhoon Indicator	In 34kt Wind Zone	In 34kt Wind Zone	Shr. Area in 34kt Wind Zone	Shr. Area in 34kt Wind Zone

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is either the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings, or the maximum share of overlapping with any typhoon wind ring during that day for the district. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024.*

4.2 Seawall Defense on Sea Rise and Sea Waves

Next, we estimate the impacts directly from sea conditions on daily nightlight measures for districts of coastal cities in China. We include both long-run sea level indicator SLA (sea level anomalies), and short-run sea condition indicator SWH (sea wave height). In Table 2, we can see that like typhoons, higher sea levels both by long-term SLA, or short-term SWH, will cause negative shocks to daily nightlight of coastal cities if without any seawall defense. These negative impacts will be again prevented by adding seawalls to the coastlines. The impact of $1m$ SLA increase is up to 6.1% of nightlight decrease, and will be saved and reduced to zero if seawall coverage is 44.2% or above. The impact of short term sea wave impact is much smaller, per $1m$ SWH exposure reducing nightlight by only 0.8%, and that decrease will be reduced to only 0.1% if the coast is fully defended by seawalls.

These results effectively verify the potential of seawall defense against long-run sea level rise besides short-term typhoons and high sea waves, making our results of seawall significance extend beyond its current main goal against typhoon, to its future use against sea level rise under climate change. Under IPCC estimated sea level rise of $0.84m$ in 2100 (report 2022, RCP 8.5)[10], taking our estimates with SLA, economic loss from climate-related sea

[10]Source: https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/.

level rise can be recovered by increasing the current seawall share of every coastal city to at least 44.2% (that accounts for 18 coastal cities needing seawall extensions).

Table 2: Sea Level Impacts on Coastal City Nightlight with Seawall Defense

	(1) $\log(NTL)$	(2) $\log(NTL)$	(3) $\log(NTL)$	(4) $\log(NTL)$
Sea Level	0.002	-0.061***	-0.004***	-0.008***
	(0.009)	(0.019)	(0.001)	(0.002)
Sea Level x Shr. Seawall		0.138***		0.007**
		(0.038)		(0.003)
N	1197483	1197483	1326082	1326082
Adj. R-sq	0.978	0.978	0.977	0.977
Sea Level Indicator	SLA	SLA	SWH	SWH

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Sea level indicators are either SLA (Sea Level Anomalies), or SWH (significant wave height). Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample period is 2015-2023 for SLA, and 2015-2024 for SWH.*

However, as suggested by engineering literature, seawall effectiveness against floods, storms and inundation can be different under sea level rise. We further explores the defensive role of seawalls under typhoons when combined with long-term sea level rises, measured by average SLA, or slope of SLA over years. Results of triple interactive regression in Table A.2 indicates that typhoon under positive sea level rise scenario will have less negative impacts on daily nightlight, consistent with the adaptation story of coastal cities already undergoing sea level rise may be more adapted to defense against the large instantaneous sea rise during typhoons even without seawalls (for example, by already migrating inland). However, adding the triple interactions, seawall defense over typhoons when there is already positive average sea level rise is reduced. This could be that the infrastructure of seawall building is not compatible with adaptation to sea level rise, so when sea rise combine with typhoons, seawall defense is not as effective. That posts the challenge for future considerations by policy makers and engineers, when climate change can increase both sea levels and typhoon frequencies, creating greater threats to the coastal regions that may not be effectively solved by building more seawalls.

4.3 Seawall Defense with Maintenance Constructions

All existing seawalls require regular maintenance, especially those damaged by large typhoons over the years. To test whether public finance investment in seawall has any impacts on their significance to defend typhoons, we add the interactions with investment measured by construction counts or average budgeting per km of coastlines for each coastal city from 2010-2024 with Eq. 3, and present our results in Table 3. As it shows, our seawall construction measures have consistent, positive and statistically significant impacts on nightlight during typhoon events. The greater the construction investment, the greater the positive impact of seawalls on nightlight when the district is hit by a typhoon. If the number of construction is 0.272 per km of coastline of the coastal city, or average investment reaches 1.61 million Yuan per construction per km of coastline, then seawall coverage needs only to be 40% (instead of 85% in the previous calculation) in order to recover all the negative shocks to nightlight brought by typhoons.

These results are consistent with the theory that not only longer seawalls defend coasts better, but also stronger seawalls defend better. In policy implications, these results can also be used to consider the trade-off of investment between building longer seawalls, versus reconstructing the existing ones. In addition to seawall constructions, we also use satellite-based approximation of seawall heights in Eq. 3 in Table A.3. Results show statistically insignificant near-zero impacts of the average height of seawalls on nightlight over typhoon events, while share of seawall coverage of coastline has their positive impacts not significantly different from our main results. Therefore, unlike continuous maintenance, adding heights is not found to have increased the defensive effect of seawalls against typhoon shocks to nightlight[11]. If maintenance increase seawall defense but not through height, it is likely through increasing the strength of the infrastructure, since extending seawalls are hardly seen in government documents yet throughout our search.

[11] This conclusion can be rather different with respect to sea level rise though, as current sea level is out of sample for the coastal cities. We haven't found direct evidence that governments are planning on building higher seawalls yet, but a more comprehensive document search is still underway.

Table 3: Typhoon Impacts on Coastal City Nightlight with Seawall Defense and Seawall Maintenance Investment

	(1) $\log(NTL)$	(2) $\log(NTL)$	(3) $\log(NTL)$	(4) $\log(NTL)$
Typhoon	-0.026***	-0.051***	-0.019***	-0.044***
	(0.007)	(0.012)	(0.005)	(0.009)
Typhoon x Shr. Seawall		0.047***		0.050***
		(0.015)		(0.014)
Typhoon x Investment	0.090**	0.118***	1.067**	1.488***
	(0.045)	(0.045)	(0.463)	(0.472)
N	1139599	1139599	1111660	1111660
Adj. R-sq	0.977	0.977	0.977	0.977
Investment Measure	No. Constructions	No. Constructions	Avg. Investment	Avg. Investment

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024. No. of constructions indicates the number of recorded maintenance construction recorded for the coastal city during 2010-2024, normalized to per km of coastline. Average investment per construction measured in 10^8 Yuan per km of coastline per construction.*

4.4 Seawall Defense with Mangroves

Mangroves are one of the most important natural-based solution against typhoons, making the conservation of mangrove forests and wetland important public and private investment in Southern China. Mangroves require warm and humid climate conditions to grow, and must experience less rigorous sea waves in order to survive along the coasts. To understand whether mangrove defense also work when seawall defense is already in place along coastal China, we run the triple interactive regression with typhoon and seawall exposures and present our results in Table 4. From the results, we can see that just like seawalls, mangrove also present positive impacts on nightlights during typhoons, consistent with the ecological theory. However, adding mangroves with seawalls together overlapping spatially, their interaction coefficient or double-exposure measures show either insignificant positive or negative impacts on nightlights during typhoons.

These suggest that mangroves together with seawalls may not be compliments for typhoon and sea rise defenses to the local coastal economies of China. Instead, they might even be substitutes. Other possibilities are that mangroves require strict natural ecosystem to grow, inconsistent with the human constructed concrete nature of seawalls, therefore existing mangrove-seawall double interactions are not optimally maintained per ecological

requirement. Since existing local government seawall planning in recent years stress ecological seawall constructions (e.g., the city of Zhuhai aims for 50% of ecological seawalls) not only for sea rise and storm defenses, but also for tourism concerns, interactions with mangroves should be carefully taken into account in future construction of seawalls, in order to maximize the impact of both natural and human constructed defenses against sea risks especially considering that mangroves may spread further north of China's coast into the future.

Table 4: Typhoon Impacts on Coastal City Nightlight with Seawall Defense and Coastal Mangroves

	(1) $\log(NTL)$	(2) $\log(NTL)$	(3) $\log(NTL)$	(4) $\log(NTL)$
Typhoon	-0.026***	-0.061***	-0.061***	-0.058***
	(0.004)	(0.008)	(0.008)	(0.008)
Typhoon x Shr. Mangrove	201.997***	275.467***	268.414***	273.037***
	(45.257)	(48.965)	(51.689)	(49.675)
Typhoon x Shr. Seawall		0.069***	0.067***	0.068***
		(0.013)	(0.014)	(0.013)
Typhoon x Shr. Seawall x Shr. Mangrove			53.897	
			(198.983)	
Typhoon x Shr. Seawall-Mangrove				-63.001**
				(27.674)
N	1139599	1139599	1139599	1139599
Adj. R-sq	0.977	0.977	0.977	0.977

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024. Mangrove exposures are measured as inverse-distance weighted sum (unit: km^2) to district centroids within 50km. In Column (4) regression, share of seawall-mangrove is measured as exposure to seawall and mangrove, estimated as the inverse-distance weighted sum (unit: km^2) to seawalls within 50km.*

4.5 Seawall Correlation with Local Economics

Since seawall share coverage of coastline is likely correlated with local economic conditions and structures, we run triple interactive regression adding city-yearly level economic variables of GDP per capita (correlation of -0.10 with seawall share), secondary industrial share (correlation of 0.29), and tertiary industrial share (correlation of -0.33). By hypothesis, coastal cities with greater income and more industrial assets have greater incentive to build seawalls for typhoon defense, while tourism cities prefer preserving the beach from concrete

structures. Our results in Table 5 has generally proved that the positive impact of seawalls against typhoon on nightlight reduction remains significant adding those economic variables. Regression results do show that typhoon impacts are less significant on cities with higher income level, which have more defensive budget, and cities with higher tertiary industries, which have less industrial assets to suffer from the extreme weathers. Coefficients on seawall share triple interaction term shows that its defense role is significant only in cities with high enough GDP per capita or high enough secondary industrial share (above 31.8%). Defense remains positive for cities with lower tertiary industrial share (below 56%). These results are then consistent with the intuition that higher income and more industrialized cities may have better maintenance of seawalls, while tourism cities may experience negative shocks from too much seawalls instead affecting the coastal views even closer to typhoon seasons.

Table 5: Typhoon Impacts on Coastal City Nightlight with Seawall Defense and Economic Variables

	(1)	(2)	(3)	(4)	(5)	(6)
	$\log(NTL)$	$\log(NTL)$	$\log(NTL)$	$\log(NTL)$	$\log(NTL)$	$\log(NTL)$
Typhoon	-0.406***	-0.060	-0.008	0.067***	-0.048**	-0.192***
	(0.110)	(0.250)	(0.018)	(0.023)	(0.019)	(0.040)
Typhoon x Econ. Var.	0.034***	0.002	-0.000	-0.003***	0.001*	0.003***
	(0.010)	(0.022)	(0.000)	(0.001)	(0.000)	(0.001)
Typhoon x Shr. Seawall		-0.798*		-0.191***		0.336***
		(0.470)		(0.054)		(0.085)
Typhoon x Econ. Var. x Shr. Seawall		0.073*		0.006***		-0.006***
		(0.041)		(0.001)		(0.002)
N	1139599	1139599	1139599	1139599	1139599	1139599
Adj. R-sq	0.977	0.977	0.977	0.977	0.977	0.977
Economic Variable	log(GDP per cap)	log(GDP per cap)	Secondary Ind. Shr.	Secondary Ind. Shr.	Tertiary Ind. Shr.	Tertiary Ind. Shr.

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024.*

5 Mechanism

In this section, we will explore why seawall defense against reduction of nightlight, which is correlated with local economic activities, during typhoon events.

5.1 Sea Activities

Firstly, we use our baseline regression on sea work activities to explore whether seawalls defend off-shore economic activities during typhoons. Table 6 presents our results. From those, we can see that typhoon has mostly reduced near coastal sea works like VBD, ship calling into ports, and trade volumes. Near-coast fishing hours seems to be increasing instead (likely due to that far sea that are mostly the active region with fishing works are more dangerous during typhoons). However, seawall coastal share interactions have positive and statistically insignificant impact on these marine work activities, meaning that seawall does not defend offshore economic activities. Therefore, the reduction to nightlight or disruption to local economies we see in the main results are unlikely coming from reduced sea-related activities from fishing and port trades.

These are intuitive results. Seawalls by construction are mainly protecting land activities, instead of providing greater shield to those at sea. It is even likely that boats and cargo traffic during typhoons are not able to find greater defense against the natural disaster given the on-shore constructions of seawalls.

Table 6: Typhoon Impacts on Sea Work Activities with Seawall Defense

	(1)	(2)	(3)	(4)
	log(VBD)	Fishing Hours	No. Port Calls	log(Total Trade Volume)
Typhoon	-0.287*	39.871**	-9.037*	-1.404***
	(0.159)	(19.208)	(5.435)	(0.437)
Typhoon × Shr. Seawall	0.114	-23.727	9.927	0.905
	(0.291)	(17.108)	(7.248)	(0.651)
N	641364	663382	189972	135329
Adj. R-sq	0.399	0.080	0.911	0.732

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024. VBD stands for VIIR Boat Detection.*

5.2 Land Activities

On the other hand, we also apply our baseline regression on indicators of land activities, represented by high-frequency carbon emission measurements, normalized to coastal city

levels. Results in Table 7 shows that though aggregate carbon emissions do not have statistically significant impacts from typhoons or seawall defense, three segregated sectors have seen negative impacts on emissions during typhoons, then positive impacts on emissions if having seawall defenses against typhoon events. These sectors are industrial, residential, and transportation. Intuitively, this matches with the assumption that typhoon impacts production activities, disturb on-road transportation through rain and sea rise, and possibly residential consumption and usage of electricity. Meanwhile, seawall defense will reduce flooding of roads and assets by the coasts, therefore preventing the decrease in industrial and transportation activities and leading to less decrease in residential consumption.

Note that the energy sector is not as much impacted, meaning typhoons and related floods that may be prevented by seawalls are not significantly impacting electricity generators of the cities[12]. Any decrease in nightlight represented economic activities are likely directly caused by typhoons and defended by seawalls, instead of through their indirect impacts on energy supplies. Based on the anecdotal reports of strong typhoons destroying near coastal renewable energy infrastructures (e.g. wind mills)[13], we also test the differential typhoon and seawall impacts on nightlights in provinces with low versus high 2018 national renewable energy contribution standards sorted by 30 mainland provinces[14]. Table A.4 shows the results that typhoon impacts on nightlights seem only significant on the high renewable energy share provinces (Shanghai, Guangdong, Guangxi), but seawall defenses are statistically insignificantly positive over these regions. Instead, the defense impact are just 10% statistically significant on low renewable energy share provinces. In interpretations, typhoons likely do impact local economies with greater share of renewable energy supplies because related infrastructures like wind mills and solar panels can be more damaged by typhoon. However, seawalls may not significantly defend those infrastructures, because the most damages are coming from wind instead of sea water flooding (or when wind mills are off-shore). Instead, fossil energy generators may be easier defended by seawalls if they are located near the coastlines.

Typhoon related disruptions to land activities especially in industrial and transportation

[12]Additional evidence will be provided when our access of China's electricity outrage data 2019-2023 is completed.
[13]Source: http://www.cb.com.cn/index/show/zj/cv/cv135275831263.
[14]Source: https://www.gov.cn/zhengce/zhengceku/2019-09/25/content_5432993.htm.

Table 7: Typhoon Impacts on Carbon Emissions with Seawall Defense

	(1) Total	(2) Industry	(3) Residential	(4) Power	(5) Transportation
Typhoon	-0.026	-0.036**	-0.037**	-0.022	-0.050**
	(0.023)	(0.018)	(0.018)	(0.020)	(0.023)
Typhoon × Shr. Seawall	0.052	0.065*	0.071*	0.034	0.113*
	(0.044)	(0.037)	(0.036)	(0.041)	(0.057)
N	115,810	115,704	115,810	109,599	115,810
Adj. R-sq	0.940	0.949	0.927	0.963	0.936

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by cities in parenthesis. Sample includes 55 coastal cities of China, daily emissions 2019-2024. Date and city fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Carbon emission as dependent variable is taken logs in these regressions.*

sectors are likely results from coastal flooding, which seawalls are engineering designed to defend against. To inspect the impact of seawalls on actual flooding instances, we collect satellite images of floods from Global Flood Monitoring. As shown in Appendix Table A.6, likely due to the low resolution of smaller flood detections (only 0.0165% of our district-day sample have any satellite documented flood) which coastal flooding from temporary typhoon exposures are usually categorized into, we currently do not detect statistically significant evidence either typhoon contributes to increasing flooding, or seawall defend against those flooding, though the sign on seawall interacting with typhoon on flood existence is negative implying flood reduction[15].

5.3 Direct Versus Indirect Coastal Districts

In Table 8, we explores whether the impacts of typhoons and seawalls apply on coastal districts directly by the sea, or non-coastal districts of coastal cities that do not directly border the sea with heterogeneity analysis Eq. 4. From these results, we can see that the greater and major negative influence of typhoons on nightlight falls on non-coastal districts of coastal cities. Meanwhile, the significant positive impacts on nightlight by greater share of coastlines defended by seawalls are also only on non-coastal districts. Results in Column (2) for coastal districts are small in magnitudes and statistically insignificant, against the intuitions that seawall has direct defense for districts directly bordering the coastlines. We

[15]We are also collecting agricultural data to see if there exist indirect evidence that coastal flooding may affect near-coast vegetation and agriculture yields, as supplementary evidence to the flooding story

also run the baseline regression on coastal district only, or aggregate the sample to city-level and average across both coastal and non-coastal districts in Table A.5. Results on nightlight are statistically insignificant, both for the negative impact of typhoon, and for the positive impact of seawall defense against typhoon.

The reason can be that non-coastal districts are normally the coastal city center and much more economically active than coastal districts. In nightlight measurement, over the sample period 2015-2024, coastal districts have average nightlight of 8.59, while non-coastal districts have 49.8% higher average nightlight of 12.87. Therefore when encountering typhoons, non-coastal districts have relatively more economic activities (e.g. labor, consumption, transportation) prone to the direct impacts of strong wind and indirect spillover impacts from sea rise, flood and disturbance to their neighboring coastal districts. As a results, the defense of seawalls, though it directly protect the infrastructures and activities for coastal districts, can be higher for non-coastal districts as spillover as well. For example, if traveling to non-coastal districts have to go through coastal districts, defense of road inundation by sea rise during typhoons by seawalls can be important to the non-coastal district's transportation activities.

Table 8: Typhoon Impacts on Nightlight with Seawall Defense, Coastal Districts Versus Non-Coastal Districts of the Coastal Cities

	(1)	(2)
	$\log(NTL)$	$\log(NTL)$
Typhoon x Coastal District	-0.013***	-0.015
	(0.005)	(0.011)
Typhoon x Non-Coastal District	-0.021***	-0.053***
	(0.006)	(0.011)
Typhoon x Shr. Seawall x Coastal District		0.006
		(0.019)
Typhoon x Shr. Seawall x Non-Coastal District		0.073***
		(0.018)
N	1139599	1139599
Adj. R-sq	0.977	0.977

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024. Coastal districts are districts directly bordering coastlines for the coastal cities (192 districts), and non-coastal districts (146 districts).*

5.4 Differential Impacts by Years

To explore whether typhoon and seawall defense impact can vary by time period, we run heterogeneity analysis regression by years and present the estimation of β_1, β_2 in Figure 6. From this regression, we can see that in earlier periods 2015-2018, though being high typhoon exposure period in the 10-year sample (Figure 2), both typhoon negative impacts and seawall positive impacts on nightlight has been statistically insignificantly different from zero. Past 2019, for most years (except for the lower typhoon exposure year of 2023), there are 5% statistically significant decreasing impacts of nightlight from typhoons, and increasing impacts from seawall defense. Magnitudes of those estimates have all been large, up to 18% for seawall defense and 10% decrease for typhoon shocks.

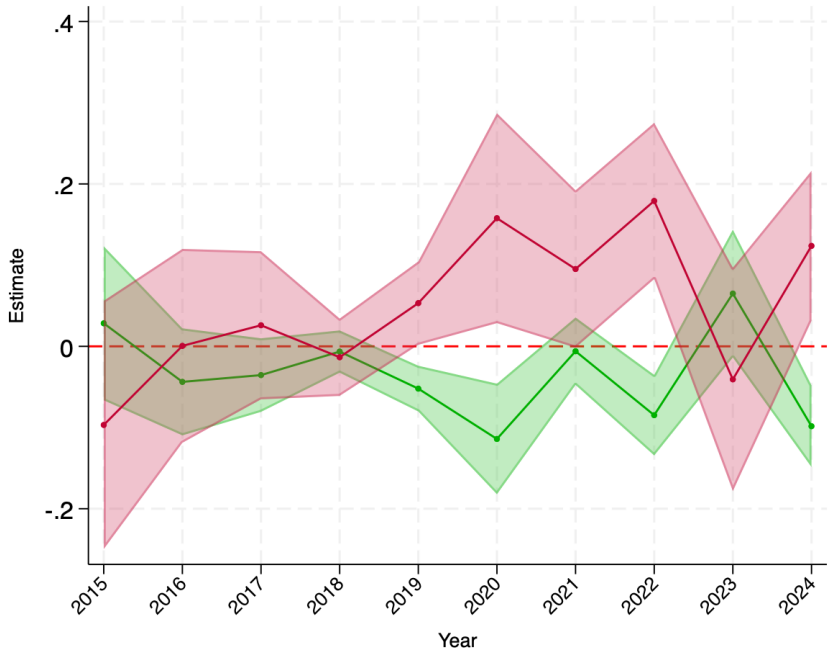


Figure 6: Typhoon and Seawall Defense Impact on Nightlight by Years

Notes: Regression estimate by Eq. 4, where groups are determined by years 2015-2024 of observations. Green line represents the estimate of β_1, typhoon impact on nightlights with zero seawall defense. Red line represents the estimate of β_2, impact of typhoon on nightlight under 100% coastline defense by seawall. 95% confidence intervals are represented by the shaded areas.

The most likely explanation for the yearly trend is that since our seawall indication is documented in 2020, maybe pre-2019 seawall construction or maintenance has not been completed and seawall defense to typhoons have not been effective. Considering that the central

government's national seawall construction plan has been issued in 2017[16], this timeline is not without foundation. Post-2019, seawall construction may have been established, thus their defense has been significant and effective. Comparing with typhoon-only regression by year in Figure A.1, we can derive the similar conclusion that in earlier periods (pre-2020) typhoon impacts have been negative (but magnitudes are relatively small, less than 5% decrease of nightlight). But afterwards seawalls have provided effective defense against typhoons, so the overall impacts of typhoons rise to near-zero on average.

5.5 Housing Prices and Demands

There have been increasing research evidence showing the negative impact of extreme weather events on housing price in China (Chen et al. 2025, Deng et al. 2025), though the growing and inelastic demand of housing in the country, especially urban areas, have induced relatively transient housing price shocks. Designed to defend against coastal flooding, seawalls have the significant channel to positively affect coastal city housing prices and reflected land values. We first prove this hypothesis using China National Bureau of Statistics released city-monthly housing price index and find statistically significant evidence that typhoon reduces housing price in coastal cities, then greater share of seawall defense reverts those price depreciation and adds to higher housing price (Table 9. The positive impact of seawall is in magnitude higher than the baseline results with nightlight as economic indicator, as less than 50% of seawall coverage is sufficient to recover the pricing loss due to typhoons from these regressions.

[TBD][17]

6 Conclusion

This paper provides the first empirical evidence on the effectiveness of seawalls in mitigating typhoon-induced economic shocks in coastal mainland Chinese cities over the period 2015-2024. Using high-frequency daily nightlight data as a proxy for economic activity, we have shown that seawalls substantially reduce the negative impacts of seasonal typhoons, primarily

[16]Source: http://www.cfgw.net.cn/2017-08/22/content_24701231.htm.

[17]Ongoing data analysis using establishment-transaction level data of Chinese housing market.

Table 9: Typhoon Impacts on City-Level Housing Price Index with Seawall Defense

	(1)	(2)	(3)	(4)	(5)
Typhoon	-4.860**	-6.854***	-102.686**	-72.600	-102.686**
	(2.095)	(2.067)	(38.164)	(45.369)	(38.164)
Typhoon x Shr. Seawall	10.708**	12.569**	216.997**	159.787	216.997**
	(4.991)	(4.733)	(97.539)	(105.794)	(97.539)
N	1524	1524	1524	1524	1524
Adj. R-sq	0.932	0.932	0.932	0.932	0.932
Typhoon Indicator	Any typhoon in month	Max daily area in month	Mean area exposure	Share of days affected	Mean of (day affected x area exposure)

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by cities in parenthesis. Dependent variable is city-monthly level of housing price index in China published by National Bureau of Statistics. Month and city fixed effects are controlled. Climate and economic controls are included. Typhoon indicator all take over monthly periods. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024.*

by protecting land-based economic activities in the industrial, residential, and transportation sectors. Notably, the strongest protective effects occur in economically dense districts located farther inland within coastal cities, highlighting the importance of indirect spillovers through transportation networks and within-city mobility rather than direct protection limited to shoreline areas alone.

Our findings further underscore the importance of seawall maintenance and reinforcement. Continuous investment in strengthening and extending existing seawalls significantly enhances their defensive capacity against typhoon shocks, supporting the economic rationale for proactive infrastructure investment ahead of future extreme events. While mangrove coverage also contributes to coastal protection, we find that seawalls constructed in areas overlapping with mangrove ecosystems may reduce overall effectiveness, pointing to potential trade-offs between gray and green infrastructure. This result emphasizes the need for coastal adaptation strategies that are carefully aligned with local ecological conditions rather than relying on uniform engineering solutions.

Beyond typhoons, we document similar protective effects of seawalls against elevated sea levels and extreme wave conditions, as measured by sea level anomalies and significant wave height. These results strengthen the external validity of our findings and suggest that seawalls can play a meaningful role in adapting to long-run climate risks associated with sea

level rise. Extrapolating from our estimates, we find that sea level shocks comparable in magnitude to current extreme typhoon events can be substantially mitigated through expanded and reinforced seawall coverage, implying that investment in coastal defense infrastructure constitutes effective adaptation strategy under climate change.

Several limitations of this study point to important directions for future research. First, our seawall data capture only static spatial information, primarily location and length. Without details on structural characteristics such as height, building materials, age, or design standards. Access to richer administrative data from water conservancy authorities would allow for a more granular evaluation of seawall performance and enable counterfactual simulations of alternative investment strategies. Second, the mechanisms through which seawalls defend against short-term extreme events, such as typhoons, may differ fundamentally from their role in responding to long-term climate stressors, including gradual sea level rise. While our results suggest that rising baseline sea levels may weaken seawall effectiveness when combined with typhoon shocks, fully understanding these dynamics will require closer integration with coastal engineering models and physical simulations. Such interdisciplinary work will be crucial for designing optimal coastal adaptation policies in a future characterized by both rising seas and intensifying storms. Finally, while this paper provides some of the first economic evidence on seawall effectiveness, comprehensive cost-benefit analysis that weigh economic benefits against construction and maintenance costs, as well as analysis regarding the spatial equilibrium effects through population migration and housing market sorting, are essential for the full understanding of the welfare implications of long-term investments in adaptation capitals such as seawalls.

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Appendix

Table A.1: Typhoon Impacts on Coastal City Nightlight with Seawall Defense, Robustness Check Alternatives

	(1) log(NTL)	(2) log(NTL)	(3) log(NTL)	(4) log(NTL)	(5) log(NTL)	(6) log(NTL)	(7) log(NTL)	(8) log(NTL)
Typhoon	-0.025***	-0.040***	-0.035***	-0.033***	-0.025***	-0.033***	-0.032***	-0.040***
	(0.006)	(0.008)	(0.010)	(0.008)	(0.005)	(0.010)	(0.010)	(0.008)
Typhoon x Shr. Seawall	0.019**	0.056***	0.046**	0.040***	0.035***	0.027**	0.022**	0.056***
	(0.009)	(0.015)	(0.018)	(0.013)	(0.009)	(0.012)	(0.011)	(0.015)
N	1139599	1139599	1139599	762548	1326082	1118299	1118299	1139599
Adj. R-sq	0.977	0.977	0.977	0.979	0.977	0.978	0.978	0.977
Alternative	Unmapped Shr. Seawall	Winsorized Seawall Shr.	Time-Varying Seawall Shr.	Limit to Typhoon Season	CMA Level 7 Wind Ring	Mapped Gaode (City)	Mapped Gaode (Country)	Mapped Open Street Map

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. *Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024. Robustness check runs through if raw seawall length is taken without mapping onto coastal shapefile, winsorizing seawall share to be bounded by 1, using time-varying seawall share defined as the ratio of length of seawall overlapped by typhoon ring over length of coastline overlapped by typhoon ring of each coastal city, limit to typhoon seasons May-December each year, using realized typhoon rings as CMA tracked Level 7 wind rings, and mapped seawalls on different shapefiles sourced from Gaode or Baidu.*

Table A.2: Typhoon and Long-Run Sea Level Change Impacts on Coastal City Nightlight with Seawall Defense

	(1)	(2)	(3)	(4)
	$\log(NTL)$	$\log(NTL)$	$\log(NTL)$	$\log(NTL)$
Typhoon	-0.019	-0.139***	-0.018***	-0.056***
	(0.019)	(0.037)	(0.004)	(0.008)
Typhoon x Sea Level	0.036	1.283***	0.052	0.541***
	(0.227)	(0.477)	(0.054)	(0.090)
Typhoon x Shr. Seawall		0.256***		0.074***
		(0.083)		(0.012)
Typhoon x Sea Level x Shr. Seawall		-2.665**		-1.022***
		(1.062)		(0.176)
N	1139599	1139599	1139599	1139599
Adj. R-sq	0.977	0.977	0.977	0.977
Long-Run Sea Level	Avg. SLA	Avg. SLA	Slope SLA	Slope SLA

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Sea level indicator SLA (Sea Level Anomalies) over long-run is the average over 2015-2023, or slope of SLA on year using simple OLS on the sample 2015-2023. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample period is 2015-2023.*

Table A.3: Typhoon Impacts on Coastal City Nightlight with Seawall Share and Seawall Height

	(1)	(2)	(3)
	$\log(NTL)$	$\log(NTL)$	$\log(NTL)$
Typhoon	-0.034***	-0.034***	-0.034***
	(0.008)	(0.008)	(0.008)
Typhoon x Seawall Height	-0.014	-0.001	-0.003
	(0.047)	(0.002)	(0.006)
Typhoon x Shr. Seawall	0.040***	0.041***	0.041***
	(0.013)	(0.014)	(0.014)
N	1139599	1139599	1139599
Adj. R-sq	0.977	0.977	0.977
Height	Mean over 50m	Mean of Top 5% over 50m	Mean of Top 1% over 50m

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Seawall heights are captured by Copernicus DEM grid data, averaged over 50m land grids of the seawall, or top 1% and 5% of those land grids. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024.*

Table A.4: Typhoon Impacts on Coastal City Nightlight with Seawall Defense, Heterogeneous on Provincial Renewable Energy Standard

	(1) $\log(NTL)$	(2) $\log(NTL)$
Typhoon x High Renew. Shr.	-0.036***	-0.055***
	(0.006)	(0.013)
Typhoon x Low Renew. Shr.	-0.001	-0.013
	(0.004)	(0.008)
Typhoon x Shr. Seawall x High Renew. Shr.		0.045
		(0.028)
Typhoon x Shr. Seawall x Low Renew. Shr.		0.025*
		(0.013)
N	1139599	1139599
Adj. R-sq	0.977	0.977

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Date, district, city-by-month of year fixed effects are controlled. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024. Renewable energy standard is sorted by minimum share required in Year 2018. Sorting 30 mainland provinces with standards required by the central government, three coastal provinces (Shanghai, Guangzhou, Guangxi) are among high renewable standard provinces (min. renewable share 2018 ≥ 19.75%), while the rest coastal provinces are sorted to low renewable standard provinces.*

Table A.5: Typhoon Impacts on Nightlight with Seawall Defense, Coastal Districts or Aggregate Coastal Cities

	(1) $\log(NTL)$	(2) $\log(NTL)$
Typhoon	-0.018	-0.015
	(0.012)	(0.011)
Typhoon x Shr. Seawall	0.003	0.011
	(0.021)	(0.018)
N	186686	637886
Adj. R-sq	0.937	0.971
District or City FE	Y	Y
Date FE	Y	Y
City-Month of Year FE	N	Y
Typhoon Indicator	In 34kt Wind Zone	In 34kt Wind Zone
Sample	Coastal Cities, City Seawall Shr.	Coastal Districts, City Seawall Shr.

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts in parenthesis. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Sample drops any coastal city districts in provinces that haven't overlap with any typhoon rings during the sample period 2015-2024. Coastal districts are districts directly bordering coastlines for the coastal cities (192 districts). Column (1) coastal city aggregate results average nightlight across all districts of each coastal city.*

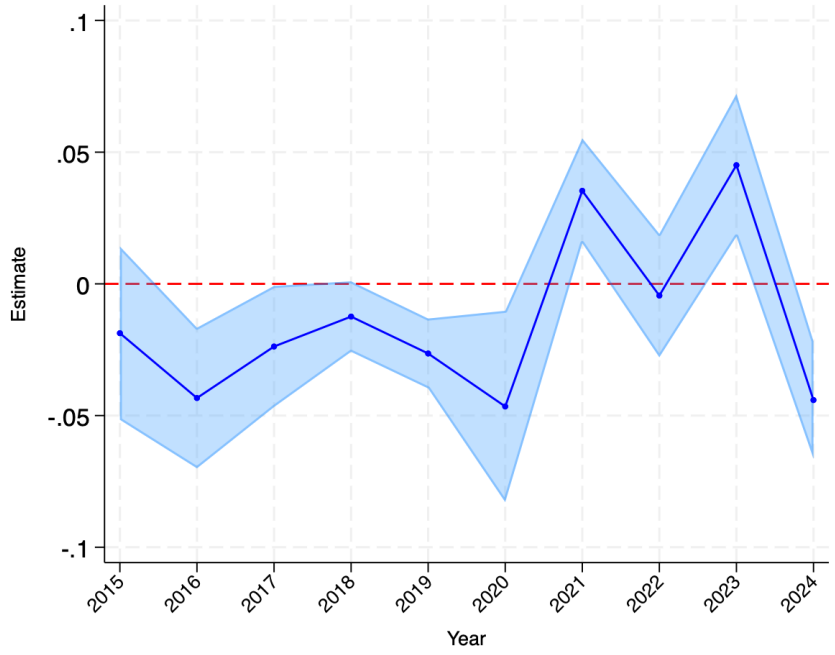


Figure A.1: Typhoon Impact on Nightlight by Years

Notes: Regression estimate by Eq. 4, where groups are determined by years 2015-2024 of observations. In this variation seawall defense interactions are dropped and only typhoon impacts are estimated. 95% confidence intervals are represented by the shaded areas.

Table A.6: Typhoon Impacts on Flood Realization with Seawall Defense

	(1) $\log(Area)$	(2) $\log(Share)$	(3) $\mathbf{1}_{Flood}$	(4) $\log(Area)$	(5) $\log(Share)$	(6) $\mathbf{1}_{Flood}$
Typhoon	-0.000	-0.000	0.000	0.001	0.000	0.000
	(0.001)	(0.001)	(0.000)	(0.007)	(0.004)	(0.001)
Typhoon x Shr. Seawall	-0.001	-0.001	-0.000	-0.003	-0.002	-0.000
	(0.001)	(0.001)	(0.000)	(0.003)	(0.002)	(0.000)
N	1185761	1185761	1185761	193623	193623	193623
Adj. R-sq	0.010	0.010	0.010	0.027	0.027	0.026
Spatial Level	District	District	District	City	City	City

*Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered by districts or cities in parenthesis. Sample includes 55 coastal cities of China, daily emissions 2019-2024. Date, district, city-by-month of year fixed effects are controlled fir district level regressions. Date and city fixed effects are controlled for city level regressions. Climate and economic controls are included. Typhoon indicator is the dummy variable indicating whether the district-date has overlapped with 34kt typhoon wind rings. Seawall share is defined as the share of coastlines being defended by seawalls by Baidu Map, per coastal city for each district belonging to. Flood dependent variables include log of the area of flood (unit: m^2), adjusted by adding 1; log of share of flood area over district or city areas, adjusted by adding 10^{-9}; and indicator of whether there is flood in the region of that day.*