The Long-Term Impact of Oil Spills on Ecosystem Recovery*

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Abstract

Maritime disasters are often appraised using contingent valuation methods, despite their weak connection to measurable ecological damage. This paper uses satellite-based measurements and a synthetic difference-in-differences design to estimate ecological losses at sea in a scalable way. Applying the approach to major oil spills worldwide, I find that large spills generate persistent ecosystem damage: ten years later, the ocean's capacity to support fish biomass is about 20 percent lower. The implied economic losses reach up to USD 1.84 billion for a single spill. These damages far exceed observed financial compensation, suggesting that existing liability frameworks substantially undervalue marine ecosystem losses.

Keywords: Marine pollution, oil spill, synthetic difference-in-differences, impact evaluation, contingent valuation

Economics Research is Lacking

- Marine ecosystems constitute the largest carbon sinks: Phytoplankton communities alone accounts for nearly half of global carbon fixation [1]
- This is three times more than the Amazon forest, the "lung of the Planet"!
- Yet, economic research on carbon sinks has focused on land use with barely any research on marine ecosystems.
- Economic valuation driven by WTP/WTA methods such as contingent valuation surveys [2,3,4].
  - Anthropocentrism: Driven by human perception/willingess to avoid disasters.
  - Inefficiency: Time consuming and expensive to conduct.
  - Unscalability: Difficult to replicate, leading to benefit-transfer methods.
- Oil spill disasters, in particular, endanger marine life, exacerbate ocean acidification, and disrupt ecosystem balance [5, 6]

Deepwater Horizon, US (2010)
Source: Office of State Gov.t of Louisiana

This Paper

Approach:

- I follow 14 oil spills worldwide (2009-2011; Figure 1), looking at impacts after 10 years.
- Satellite data: Copernicus Global Ocean Physics Reanalysis as primary analysis data.
- Causal Inference: Estimation of damages via Synthetic Difference-in-Differences [7]
- Timing: ≥10 years pre-treamtent (1998), ≥10-years post-treatment (2020).

Contributions:

- Ecological focus: Identify long-run ecosystem damages by assessing the marine ecological health, providing a data-driven, scalable alternative to traditional economic valuation.
- Non-convex Impact: Recover some of the extent and shape of ecological damage function.
- Policy Relevance: Optimal liability rules, incentives for prevention, and disaster response.
- Trans-disciplinary: Bridging environmental valuation and economic valuation.

Research Question

What are the long-term environmental and economic impacts of oil spills on marine ecology?

Data & Methodology

- Global information on spills are scattered and incomplete.
- I use multiple official & expert sources to collect spill dates, locations, spill volume, and compensation.
  - Two main categories: Small spills (≤750 tons), large spills (>750 tons)
  - One outlier: Deepwater Horizon spill.

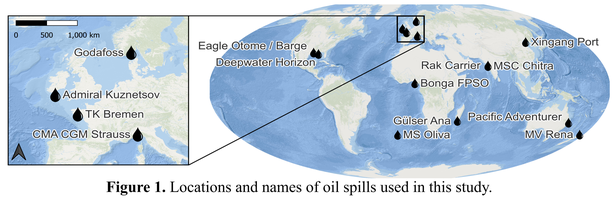


Figure 1. Locations and names of oil spills used in this study.

Dependent Variables	Additional Controls
Chl-α: Intensity of lux of carbon	**Environmental:** Sea salinity and temperature
C_{Phyto}: Biomass of phytplankton carbon	**Hydrological:** Ocean current direction and velocity
SBF: Fish biomass that ecosystem can support	**Human factors:** Fishing hours & vessel frequency

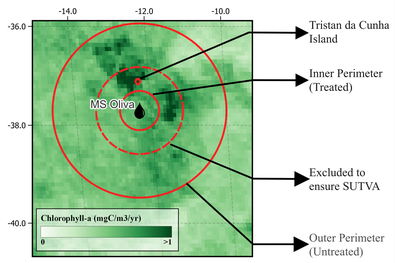
Synthetic Difference-in-Differences

Formulation

$$\underset{\beta,\alpha,\gamma,\delta}{argmin} \sum_{i=1}^{N}\sum_{t=1}^{T}\left(\ln(Y_{it}) - \gamma_i - \delta_t - D_{it}^{treated}\beta\right)^2 \hat{\omega}_i\hat{\lambda}_t$$

- Solves to obtain impact estimate coefficient β where:
  - Y_{it} is the dependent variable at year t for pixel i,
  - γ_i and δ_t are the pixel and year fixed-effects,
  - $D_{it}^{Treated}$ indicates whether a pixel is treated or not,
  - ω_i and λ_t are the estimated unit and time weights.

Visualization
(For one spill)



Benchmark Model:

- No covariates,
- Treated areas: 45-kilometer inner perimeter,
- Untreated areas: 100 to 200 km from spill, 80 km from the coast.

Results

Benchmark Model

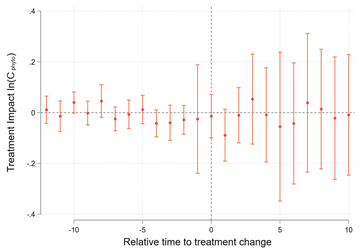
ATT (2012-2020)	Chlorophyll-α	Phytoplankton carbon	Supportable fish biomass	No. of donors	No. of spills
All large spills:	-0.158** (0.0667)	-0.259*** (0.0662)	-0.198*** (0.0664)	120	6
All small spills:	0.0005 (0.0505)	-0.0139 (0.0764)	0.0031 (0.0444)	126	7

- 10 years after the spills, on average, I find non-convex damages:
- **Large spills:** persistent decline:
  - 26% decrease in Cphyto,
  - 16% decrease in Chl-α, and
  - 20% decrease in SFB,
- **Small spills:** no significant impact

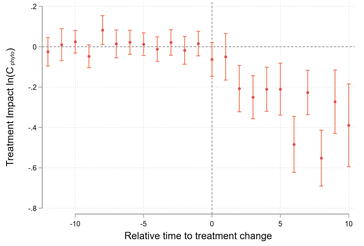
Robustness & sensitivity of model:

- Diverse set of alternative specifications:
  - Alternative resolutions,
  - Alternative distances for pools of donors,
  - Added covariates based on aforementioned factors.
- Monte Carlo experiment to validate identification strategy.
- **Results:** Findings are robust to alternatives, changes in estimates are as expected.

Event-Study: Small Spills



Event-Study: Large Spills



Economic & Policy Implications

Approach:

- Monetize plankton impact through quantification of Biological Carbon Pump [8]
- Monetize damage on fish life through quantification of real economic fish value [9]
- Cost estimates for 1 spill can reach $1.84B,
- Prestige spill's damages, despite being 50 times the volume of Xingang Port spill, are comparable.

Spill Name	Estimated Damages (millions, USD) BCP	Real Fish Value	Total	Past Spill Compensations (millions, USD)
Xingang Port	1.51 [0.8 - 2.2]	1,110.36 [379.6 - 1,839.1]	1,111.87	28.53
MSC Chitra	5.51 [3 - 8]	389.82 [133.3 - 645.7]	395.33	0.34
Bonga FPSO	4.74 [2.6 - 6.9]	246.23 [84.2 - 407.8]	250.97	73.17
Eagle Otome / Barge	2.97 [1.6 - 4.3]	216.49 [74.0 - 358.6]	219.47	0.32
MV Rena	2.93 [1.6 - 4.3]	36.56 [12.5 - 60.5]	39.48	26.83
MS Oliva	1.53 [0.8 - 2.2]	0.04 [0.01 - 0.07]	1.57	— [a]
Average [b]	3.53	399.89	403.42	25.84

What does it mean?

- Decline in CO2-capture exacerbates ocean acidification, a climate tipping point.
- Outdated & harmful disaster-response policies with used for oil removal such as chemical dispersants worsen outcomes for phytoplankton communities.
- Spill-affected areas are high-rarity and -richness: significant biodiversity impact.

WIP Paper:

References: