Removing federal subsidies from high-hazard coastal areas slows development

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Open Research Statement: All data and code used in this research is either (a) publicly available data acquired from US government agencies (e.g., NOAA, USGS), (b) data acquired from Zillow, Inc. (entire national dataset is available upon request from the providers via Data Use Agreement) or Boundary Solutions Inc. (available via paid subscription), or (c) is a novel built structures dataset created by the researchers using USGS high-altitude, historical satellite imagery. All data and code used in this analysis will be made available via a public repository (UNC Dataverse) upon acceptance for publication, including the samples of cadastral data with land use characteristics used in this study and the user-created built structures data. Data is available upon request during the review process, should the Subject-matter Editor deem it necessary.

Abstract

The federal government has implemented a variety of policies and subsidies that help coastal development remain viable, including investments in risk reduction measures, subsidized flood insurance, and post-disaster assistance. In this study, we explore how the removal of federal subsidies impacts coastal development patterns by measuring the causal effect of the U.S. Coastal Barrier Resources Act (CBRA) on building activity. Implemented in 1982, CBRA withdrew eligibility for federal funding for infrastructure, post-disaster assistance, and subsidized flood insurance along designated sections of coastal barriers ("CBRA units"). Using a novel built structures dataset, we employ a spatial regression discontinuity design to compare development rates inside and outside CBRA units in 1980 and 2016. We demonstrate that CBRA has caused significant reductions in development activity, with development rates in CBRA more than 75% lower than areas outside CBRA. Our findings suggest that policies like CBRA can be effective at slowing development in other sensitive or hazardous areas, and could help to preserve natural environments for habitat conservation and climate adaptation purposes.

1. Introduction

Many factors influence the location and extent of urban development, including local land market conditions; accessibility to amenities; local land use controls; and government provision of infrastructure (roads, bridges, water, and sewer networks). Development in coastal areas presents an assortment of additional challenges and opportunities. Coastal regions are some of the fastest growing in the United States (US Census 2018), yet storms and flooding pose substantial risks, increasing the financial cost of building in hazardous coastal areas and creating a barrier to development. To offset these risks, a variety of policies and subsidies have been implemented by governments to spur development (Bagstad *et al.* 2007), including risk reduction investments (e.g., shoreline armoring, beach nourishment, flood control), subsidized flood insurance (National Flood Insurance Pogram, NFIP; Thomas and Leichenko 2011), and post-disaster assistance (Olshansky and Johnson 2014).

Substantial evidence documents how public subsidies shape urban development patterns, with particular emphasis on their role stimulating the conversion of peripheral agricultural land into sprawling, low-density development (Ewing 2008). Subsidies for transportation (Su and DeSalvo 2008), housing (Voith and Gyourko 2002), and utilities (Speir and Stephenson 2002) influence land use decisions by altering the price of development. While most land use policies are crafted by state and local governments, subsidies provided by the federal government play an important role in shaping urban development (Buzbee 1999; Voith and Gyourko 2002). However, in the absence of federal subsidies, does development continue unimpeded? In this paper, we explore how the *removal* of federal subsidies impacts urban development patterns in coastal regions.

To understand the long-term impact of subsidy removal on development rates in coastal areas, we measure the causal effects of the U.S. Coastal Barrier Resources Act ("CBRA"), a 1982 federal law enacted to "to minimize the loss of human life, wasteful expenditure of Federal revenues, and the damage to fish, wildlife, and other natural resources associated with the coastal barriers along the Atlantic and Gulf coasts" (16 U.S.C. 3501 et seq). CBRA designated "undeveloped coastal barriers" (defined as areas with density of development less than 1 structure per 5 acres [~ 2 ha] of land and lacking infrastructure; for brevity, we call these "CBRA units") to be: 1) ineligible for federal financial assistance for infrastructure (roads, bridges, water supply, etc.) and post-disaster assistance, and 2) unable to participate in the federally-subsidized NFIP.

Having now been operational for nearly 40 years, CBRA represents an ideal vehicle for studying subsidy removal at a broad spatial scale. Prior research on CBRA found evidence that some CBRA units had continued developing as a result of subsidies provided by state and local governments, filling the funding gap created by the federal government (Salvesen 2005; USGAO 2007). These studies demonstrated that CBRA can be undermined by federalism norms that preserve local government control of major land use policy decisions (Buzbee 1999). Thus, while CBRA serves as a strong signal countering growth in sensitive coastal areas, policies from overlapping jurisdictions – such as state and local governments – may provide competing regulatory and financial signals that influence its ability to effectively shape development outcomes.

Unfortunately, past studies of CBRA's effectiveness have been limited by their use of cross-sectional data, which are poorly suited for measuring the effects of growth management policies (Dempsey and Plantinga 2013). For instance, a recent examination of CBRA's impacts in southeastern states revealed markedly less dense development in CBRA units, with substantially more land conserved as open space compared to surrounding non-CBRA areas (Onda *et al.* 2020). These findings, however, were unable to account for potential endogeneity. In the context of CBRA, which established units based on low development levels in 1982, it is possible that limited present-day development might be attributed to underlying land characteristics that had stymied development prior to 1982, rather than the impact of federal subsidy removal. As a result, no prior studies of CBRA have sought to systematically measure its *causal* impacts.

We overcome this limitation by using a novel building structure dataset and a spatial regression discontinuity design, comparing development rates along either side of CBRA boundaries. Our findings demonstrate that CBRA has a significant effect reducing development activity, and that this effect is caused by the delineation of CBRA boundaries. This has important policy ramifications for coastal land management as well as climate adaptation, suggesting that the removal of federal subsidies may be an effective method for deterring development in sensitive and hazardous coastal areas.

2. Methods

2.1 Study Area & Data

We selected five study states along the U.S. Atlantic and Gulf coasts – Alabama, Delaware, Florida, North Carolina, and Texas – that possess a wide variety of political, economic, and geographic characteristics, as well as a range of coastal development patterns. We divided each states' coastline into a grid comprised of 500m^2 cells, which we overlaid with geospatial data describing the locations and extents of CBRA units (n = 588 units; USFWS 2019). We extracted all grid cells intersecting CBRA unit boundaries (n = 3,064 cells), such that each cell included both CBRA and non-CBRA areas; together, these "grid sections" comprise the entire grid cell. For each of these grid sections, we calculate the density of structures (number of structures per developable area) using the following datasets.

To delineate developable areas within each grid cell, we used datasets describing waterbodies and protected areas, removing them from the grid sections. We acquired coastal land cover data from the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (NOAA 2019), which we condensed to describe 'water' and 'non-water' areas. We then subtracted the area classified as 'water' to estimate the amount of land – of any type – within each grid section. Second, we identified and removed protected areas from grid cells using the U.S. Geological Survey's Protected Areas Database (USGS 2020), which includes a variety of federal, state, and local parks, conservation easements, and other dedicated open spaces. These types of land development protections likely have a substantial influence on development patterns, and may confound findings specific to CBRA.

To identify the number of structures, two research assistants, working independently, identified and located all structures within each grid cell using historical aerial photos from 1980 and 2016 (USGS 2016; see WebPanel 1 for more detail). Due to limitations in interpreting high-altitude aerial imagery, each building structure – irrespective of a high-rise condominium or single-family home – was represented by a point.

2.2 Analytical Methods

Our data collection and processing efforts produced a sample of grid cells broken into CBRA and non-CBRA sections, with areas of water and protected lands subtracted from the total area of each section. Removal of waterbodies and protected lands produced many grid cells of inadequate size for a comparison of development densities inside and outside of CBRA.

We removed grid cells that had limited amounts of developable areas, excluding from our sample any grid cell with 10 percent or less of its original area remaining after removal of waterbodies and protected lands (removed n = 753). We also excluded any grid cells that were heavily unbalanced in area within CBRA and non-CBRA sections, specifically those with 90 percent or more of their land inside or outside CBRA (removed n = 995). Taken together, this process produced a subset of our sample frame (n=1,316 grid cells, 2,632 CBRA and non-CBRA grid sections) in which grid cells only included land (i.e., non-water areas), contained at least 10 percent of both CBRA and non-CBRA land, and did not include other types of common development restrictions (not including zoning).

Building structure data was then used to calculate the density of development for each CBRA and non-CBRA grid section. We calculated structure density as the number of structures per hectare ("st/ha") of unprotected land. This process was repeated for 1980 and 2016 structure data, producing a density of development two years prior to the enactment of CBRA (1980) and 34 years after (2016). These values were then used to calculate the change in development density ("CDD") over this 36-year period (st/ha_{2016}-st/ha_{1980}). We conducted a check on building structure density using cadastral data, replete with land use characteristics, focusing on study areas that exhibited zero or negative development rates (see WebPanel 2 for more detail).

We used a spatial regression discontinuity design to measure the impact of CBRA on development. Discontinuity designs are methods of inference often used when a social or political process assigns observations to a treatment based on a threshold value or boundary (such as a geographic or political boundary; Dunning 2012; Keele and Titiunik 2015). In these instances, the assignment criteria used for observations on either side of the threshold can be assumed to be as-if random (Dunning 2012; Keele and Titiunik 2015). This underlying assumption applies to the delineation of CBRA boundaries, where land located just inside and just outside the boundary can be assumed to be similar in all ways except assignment to treatment (location in CBRA). Accordingly, a paired t-test, measuring the difference in the CDD on either side of the CBRA boundary within a grid cell, is useful for evaluating the causal effect of CBRA designation (Dunning 2012).

We also undertook a sensitivity analysis of CBRA's boundaries to explore for potential endogeneity (Figure 2). Specifically, we used buffers of different magnitudes to artificially change the location of CBRA boundaries, both shrinking (negative buffer, values of -25m, -50m, -75m, -100m) and expanding (positive buffer, values of 25m, 50m, 75m, 100m) CBRA units. Buildings were reassigned CBRA or non-CBRA designation based on their location relative to the modified CBRA boundary and development densities were re-calculated at each level. This test, coupled with the discontinuity design, allows for an assessment of the importance of the real boundary of CBRA and whether its placement is the primary factor explaining differential outcomes. A number of other studies have used similar techniques to isolate treatment effects by artificially modifying geographic discontinuities (e.g., Gonzalez 2021; Kendall *et al.* 2021).

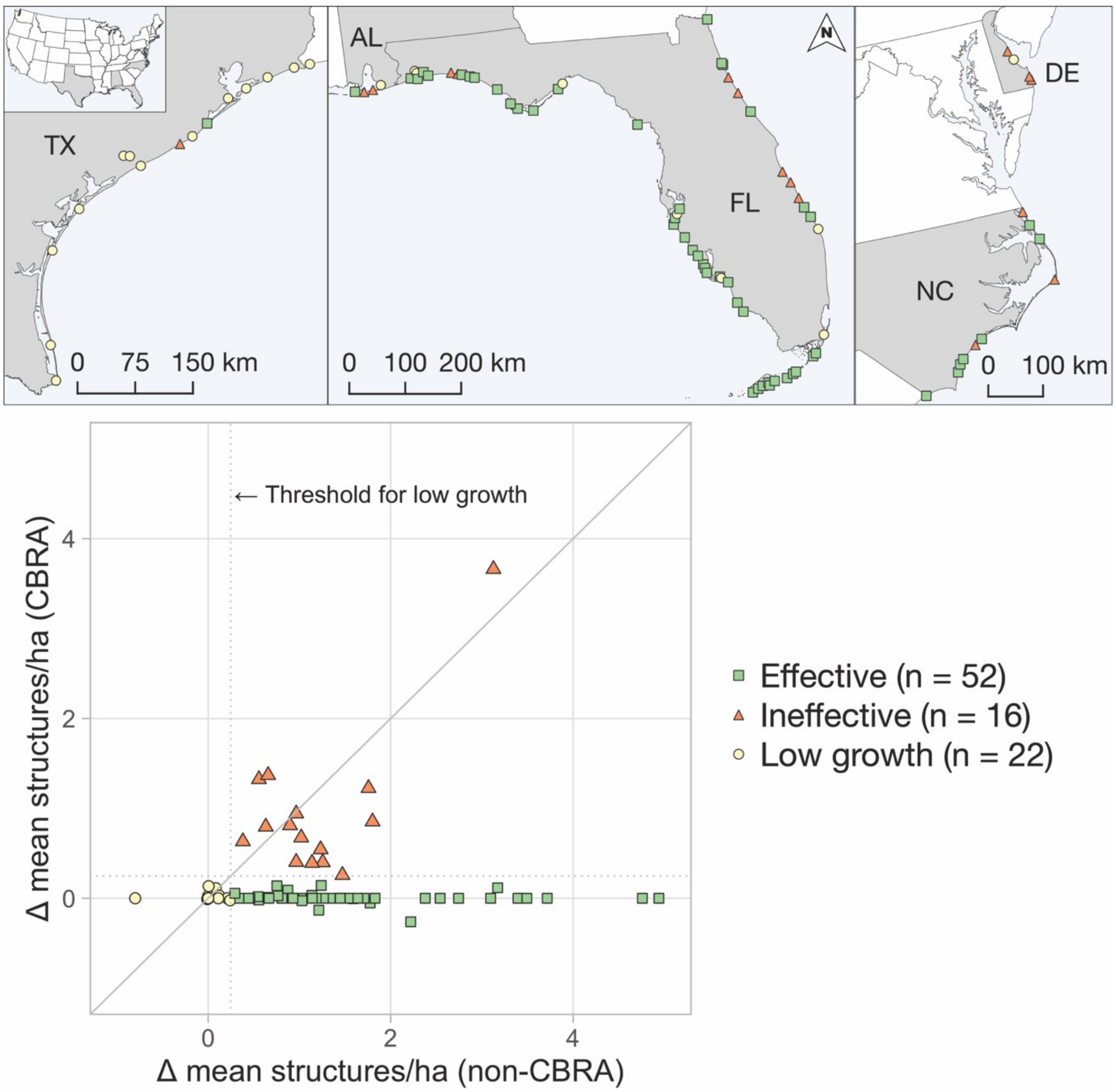
3. Results

3.1 Comparing development inside and outside of CBRA

We find that CBRA designation has caused significant decreases in development rates relative to neighboring, non-CBRA areas (paired t-test $\bar{X}_{\text{non-CBRA}} - \bar{X}_{\text{CBRA}} = 0.63$ st/ha; $p<0.01$; 95% CI: 0.54-0.72). Between 1980 and 2016, structure density in non-CBRA grid sections grew at an average rate 4.4 times faster than those in CBRA. Specifically, non-CBRA grid sections exhibited an average CDD of 0.80 st/ha (0.50 st/ha in 1980 and 1.30 st/ha in 2016), while grid sections in CBRA exhibited a change of only 0.18 st/ha (0.01 st/ha in 1980 and 0.19 st/ha in 2016). The vast majority of CBRA grid sections exhibited no (87.1%) or negative (2%) CDD, whereas 57.1% of non-CBRA grid sections experienced no or negative CDD over our 36-year study period. However, of those CBRA grid sections that experienced a positive CDD, nearly half (49.3%) outpaced their neighboring non-CBRA grid sections.

Grid sections were grouped to produce average CDDs for their associated CBRA unit (n = 90; Figure 1). At the unit-level, 29 CBRA units (32%) exhibited a positive CDD, compared to 76 associated non-CBRA areas (84%). Thirteen (14%) CBRA units had CDDs that exceeded their neighboring non-CBRA areas, yet just nine (10%) of these exhibited positive CDDs. Similar to the findings of Salvesen (2005) and GAO (2007), a small number of CBRA units exhibited relatively high levels of development since 1982; the CBRA units with the four highest CDDs all outpaced their neighboring non-CBRA areas, each with a CDD greater than 1.3 st/ha. However, most (68%) CBRA units experienced either no growth or negative growth, while 20% of units experienced very low levels of growth (below 0.62 st/ha).

Figure 1. Classification of CBRA unit effectiveness based on development rates directly within and outside CBRA unit boundaries. "Effective": mean CDD (non-CBRA) > 0.247 st/ha & mean CDD (CBRA) ≤ 0.247 st/ha. "Ineffective": mean CDD (CBRA) > 0.247 st/ha. "Low growth": mean CDD (non-CBRA & CBRA) ≤ 0.247 st/ha. For reference, 0.247 st/ha (0.1 st/acre) is equal to half the maximum development density allowed by CBRA for potential designation as a CBRA unit. Note: zoom-level on plot does not depict two extreme outliers: N. Bethany Beach, DE (mean CBRA CDD = 14.6 st/ha) and Bowditch Point (mean non-CBRA CDD = –5.5 st/ha).



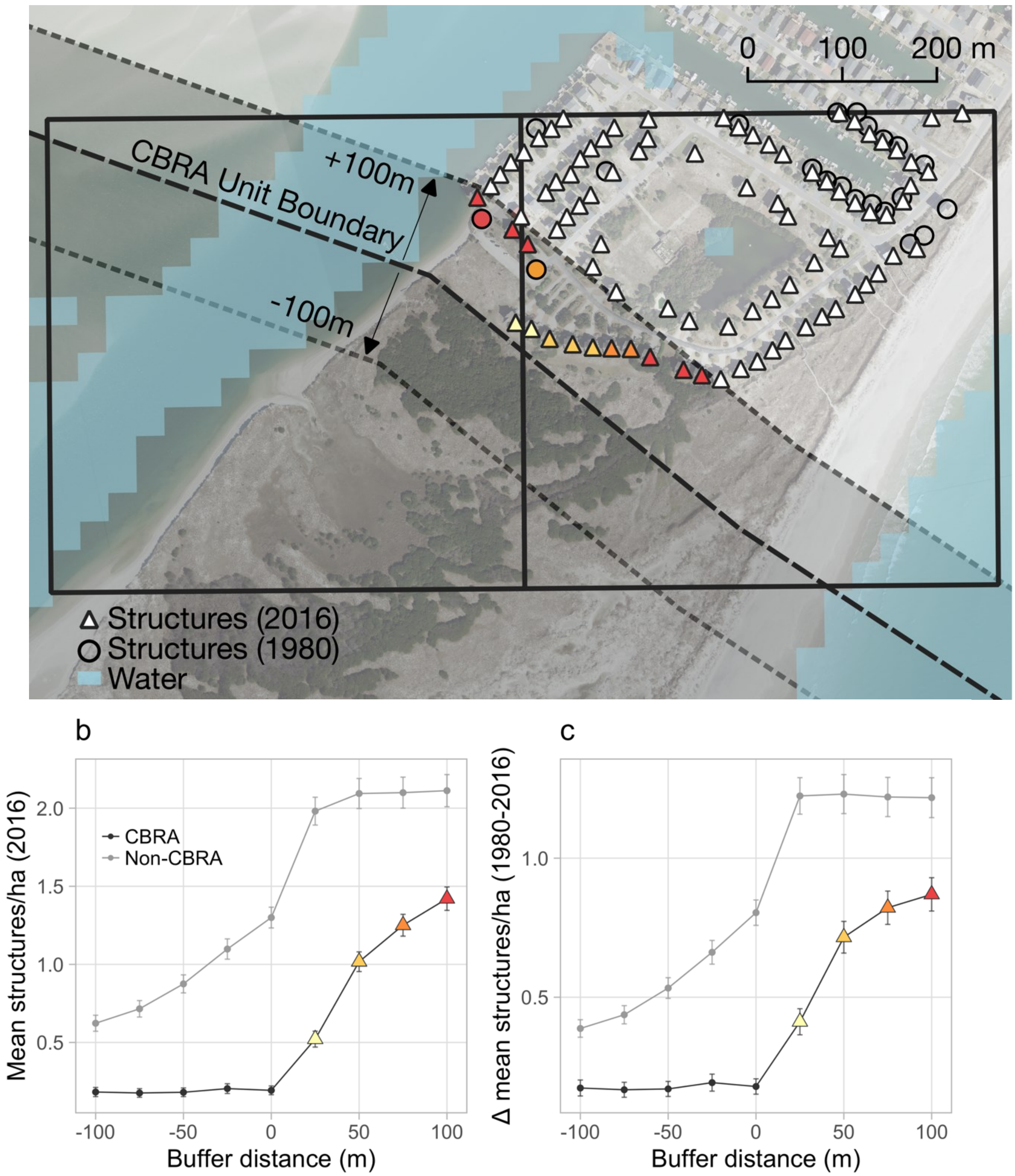
We then used parcel-level information from 2016 to explore whether structure-level densification (i.e., replacement of single-family residential structures with multi-family residential structures) might explain why certain areas within our study exhibit negative growth rates. Using this cross-sectional dataset, we find no evidence that the conversion of land to more intense uses is an underlying reason for negative CDDs. Specifically, out of 599 developed parcels in grid cells exhibiting "negative" growth (i.e., lower densities in 2016 than 1980), only 3 have multi-family residential land uses; the vast majority of these parcels are single-family residential.

3.2 The importance of CBRA boundaries

Our examination of development rates from 1980 to 2016 reveals clear differences inside and outside of CBRA; however, despite our pre-post design, it is possible that some of the measured effect is endogenous. For instance, low development rates in CBRA may be due to land characteristics that helped to stifle development prior to the enactment of CBRA, leading to the land's inclusion within a CBRA unit. In order to test for potential endogeneity, we explored the importance of CBRA boundaries – which denote the precise geographies where federal subsidies are unavailable -- and examined how sensitive development is to small changes in CBRA boundary location.

Given that Congress drew boundaries for CBRA units without regards for land cover, we would expect small modifications of these boundaries to produce noticeable differences in development if subsidy removal – rather than parcel characteristics, such as soil, amenities and proximity to development drivers – primarily influenced development outcomes. While land cover is unlikely to change dramatically and become undevelopable over very short distances, the availability of federal subsidies is delineated by the precise location of CBRA's geographic boundary. By making small alterations to CBRA's boundary, we can pinpoint whether the location of CBRA boundaries is the primary factor explaining differential outcomes, or if underlying land characteristics are influencing our results.

Figure 2. Sensitivity analysis of CBRA's boundaries. (a) Example of grid cells and building structures, along with expansion and contraction of CBRA boundary for sensitivity analysis (b) structure densities in 2016 of CBRA units and non-CBRA areas with standard errors and (c) change in structure densities of CBRA units and non-CBRA areas with standard errors.



Our findings demonstrate that the effect on development occurs at the location of CBRA boundaries and suggest that endogeneity is not systematically biasing the results of this study (Figure 2). As our prior results demonstrated, CDDs in non-CBRA areas are markedly higher than CBRA units at real CBRA boundary locations (i.e., buffer distance = 0 m, 0.63 st/ha). However, when we expanded CBRA boundaries, and land located in non-CBRA areas was absorbed into CBRA units, the difference between CBRA and non-CBRA CDDs narrowed substantially. For instance, when we expanded CBRA boundaries by 100m, the CDD difference drops by 44.4% to 0.35 st/ha. Alternatively, as CBRA boundaries were shrunk and the land located within CBRA was shifted to non-CBRA, the CDD in non-CBRA areas began to mirror that of CBRA units, such that the difference with a -100m buffer distance is 0.21 st/ha (-66.7% change).

4. Discussion and Conclusion

CBRA was created to limit wasteful federal expenditures, reduce loss of human life from disasters, and preserve sensitive natural resources along U.S. coastal barriers by removing federal subsidies that might otherwise foster development of these areas. This study has sought to reexamine its effect on development using a regression discontinuity design.

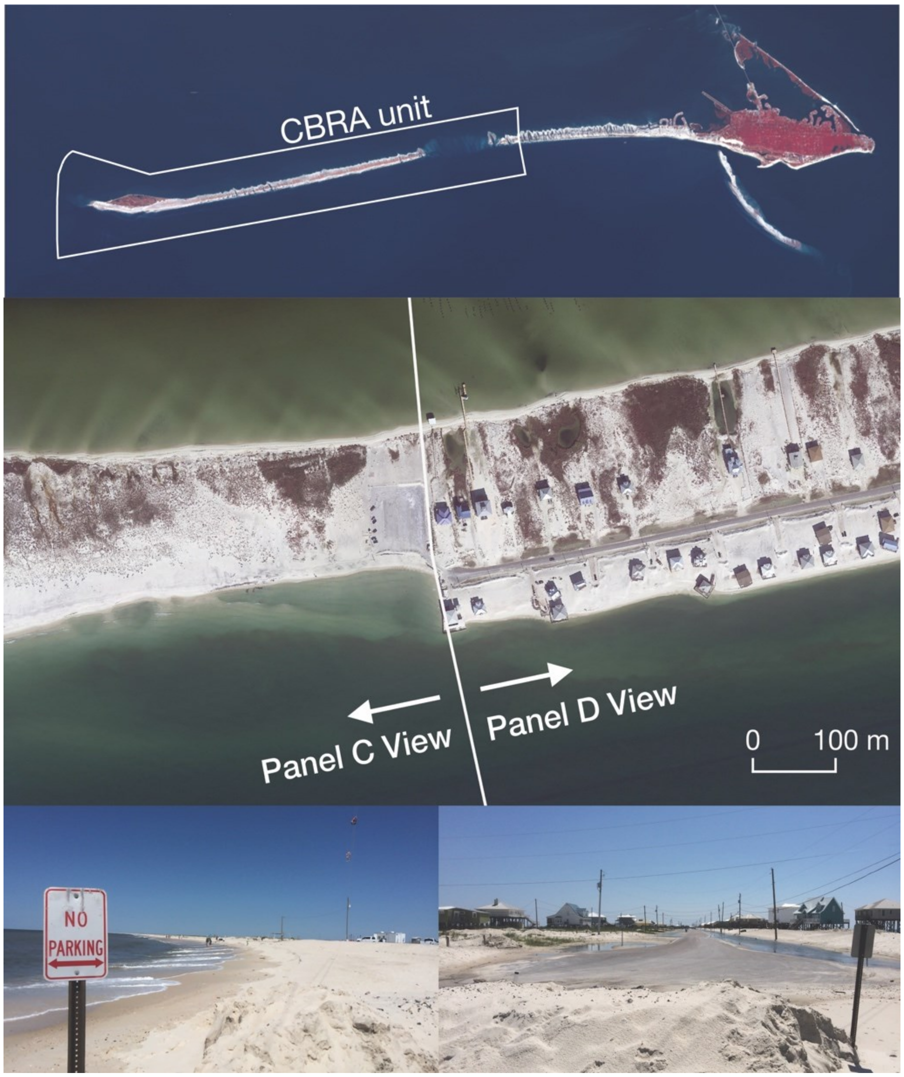
Our findings reveal a clear and substantial difference in the rates of development inside and outside CBRA boundaries. From 1980 to 2016, study areas in CBRA developed at less than one quarter the rate of those outside CBRA, with the vast majority exhibiting no development. Further, we demonstrate that CBRA's impact is due to the location of its boundaries, rather than unobserved land characteristics. In short, we find that the removal of federal funding for infrastructure projects and post-disaster assistance, as well as the unavailability of subsidized flood insurance, severely limits development activity along the coast.

While development in CBRA is largely outpaced by development outside CBRA, we observe a number of outliers with non-negligible levels of growth. We offer two, non-mutually exclusive explanations for why some CBRA units develop, while most do not. First, the amenity value of the land within a given CBRA unit may occasionally exceed the additional financial cost of developing even with CBRA restrictions. The relatively high levels of growth in a handful of CBRA units (see Figure 1) suggests that, when the value of land in CBRA is greater than its financial restrictions, the impact of CBRA may be negligible. Moreover, spillover development (from neighboring non-CBRA areas) does not appear to be the universal driver of this development, given that 1 in 8 CBRA grid sections with a positive CDD had neighboring non-CBRA grid sections that were completely undeveloped in 2016. In other words, scarcity of adjacent undeveloped coastal land is not the sole cause of development in CBRA. This phenomenon reinforces Onda et al.'s (2020) finding that CBRA may, under certain conditions, create an exclusionary luxury effect that amplifies the attractiveness of its land and stimulates low-level development.

Second, as Salvesen (2005) and GAO (2007) observed in their studies of CBRA, state and local governments have occasionally stepped in to fill the funding gap created by the federal government. In these instances, lower levels of government with overlapping jurisdictions may provide financial assistance for development, particularly funding for infrastructure, that overcomes the signal created by the federal government. For example, county provision of a water line for North Carolina's North Topsail Beach CBRA unit, along with state investment in a highway relocation, helped create conditions for a resort development in CBRA (Salvesen 2005). Prior studies on growth management regimes have found these policies to be most effective when "each level of government coordinates their plans with other governmental levels" (Bengston *et al.* 2004 p. 282). In the context of coastal development and CBRA, however, each level of government may have different incentives, creating a barrier to coordination and policy alignment. While the federal government enacted CBRA to reduce its financial liabilities due to coastal hazards, state and local governments are often motivated to spur development in pursuit of growth and the expansion of the local tax base, even in areas with substantial hazard risks (Youngman 2015). This mismatch in government interests may prompt state and local governments to disregard the financial limitations posed by CBRA and pursue policies that help create conditions suitable to growth and development within CBRA.

Despite conflicting incentives and limited regulatory authority on land use, we have found clear evidence that the removal of federal subsidies from coastal areas leads to reductions in development. Not only has CBRA protected sensitive coastal habitat from development, it has also succeeded in limiting federal expenditures on disaster recovery. Between 1989 and 2013, CBRA reduced federal expenditures by an estimated $9.5 billion, with up to eleven times more savings projected over the next half-century (Coburn and Whitehead 2019). Expansion of subsidy removal policy to non-CBRA coastal areas, riverine floodplains, and other hazard-prone areas, ought to be considered as a strategy that can prevent the creation of future liabilities for the federal government.

Figure 3. The CBRA unit (Q02) at the west end of Dauphin Island, Alabama, one of the most hazard-prone coastal barriers in the U.S. Panel (a) depicts the island shortly after Hurricane Katrina in 2005, which cut a 1.5 mile wide gap (the "Katrina Cut") in the island that was later repaired using money from the BP oil spill (Courtesy of the National Aeronautics and Space Administration's Earth Observatory). Panel (b) depicts present-day (2021) land use and development patterns near the CBRA unit boundary (Imagery ©2021 Google, Maxar Technologies, U.S. Geological Survey, USDA Farm Service Agency). Panels (c) and (d) show on-the-ground views of development on either side of CBRA unit boundary (D. Salvesen).



Given sea level rise and projected increases in severe storms, devising methods for applying subsidy removal policy to developed coastal areas is also prudent. For instance, designating a time (e.g., in five or ten years) or event (e.g., one year after the next presidential disaster declaration) after which federal subsidies will no longer be available may help discourage further densification in hazardous non-CBRA areas and work synergistically to incentivize managed retreat (e.g., Hino *et al.* 2017; Mach *et al.* 2019). Similarly, as rising seas shift coastal flood zones inland, boundaries for areas under subsidy removal should also be moved inland, creating a continuously updated signal of environmental change and increasing hazard risks. Non-federal governments, although they possess some incentives to pursue growth, might explore using CBRA as a template to disincentivize development and other anthropogenic modifications (e.g., shoreline armoring; see Feagin *et al.* 2010; Branham *et al.* 2021) that threaten the function and form of valuable coastal barriers, in order to steer development to less sensitive areas.

The success of CBRA's policy of subsidy removal makes it particularly useful for climate adaptation planning in coastal areas. Approximately 1,500 homes are expected to be lost to coastal erosion annually over the coming decades, due to a combination of increasingly risky development patterns, more hazardous storms, and sea level rise (Neal *et al.* 2017). Despite these projections, governments continue to facilitate new development on environmentally sensitive and hazard-prone coastal lands through a range of policies and investments, such as zoning variances, bridge and highway construction, and beach nourishment (e.g., Salvesen 2005; Bagstad *et al.* 2007; Armstrong *et al.* 2016). This subsidization of risky development increases community vulnerability and creates future liabilities that may necessitate further government funding to facilitate managed retreat (e.g., Mach *et al.* 2019). This study suggests that federal subsidy removal, despite a lack of explicit coordination with state and local governments, can break this cycle and deter development in hazardous areas. Importantly, it does so without necessitating the use of eminent domain or large-scale land purchases, which can face steep political resistance. A gradual rollout of expanded subsidy removal policy, along with concessions for developed areas (e.g., simultaneous offering of home buyouts), may make for a more politically palatable adaptation policy than the alternatives.

Given the dual threat of sea level rise and development pressures, robust policies are needed to ensure the sustainable management of coastal habitats, which provide many important ecosystem services, including protection from severe storms (Sun and Carson 2020). This research demonstrates that removing government subsidies is a useful policy that can promote the preservation of important natural resources while encouraging people and property to stay out of harm's way.

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References

Allen J. 2005. Hurricane Katrina Erodes the U.S. Gulf Coast.

Armstrong SB, Lazarus ED, Limber PW, *et al.* 2016. Indications of a positive feedback between coastal development and beach nourishment. *Earths Future* **4**: 626–35.

Bagstad KJ, Stapleton K, and D'Agostino JR. 2007. Taxes, subsidies, and insurance as drivers of United States coastal development. *Ecol Econ* **63**: 285–98.

Bengston DN, Fletcher JO, and Nelson KC. 2004. Public policies for managing urban growth and protecting open space: policy instruments and lessons learned in the United States. *Landsc Urban Plan* **69**: 271–86.

Branham J, Onda K, Kaza N, *et al.* 2021. How does the removal of federal subsidies affect investment in coastal protection infrastructure? *Land Use Policy* **102**: 105245.

Buzbee WW. 1999. Urban Sprawl, Federalism, and the Problem of Institutional Complexity. *Fordham Law Rev* **68**: 57–136.

Coburn AS and Whitehead JC. 2019. An Analysis of Federal Expenditures Related to the Coastal Barrier Resources Act (CBRA) of 1982. *J Coast Res* **35**: 1358.

Dempsey JA and Plantinga AJ. 2013. How well do urban growth boundaries contain development? Results for Oregon using a difference-in-difference estimator. *Reg Sci Urban Econ* **43**: 996–1007.

Dunning T. 2012. Natural Experiments in the Social Sciences: A Design-Based Approach. Cambridge, UK: Cambridge University Press.

Ewing RH. 2008. Characteristics, Causes, and Effects of Sprawl: A Literature Review. In: Marzluff JM, Shulenberger E, Endlicher W, *et al.* (Eds). Urban Ecology: An International Perspective on the Interaction Between Humans and Nature. Springer.

Feagin RA, Smith WK, Psuty NP, *et al.* 2010. Barrier Islands: Coupling Anthropogenic Stability with Ecological Sustainability. *J Coast Res* **26**: 987–92.

Gonzalez RM. 2021. Cell Phone Access and Election Fraud: Evidence from a Spatial Regression Discontinuity Design in Afghanistan. *Am Econ J Appl Econ* **13**: 1–51.

Hino M, Field CB, and Mach KJ. 2017. Managed retreat as a response to natural hazard risk. *Nat Clim Change* **7**: 364–70.

Keele LJ and Titiunik R. 2015. Geographic Boundaries as Regression Discontinuities. *Polit Anal* **23**: 127–55.

Kendall E, Beck B, and Antonelli J. 2021. Robust inference for geographic regression discontinuity designs: assessing the impact of police precincts. *ArXiv210616124 Stat*.

Mach KJ, Kraan CM, Hino M, *et al.* 2019. Managed retreat through voluntary buyouts of flood-prone properties. *Sci Adv* **5**: eaax8995.

Mattheus CR, Rodriguez AB, McKee BA, and Currin CA. 2010. Impact of land-use change and hard structures on the evolution of fringing marsh shorelines. *Estuar Coast Shelf Sci* **88**: 365–76.

Neal WJ, Bush DM, and Pilkey OH. 2017. Managed Retreat. In: Bobrowsky P, Marker B (Eds). Encyclopedia of Engineering Geology. Cham: Springer International Publishing.

NOAA. 2019. C-CAP Land Cover Atlashttps://coast.noaa.gov/digitalcoast/tools/lca.html. Viewed

Olshansky RB and Johnson LA. 2014. The Evolution of the Federal Role in Supporting Community Recovery After U.S. Disasters. *J Am Plann Assoc* **80**: 293–304.

Onda K, Branham J, BenDor TK, *et al.* 2020. Does removal of federal subsidies discourage urban development? An evaluation of the US Coastal Barrier Resources Act. *PLOS ONE* **15**.

Salvesen D. 2005. The Coastal Barrier Resources Act: Has It Discouraged Coastal Development? *Coast Manag* **33**: 181–95.

Speir C and Stephenson K. 2002. Does Sprawl Cost Us All?: *Isolating the Effects of Housing Patterns on Public Water and Sewer Costs*. *J Am Plann Assoc* **68**: 56–70.

Su Q and DeSalvo JS. 2008. The Effect of Transportation Subsidies on Urban Sprawl. *J Reg Sci* **48**: 567–94.

Sun F and Carson RT. 2020. Coastal wetlands reduce property damage during tropical cyclones. *Proc Natl Acad Sci* **117**: 5719–25.

Thomas A and Leichenko R. 2011. Adaptation through insurance: lessons from the NFIP. *Int J Clim Change Strateg Manag* **3**: 250–63.

US Census. 2018. Coastline County Population Continues to Growhttps://www.census.gov/library/stories/2018/08/coastal-county-population-rises.html. Viewed 23 Feb 2020.

USFWS. 2019. Digital CBRS Boundaries.

USGAO. 2007. Coastal Barrier Resources System: Status of Development That Has Occurred and Financial Assistance Provided by Federal Agencies. Washington D.C: United States Government Accountability Office.

USGS. 2016. USGS EROS Archive - Aerial Photography - National High Altitude Photography (NHAP)https://www.usgs.gov/centers/eros/science/usgs-eros-archive-aerial-photography-national-high-altitude-photography-nhap?qt-science_center_objects=0#qt-science_center_objects. Viewed

USGS. 2020. Protected Areas Database of the United States (PAD-US 2.0). *US Geol Surv Gap Anal Proj*.

Voith R and Gyourko J. 2002. Capitalization of federal taxes, the relative price of housing, and urban form: density and sorting effects. *Reg Sci Urban Econ* **32**: 673–90.

Youngman N. 2015. The development of manufactured flood risk: New Orleans' mid-century growth machine and the hurricane of 1947. *Disasters* **39**: s166–87.