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The Shape of Regulation: 40 Years of Florida Flood Maps[†]

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Many regulations are spatial, imposed in certain geographies but not others. Examples include designated critical habitats under the Endangered Species Act, zoning restrictions, and floodplains. These regulations exist to achieve social benefits, but they impose private costs on regulated participants. In this paper, we study how the geography of regulation evolves over time as opportunities and incentives to influence it arise. Our focus is floodplain regulation, a consequential and spatially granular policy designed to align privately and socially optimal incentives to build in areas at risk of flooding.[1] Our analysis centers on a long panel of maps delineating the extent of the regulated floodplain in Florida, beginning with digitized scans of the first maps drawn during the policy's introduction around 1980 (from Ostriker and Russo 2024) and continuing through 2017.

Opportunities to update flood maps emerged *after* the initial delineation of the flood zone, which was based on a coarsening of an underlying hydrological model (National Research Council 2009). Though the geography of flood risk and floodplain regulation is highly persistent—80 percent of land is mapped consistently over the 40-year panel—map updates may be concentrated in particular types of places, thereby causing modern-day flood zone geometries to vary with area characteristics.

Our approach to analyzing these changes is inspired by work in economics and political science studying the determinants and effects of shape in cities (Harari 2020). Particularly closely related is a literature on gerrymandering that uses characteristics of district polygons to define and study the determinants of "irregular" districts (see, e.g., Kaufman, King, and Komisarchik 2021 and Weill 2023 for a similar application). We study how our measure of the regularity of flood zones—defined as the ratio of the area of each regulated polygon to that of its convex hull—has changed over the regulation's history. We then investigate the correlates of these changes.

We find three main results. First, there is no correlation between development and irregularity in the original maps, consistent with the limited scope for homeowner influence in the initial mapping process. Second, we find decreases in regularity over time, concentrated in highly developed geographies where more individuals stand to lose from the regulations. Finally, changes in polygon shape are uncorrelated with reductions in flood risk, suggesting that greater map irregularity may not reflect adaptation. We conclude by discussing implications for the empirical analysis of spatially differentiated regulation.

I. Institutional Details and Data

The Federal Emergency Management Authority (FEMA) regulates housing in areas at risk of flooding in the United States. Because flood risk varies across space, regulations are targeted to geographies demarcated as Special Flood Hazard Areas (SFHAs), or "flood zones," by the National Flood Insurance Program (NFIP). In these regulated areas, all new construction and substantial home improvements must comply with flood-safe building regulations. Many homeowners in the regulated areas also face a flood insurance mandate, and all homeowners face higher flood insurance prices for otherwise-equivalent houses. These regulations impose costs on homeowners and developers but also substantially reduce flood damages (Ostriker and Russo 2024).

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[1] Multiple reasons for such a wedge have been discussed and documented, including risk misperceptions and expectations of government aid.

The extent of the regulated locations is determined by FEMA's flood mapping process. Maps were first developed in the late 1970s and early 1980s, using relatively coarse hydrological studies (National Research Council 2009). These maps have been updated over time, both due to FEMA requirements and because, after the initial maps were drawn, owners could request map amendments or petition for carve-outs to correct inaccuracies or if they could prove that the physical characteristics of the land had changed. Because of the high costs of the regulation, homeowners or developers inside the flood zone had incentives to petition FEMA or to elevate the land to remove their property from the flood zone.[2] Through this updating process, flood zone designation could over time become endogenous to either existing buildings or new construction.

We study the evolution of flood maps in Florida over the history of the NFIP. We include digitized scans of the first maps in eleven counties (drawn between 1977 and 1984), together with maps active in 1996, 2010, and 2017. We combine these maps with detailed data on land use and land characteristics, property characteristics, flood risk, and flood insurance policies to understand how changing maps correlate with features of the land, its housing stock, flood risk, and insurance market outcomes. Land use data are constructed from (i) US Geological Survey classifications of high-altitude photographs taken between 1971 and 1982 and (ii) National Land Cover Dataset classifications of Landsat imagery in 2016, both measured at the 30 meter (m) $\times$ 30 m pixel level. Property characteristics from the Florida Department of Revenue property tax records (2005–2020) provide detailed information about structures, including sales prices and location. We measure flood risk using estimates from a third-party hydrological model produced by the First Street Foundation. To capture the possibility of changes in risk due to changing land characteristics over time, we use a novel panel of land elevation data in Miami-Dade County, generated from LiDAR measurements taken in 2007 and 2018. We also obtain administrative data on NFIP policies from 2010 to 2017 to provide information about flood insurance premiums and coverage.

II. Measuring the Irregularity of Regulated Areas

While the overall spatial extent of regulation is highly persistent—80 percent of all land in our sample maintains the same regulatory status from the initial maps (1977–1984) to 2017—our analysis is motivated by the hypothesis that as homeowners and developers face incentives and opportunities to deregulate their properties, the shapes of flood zones could become increasingly irregular.

We build on existing approaches to measure shape regularity (Kaufman, King, and Komisarchik 2021). Our preferred metric is polygon solidity, defined as the ratio of the area of a polygon x to that of its convex hull, $\mathrm{conv}\,x$:

$$sol(x) = \frac{area(x)}{area(\mathrm{conv}\,x)}. \tag{1}$$

A convex polygon has $sol(x) = 1$; a nonconvex polygon (e.g., with many holes) has $sol(x) < 1$.

We calculate the weighted average solidity within a census tract. For each county map in each year, we (i) split the flood zone across a 2500 m square grid,[3] (ii) calculate the solidity of each distinct polygon using the definition in equation (1), and then (iii) construct the weighted-average census tract solidity for that map year, with weights equal to flood zone polygon area.[4]

Figure 1 presents kernel density plots of the average census-tract-level solidity of regulated areas in the initial maps (1977–1984), in 1996, and in 2017. There is a distribution of solidity within each map year, reflecting the fact that estimated flood extents, which determine the regulated area, need not be convex polygons. However, it is notable that there is large mass close to one in the circa-1980 maps. Figure 1 also illustrates a clear decrease in solidity, or increase in the irregularity of regulated

[2] See https://www.fema.gov/flood-maps/change-your-flood-zone/loma-lomr-f for more details.
[3] This caps the size of an individual flood zone polygon at 2500 m $\times$ 2500 m.
[4] We hold constant the census tract boundaries defined as of 2010.

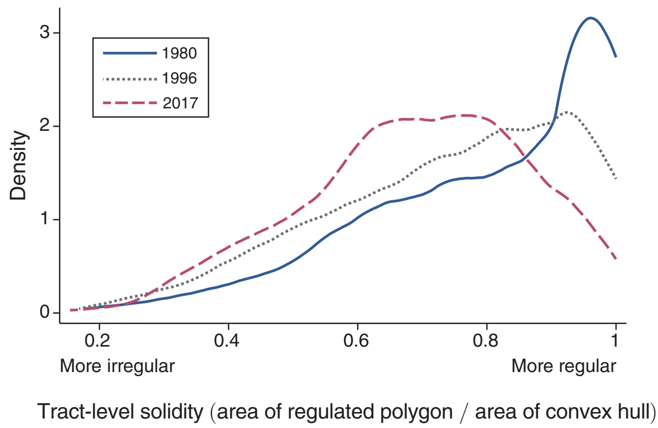

FIGURE 1. KERNEL DENSITY PLOTS OF SOLIDITY OVER TIME

Notes: Figure presents kernel density plots of census-tract-level flood map solidity in 1980 (from the 1977–1984 maps), 1996, and 2017. Solidity is calculated using the definition in equation (1) and aggregated across polygons in the census tract, weighted by regulated polygon area.

areas, over time. This finding echoes Weill (2023), who also documents an increase in the complexity of flood maps (measured with a related score) between 2005 and 2019.

III. Correlates of Map Changes over Time

We investigate how the reductions in solidity documented in Figure 1 correlate with development patterns. Land development could impact the shape of regulated areas for multiple reasons. As discussed above, economic incentives may lead homeowners or developers to strategically petition or adapt to avoid being included in the regulated area. This could generate a negative correlation between development and solidity over time. There may be other causes of such a correlation: Land development may also impact the modeled hydraulics, which would likely *also* push in the direction of reducing solidity. As we discuss below, however, we find no evidence that the decrease in solidity is driven by cross-sectional differences in modeled hydraulics across geographies.

Figure 2, panel A plots a binned scatterplot of the correlation between census tract (weighted) average flood zone solidity and development shares, both measured in the late 1970s and early 1980s. Figure 2, panel A illustrates *no correlation* between development shares and the solidity of the regulated maps at the time the maps were drawn. This empirical evidence is consistent with the map construction following a scientific regulatory process, which homeowners or other stakeholders had limited ability to influence. It also provides suggestive evidence against the hypothesis that maps became more irregular because they captured irregular water flows around developed land, as we might expect to see that pattern reflected, to some extent, in the cross-section.

By contrast, Figure 2, panel B demonstrates a strong negative correlation between solidity and development shares by 2016/2017.[5] Moving from a tract in the tenth to the ninetieth percentile of land development is associated with a reduction in polygon solidity of 0.3 standard deviations. Together with the absence of any corresponding negative correlation at the time the maps were drawn, we interpret these results as suggestive evidence that regulated areas evolve endogenously to development patterns. However, since we find that 80 percent of the land in our sample is consistently mapped

[5] Development shares in the National Land Cover Dataset are measured as of 2016, while flood maps are a 2017 snapshot.

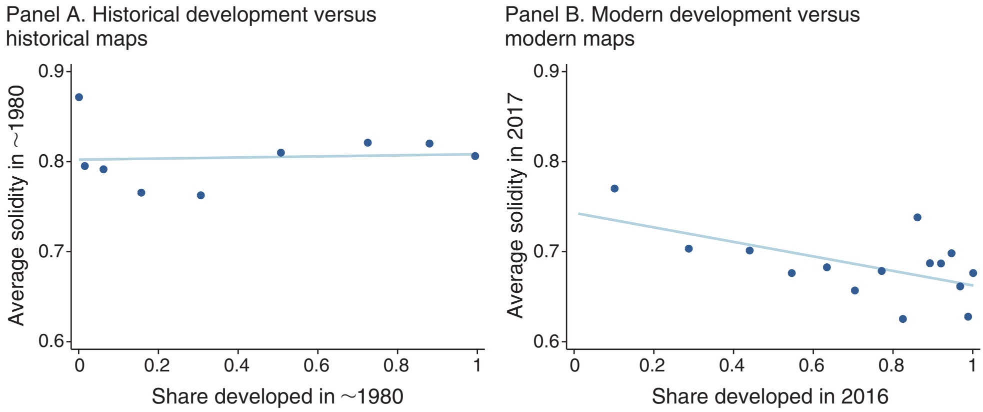

Figure 2. The Correlation between Solidity and Development over Time

Notes: Figures present binned scatterplots of development and solidity at the time of the original maps. Panel A shows development measured between 1971 and 1982 and maps drawn between 1977 and 1984. Panel B shows the binned scatterplot in the modern day using development measured in 2016 and maps active as of 2017.

over time, we view this as evidence that development may affect the shape of regulated areas—e.g., by adding holes and reducing solidity—while leaving broad spatial regulation patterns intact.

A. *Existing and New Development Both Predict Increasing Irregularity*

We probe the correlations presented in Figure 2 by investigating additional correlates of changes in solidity over time. Specifically, we estimate the following census-tract-level regression:

$$\Delta_{1980,2017}\, sol_i = \alpha + \boldsymbol{\beta} \mathbf{z}_i + \epsilon_i, \tag{2}$$

where $\Delta_{1980,2017}\, sol_i$ is the change in weighted-average map solidity in census tract i between the initial map (1977–1984) and 2017 map and $\mathbf{z}_i$ are census-tract-level characteristics. Table 1 presents coefficient estimates of β with standard errors clustered at the county level. For ease of interpretation, both $\Delta_{1980,2017}\, sol_i$ and characteristics $\mathbf{z}_i$ are normalized their by standard deviations.[6]

Table 1 presents results, both without and with controls for the estimated flood risk of the census tract. Consistent with Figure 2, all measures of development—the developed share in 1980, the increase in development from 1980 to 2016, and the single family residential share of structures—are significantly negatively correlated with changes in solidity. While the negative coefficient on log sales price implies that tracts with more expensive homes have larger reductions in solidity, the magnitude is statistically insignificant.

Finally, changes in polygon regularity are uncorrelated with the estimated flood risk of a census tract (column 2). The coefficient is small and statistically indistinguishable from zero. Controlling for flood risk does not affect any coefficients on development-related characteristics. This further reinforces the conclusions in Figure 2: The amount of people who stand to lose from being regulated is the strongest predictor of the increasing irregularity of regulated areas over time. The welfare effects of this pattern are ambiguous. It could reflect both unwarranted changes and improvements in flood risk information or adaptation investments concentrated in more developed locations.[7]

[6] $\Delta_{1980,2017}\, sol_i$ is normalized by the cross–census tract standard deviation in solidity in the 2017 maps.
[7] Indeed, Weill (2023) documents both Type I and Type II errors in the map updating process.

Table 1—Changes in Flood Zone Solidity from 1980 to 2017 versus Tract Characteristics

	Outcome: change in tract solidity from ~1980–2017	
	(1)	(2)
Share of land developed, ~1980 (SD)	−0.328	−0.328
	(0.099)	(0.099)
Share of land developed, ~1980 to 2017 (SD)	−0.347	−0.348
	(0.118)	(0.117)
Single-family share of residential development (SD)	−0.137	−0.137
	(0.049)	(0.041)
log sales price (single-family residences) (SD)	−0.059	−0.058
	(0.061)	(0.085)
Share of land in First Street Flood Zone (SD)		−0.005
		(0.092)
Observations (census tracts)	998	998

Notes: Table presents coefficient estimates from equation (2). All independent variables are normalized by their standard deviations. Change in tract solidity from ~1980 to 2017 ($\Delta_{1980,2017}\, sol_i$) is normalized by the 2017 cross-sectional standard deviation in the regression sample. Sample is restricted to the 998 census tracts across 11 counties with observations in ~1980 and 2017. Standard errors are clustered at the county level.

B. *Lower Solidity Correlates with Lower Flood Insurance Prices but Not Increased Adaptation*

How does the changing irregularity of regulated areas impact homeowners and the NFIP? While a causal analysis is out of the scope of this paper, we document suggestive evidence by associating changes in solidity with changes in NFIP premiums and coverage shares, as well as land elevation. Our focus on flood insurance outcomes is motivated by the fact that in the regulated areas, insurance is mandated and more expensive. Our focus on land elevation is motivated by the fact that one approach to "remove" land from the flood zone is through adaptation by adding fill to elevate the land underneath the building footprint.

Because of our more limited panel for these variables, we focus on changes from 2007–2010 to 2017–2018.[8] Though shorter, this time period is still long enough to cover a number of map changes, and we can expand our sample beyond the 11 counties for which we have digitized original maps.

We estimate the following equation:

$$\Delta y_i \;=\; \theta + \gamma \Delta_{2010,2017}\, sol_i + \boldsymbol{\eta} \mathbf{z}_i + \nu_i, \tag{3}$$

which correlates changes in outcomes y_i with changes in census tract (weighted) average solidity, controlling for tract characteristics $\mathbf{z}_i$. Standard errors are clustered at the county level. The characteristics $\mathbf{z}_i$ equal the total regulated area in the census tract as of 2010 and 2017; with these controls, the coefficient γ should be interpreted as the correlation between the change in *shape* of the regulated area and the change in outcome, conditional on the regulation's total coverage.

Table 2 presents results. The first two columns of Table 2 document that a 1 standard deviation increase in solidity is associated with a \$0.07 increase in premiums per \$1,000 of coverage among purchased policies. As the maps in a census tract become 1 standard deviation more irregular (less solid), the prices of policies held by homeowners become 2–3 percent cheaper (about \$18 for \$250,000 of coverage, the maximum amount for a home). This effect persists after controlling for the total regulated area (both in 2010 and 2017). While we caution against a causal interpretation, this is another piece of evidence consistent with the fact that homeowners stand to gain—in the form of cheaper insurance prices—from "removing themselves" from the regulated area. Insurance take-up (columns 3 and 4) is unaffected.

Finally, in columns 5 and 6, we attempt to test whether changes in map shape reflect changes in risk via adaptation, specifically using "fill" to elevate the ground below the house during construction.

[8] We have elevation measures in 2007 and 2018 and NFIP policy data and maps in 2010 and 2017.

Table 2—Insurance Outcomes, Adaptation, and Flood Zone Solidity

	Flood insurance				Adaptation	
	Δpremiums (per $1,000 of coverage)		Δflood insurance market share		Δland elevation	
	(1)	(2)	(3)	(4)	(5)	(6)
ΔSolidity from 2010 to 2017	0.067	0.072	−0.002	−0.001	0.007	0.007
	(0.030)	(0.025)	(0.005)	(0.004)	(0.019)	(0.019)
Flood zone extent controls		✓		✓		✓
Dep. var. mean (2010)	2.706	2.706	0.245	0.245	6.667	6.667
Observations (census tracts)	1,967	1,967	1,967	1,967	432	432

Notes: Table presents coefficient estimates from equation (3). ΔSolidity from 2010 to 2017 $\left(\Delta_{2010,2017}\, sol_i\right)$ is normalized by the 2017 cross-sectional standard deviation of solidity in the regression sample. Flood insurance market share is calculated as the number of policies divided by the number of residential structures in the census tract. Elevation is measured in feet above sea level. Flood extent controls control for the area covered by the flood zone in 2010 and 2017. Standard errors are clustered at the county level in columns 1–4. Columns 1–4 include the 31 Florida counties with maps observed in both the 2010 and 2017 snapshots. Columns 5 and 6 restrict to Miami-Dade County only and report heteroskedasticity-robust standard errors.

This analysis is restricted to Miami-Dade County, where we obtain a panel of high-resolution LiDAR data to measure changes in land elevation. Despite a smaller sample size, Table 2 documents a precise zero correlation between changes in map solidity and changes in elevation.

Together, the analysis in Table 1 and Table 2 suggests that the changing irregularity of flood maps may depend more on economic incentives to avoid regulation than differences in flood risk across space or time. It also suggests that the economic incentives to deregulate that are implicit in NFIP premiums are not large enough to encourage homeowners in the flood zone to substantially adapt their properties by adding fill. Instead, floodplain regulation primarily achieves its adaptation objectives via direct regulation through building codes or by diverting construction to alternative, safer locations (Ostriker and Russo 2024).

IV. Conclusion

Our results have important implications for the empirical analysis of regulation. Despite evolving irregularity, maps of regulated flood zone extents are highly persistent. Therefore, they can be expected to affect outcomes over the medium to long run (Ostriker and Russo 2024). However, our results highlight nuances for empirical analyses that leverage regulatory boundaries. The possibility of manipulation of the running variable—strategically locating on one side of the cutoff versus another—is a key threat to standard regression discontinuity designs. In spatial boundary analyses, strategic location choice may in fact be the outcome of interest. However, the design may then be undermined by the possibility that the boundary itself may be endogenous to location choice. This paper provides evidence of the practical relevance of this concern when maps can be updated, possibly endogenously. We also present a solution when institutional details and data availability permit: to go back in time to the initial maps, before any map updates could occur.

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