Paving the Swamp: Consequences of Land Use Regulation Under the Clean Water Act*

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Abstract

How does environmental regulation of land use affect the environment and the economy? We study recent changes to U.S. Clean Water Act regulation, measured using wetland maps and machine learning. Four findings emerge. First, a 2020 White House rule reduced the average non-residential property's probability of being regulated under the Clean Water Act by about 40 percent. Second, by deregulating wetlands, this rule increased the value of U.S. non-residential properties by about 1%, with larger effects for properties facing greater deregulation and near-zero effects for residential properties. Third, remote sensing indicates that deregulation expanded impervious surfaces like pavement and reduced wetland area. Fourth, the deregulation increased non-residential land values by over $50 billion, which exceeds the estimated loss in the present discounted value of wetlands' flood mitigation services; we carefully discuss welfare implications.

JEL: H23, Q25, Q50, R30, R52

Keywords: Land use regulation; Clean Water Act; wetlands; real estate

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1 Introduction

We study recent judicial and White House reforms to land use regulation under the U.S. Clean Water Act. We investigate how these reforms affect regulatory stringency, land markets, development, and the environment, then compare the resulting aggregate change in land values against changes in ecosystem service values, particularly flood mitigation.

Many environmental policies restrict land use and development. The U.S. Endangered Species Act, for example, constrains land use near critically threatened species. The National Environmental Policy Act requires environmental planning before development. Australia, Brazil, China, the European Union, India, and other regions also widely regulate land use to pursue environmental objectives (Table A1).

Debates fiercely contest whether such land use regulations optimally balance economic costs and environmental benefits. Land use restrictions can limit the supply of developed land, skew housing values, and misallocate economic activity away from productive regions. The political impact of *Abundance* (Klein and Thompson 2025) reflects concerns with the restrictiveness of environmental land use policies. California's legislature recently curtailed the California Environmental Quality Act, once considered politically sacrosanct, due to what Governor Gavin Newsom called "too much demand chasing too little supply" (Blood and Weber 2025; White 2025). To streamline environmental permitting, the U.S. House passed the PERMIT Act in December 2025, with bipartisan support. Environmental laws that limit development, however, could protect valuable ecosystem services, such as flood mitigation, biodiversity, and air and water quality.

The 1972 Clean Water Act provides an important setting to study these tradeoffs. Although the Clean Water Act directly limits pollution in U.S. waterways, its implementation ultimately affects land use. The Act restricts the discharge of dredge and fill material into "Waters of the United States" (WOTUS), a phrase that can include wetlands where water is present infrequently or historically, and where development could otherwise occur. More broadly, the high-value areas of iconic cities built on former wetlands demonstrate the longstanding importance of wetland development, including Boston's South End and London's East End (former tidal marshes), Eastern Mexico City (former lake), much of Jakarta (former swampy alluvial plain), and much of New Orleans (former cypress swamps).

To comply with the Clean Water Act's land use regulation, developers typically commission a wetland consulting report, request the U.S. Army Corps of Engineers to determine jurisdiction, then obtain and comply with a federal wetland permit. Permits can require changing project design, leaving areas undeveloped, building new nearby wetlands, spending on other compensatory mitigation investments like fish ladders, and adding delay and uncertainty. This process affects many industries, especially solar and wind power generation, electricity transmission, and data centers. In congressional testimony on data center development, Microsoft's president summarized (Halverson 2025):

> The Number 1 challenge in the United States when it comes to permitting is not local, it's not state, it is the federal wetlands permit administered by the Army Corps.

We focus on one of the largest recent policy changes to the Clean Water Act, the 2020 Navigable Waters Protection Rule (NWPR) and the subsequent judicial stay suspending it. NWPR deregulated ephemeral streams that flow infrequently, and thus are not "relatively permanent," and isolated wetlands, which lack a continuous surface water connection to navigable waters.

A case study helps clarify. Bridgeland, Texas, is an 11,500 acre master planned community on the outskirts of Houston. Just after NWPR was implemented, Bridgeland obtained a determination that the Clean Water Act did not regulate areas surrounding a floodplain near a stream, allowing development to proceed without Clean Water Act regulation. Bridgeland has since developed parts of this area into multi-million dollar homes surrounded by trails and water features.[1] Google Earth aerial imagery from 2016 shows the creek flooding parts of the surrounding area (Figure 1). Imagery from current years shows houses, bulldozed land, and built water features. Zillow.com (2025) lists Bridgeland homes for sale with prices of $300,000 to $2,900,000. At the same time, over 80% of Bridgeland properties have a major risk of flooding in the next 30 years (First Street Foundation 2025). The Houston region faces heavy periodic rainfall and flooding (Harris County Flood Control District 2025), and development can increase flood risks downstream.

To move from a case study to national analysis, we proceed in four steps. First, we examine how NWPR affected regulatory stringency. To identify properties that change jurisdiction, we use both the leading federal map of water resources and a machine learning algorithm. These two approaches have complementary strengths—the wetland map allows

[1] See Bridgeland's promotional video: https://www.bridgeland.com/ (accessed March 18, 2026)

for simple interpretation in geophysical terms and reflects information stakeholders can readily access, while the algorithm allows interpretation in terms of the probability of regulation. For algorithm training and validation, we use data on approved jurisdictional determinations[2], case-by-case decisions about whether a specific water resource is regulated or not, from the Environmental Protection Agency (EPA) and Army Corps.

We find that NWPR dramatically decreased Clean Water Act jurisdiction, and the subsequent judicial stay somewhat restored regulation. NWPR decreased the probability of regulation by 8.3 percentage points for properties without mapped water resources but 28.0 percentage points for sites fully covered with mapped water resources. The algorithm indicates that the probability of regulation for the average nonresidential site fell under NWPR from 33% to 20%, a decline of 40% relative to baseline.

Second, we use property-level data from CoreLogic on the near-universe of U.S. land transactions to study how Clean Water Act regulation affects land markets. We focus on non-residential properties, which face more restrictive Clean Water Act regulation. Values of non-residential properties that NWPR deregulated have relatively flat trends before NWPR, jump in value under NWPR, and move back towards baseline values after NWPR. NWPR increased the value of the average non-residential property by $1,820 to $5,500, or approximately 1%, with larger effects for properties facing more extensive deregulation.

Several tests support the research design. First, event study graphs assess the timing of Army Corps approved jurisdictional determinations and property price responses around NWPR's implementation and subsequent judicial stay. Second, we investigate sensitivity to adding property-level proxies for the COVID housing boom (Ramani et al. 2024) and baseline property assessed values. Third, we compare NWPR's land market effects for non-residential properties, where regulation is more restrictive, versus residential properties. Fourth, we extend a subset of the data through almost a decade before NWPR, to test for extended pre-trends or anticipation. Fifth, semi-parametric binned regressions flexibly assess how the extent of deregulation affects property values. Sixth, we estimate the effect of NWPR on land values in regions with large COVID residential housing booms versus other regions. Seventh, we examine how the effects of NWPR vary with distance to the nearest wetland to assess potential spatial spillovers.

[2] These are "approved" by the Army Corps in that they are legally binding, but an approved jurisdictional determination can declare a water resource to be jurisdictional or not.

The paper's third section investigates how Clean Water Act regulation affects remotely-sensed measures of impervious surfaces and wetland extent. These estimates clarify a mechanism for this regulation to affect land values and help measure its impact on one important ecosystem service. We find that Clean Water Act jurisdictional determinations coincide with large changes in development. Trends in development and water resources are relatively flat before an approved jurisdictional determination, for both regulated and non-regulated sites. In years after an approved jurisdictional determination, impervious surfaces like pavement expand while wetland area contracts. Clean Water Act regulation decreases these development impacts.

The paper's fourth section compares estimates of the economic cost of Clean Water Act regulation estimated from property values against flood mitigation, one important benefit of wetlands, and more briefly discusses other ecosystem services. We take estimates of wetlands' flood mitigation benefits from recent quasi-experimental studies (Taylor and Druckenmiller 2022; Aronoff and Rafey 2026; Gourevitch et al. 2026) and estimates for other ecosystem services from several meta-analyses. We estimate that NWPR decreased flood mitigation benefits by \$8.5 billion to \$13.1 billion, with the range reflecting alternative measures of jurisdictional change under NWPR from either the wetland map or the algorithm. We find that NWPR's land value benefits exceed its cost in terms of lost flood protection benefits by a factor of 6.0 or more.

To interpret the social welfare consequences of these changes, we discuss evidence on the importance of flood protection versus other ecosystem services for wetlands, including biodiversity, water quality, recreation, food provisioning, carbon sequestration, and others. We also discuss possible general equilibrium shifts in the hedonic price function. Both extensions suggest that our analysis captures a substantial component of the land market benefits and ecosystem service costs of this reform, though not all.

This paper departs from existing work in several ways. We believe it provides the first national ex post estimate of the impact of the Clean Water Act's regulation of land use on economic and environmental outcomes. The leading estimate of the cost of Clean Water Act land use regulation, cited in *amicus* briefs in both the *Rapanos* and *Sackett* Supreme Court cases, comes from phone interviews with applicants for 103 Clean Water Act wetland permits in the year 1999 (Sunding and Zilberman 2002). That study summarizes reported costs of internal staff time and outside experts but abstracts from costs of wetland offsets, changes in project design, costs of carrying additional capital, projects that completed approved jurisdictional determinations but not permits, delays and uncertainty, and cases where expected regulatory costs precluded development; our analysis of land values has the potential to cover all these costs. The EPA and Army Corps (2021) estimate the cost of permit fees and mitigation costs for Clean Water Act regulation, though not other costs. Liu (2025) studies how litigation relates to the timeline of permit reviews. Prominent media stories describe NWPR (Davenport 2020; Ferek and Puko 2020; Daly 2021) and its impacts on large construction projects (Cassels 2021; Magill 2021). Many *Science* papers debate NWPR's scientific justifications but do not directly observe its ex post economic or environmental effects (Boyle et al. 2017; Sullivan et al. 2020; Keiser et al. 2021; Brinkerhoff et al. 2024). Machine learning and geophysical models analyze how recent Clean Water Act rules affect jurisdiction (Gold 2024; Greenhill et al. 2024; Greenhill et al. 2025).

We also build on work studying other components of the Clean Water Act and other major U.S. environmental laws. Some studies analyze grants from the Clean Water Act for abatement technology in wastewater treatment plants in the 1970s and 1980s (Keiser and Shapiro 2019; Flynn and Marcus 2025; Jerch forthcoming). Others study the Clean Water Act's abatement technology requirements for industrial plants, also typically using older data (Earnhart and Segerson 2012; Behrer et al. 2021). These are separate from the land use regulations we study. Most plants studied in existing work discharge polluted water into relatively permanent streams or rivers, which have remained under Clean Water Act jurisdiction.[3] Much economic research estimates the ex post costs of other major U.S. environmental regulations, including the Clean Air Act (Becker and Henderson 2000; Greenstone 2002; Walker 2013; Jacobsen et al. 2023; Shapiro and Walker 2025) and the Endangered Species Act (Auffhammer et al. 2020; Frank et al. 2025).

This paper also provides novel estimates of the cost of protecting wetlands, which are a critical natural resource globally. Wetlands create a classic positive externality by mitigating floods, improving water quality, and enhancing biodiversity (Heimlich 1998; Turner et al. 2000). A few papers analyze specific economic aspects of wetlands. Stavins and Jaffe (1990) model conversion of wetlands to agriculture in the Mississippi Valley. Taylor and Drucken-

[3] Using colorful language about not fouling one's own swimming pool or backyard, several regulators have explained that many industrial and wastewater treatment plants avoid routinely discharging even treated wastewater into water resources that do not regularly or ever flow, like isolated wetlands or ephemeral streams, which are the focus of ongoing debates around the Clean Water Act's land use regulation.

miller (2022) estimate U.S. wetlands' flood protection benefits. Mangrove forests, a type of coastal wetland, mitigate storm damages (Hochard et al. 2019; Valle et al. 2020). Aronoff and Rafey (2026) study offset markets for wetlands in Florida, and Karwowski and Skidmore (2026) estimate the benefits of easement protections for wetlands in restoring water quality. Stated preference, travel cost, and related studies examine case studies of ecosystem services, including wetlands (Brouwer et al. 1999; De Groot et al. 2012; Brander et al. 2013; Bilkovic et al. 2025). We believe that economic research on wetlands is relatively scarce relative to wetlands' global environmental and economic importance.

Finally, we build on research analyzing land use regulation by examining a leading environmental case of it. Frank et al. (2025), Van Der Kroft et al. (2025), and Soltas and Gruber (2026) use proprietary permit data to analyze effects of environmental regulation and development, though these data do not record Clean Water Act permits, and research on environmental land use regulation more broadly is limited (Balboni and Shapiro 2025). A broader agenda, related to *Abundance* (Klein and Thompson 2025), studies how regulation affects infrastructure development (Brooks and Liscow 2023; Bartik et al. 2024; Bauer et al. 2024; D'Amico et al. 2024; Liscow 2025). We also help address the Congressional Budget Office's call for research on the economic effects of federal permitting, which highlights the Clean Water Act as needing analysis (Kile et al. 2025).

We proceed as follows. Section 2 provides background. Section 3 describes the data. Section 4 formalizes the research design by discussing econometric and machine learning models. Sections 5–8 study changes in regulatory stringency, property values, development outcomes, and measured costs and benefits. Section 9 concludes.

2 Background: Wetlands and the Clean Water Act

2.1 Wetlands

Brief context helps explain our analysis. Wetlands include areas where water saturates or inundates the surface of soil with sufficient frequency and duration to support water-loving (hydrophytic) vegetation (U.S. Army Corps of Engineers 1987). Wetlands include swamps, marshes, bogs, fens, estuaries, and deltas (Sullivan et al. 2020). Wetlands tend to form in flat areas where terrain and precipitation naturally route water, sometimes in the floodplains of surface waters. The widely-used Cowardin et al. (1979) classification system groups wetlands and deepwater habitats into palustrine, riverine, lacustrine, estuarine, and marine systems.[4] We use "wetlands" to include only swamps, marshes and the like (i.e., palustrine wetlands); we refer to these together with lakes, ponds, rivers, and the like as "water resources."

To identify a wetland's existence and area, scientists and engineers often consider the presence of water, water-loving plants, or characteristic soils. To identify water presence, engineers may visit a site or consult ground or aerial imagery from multiple seasons, sometimes including historical data. While prolonged saturation from standing surface water obviously characterizes wetlands, a sufficiently shallow groundwater table can form wetlands by saturating surface soils. To delineate wetlands, scientists may also take samples to identify where a majority of vegetation is water-loving.

Wetland policy has a complex history. Historically, policymakers viewed wetlands as a source of disease and an impediment to agriculture and transportation. Federal laws throughout the 19th century encouraged residents to drain wetlands under the banner of "Reclamation." Over 85 percent of wetlands in California and Midwestern states like Iowa, Missouri, Illinois, Indiana, and Ohio disappeared over this period; states in the arid West and mid-Atlantic drained a smaller share.

Evolving views of wetlands in the 1960s and 1970s led to a reversal of federal policy to protecting rather than draining wetlands. President Carter's Executive Order 11990 in 1977 directed the federal government to protect wetlands, which subsequent presidents articulated as "No Net Loss" of wetlands. Swampbuster, a provision of the 1985 Food Security Act, provides incentives to discourage conversion of wetlands to agricultural lands (Dahl and Allord 1997). Section 404 of the Clean Water Act, our focus, provides another tool to support "No Net Loss."

The FWS's National Wetlands Inventory (NWI), the main wetland dataset we use, provides data for wetland trend analyses. The 2019 NWI estimates that wetlands account for 6% of U.S. area (Lang et al. 2024). Because it helps monitor No Net Loss, the NWI identifies wetlands based on their biological definition in terms of hydrology, which is independent of Clean Water Act regulations, so NWI does not perfectly identify Clean Water Act jurisdiction.

[4] Riverine systems generally include rivers and streams; lacustrine include ponds and lakes, etc. Palustrine includes a subset of wetlands.

Various technologies can drain wetlands to allow development. Canals, culverts, ditches, tile drainage, channels, and pumps redirect water to drain wetlands. Geophysical characteristics like hydric soils (soils permanently altered by prolonged saturation), topography, and subsurface geology typically persist even when drainage technologies divert water.

Wetlands provide a broad set of ecosystem services. By acting as a sponge in areas where water habitually flows, wetlands store and gradually release surface water, so mitigate flooding. Wetland soils and vegetation can filter pollutants, improving downstream surface water quality and benefiting uses like agriculture, aquatic recreation, and drinking water. Wetlands also provide habitat for fish, waterfowl, and other wildlife, enhancing biodiversity. In addition, wetlands can sequester carbon in soils, reduce erosion and protect shorelines, and support groundwater recharge (Mitsch et al. 2023; Barbier et al. 2011). Prehistoric wetlands also created enduring value; most fossil fuels formed from the decomposition of organic material in ancient swamps.

2.2 Clean Water Act

The 1972 Clean Water Act initially had two main activities. Sections 201–221 and 603 of the Act subsidize capital investment in wastewater treatment plants. Section 402 of the Act enforces the National Pollutant Discharge Elimination System (NPDES), which limits pollution for industrial plants that directly discharge pollution into jurisdictional waters.

Section 404 of the Act, our focus, restricts the discharge of "dredge and fill material" into jurisdictional waters. In practice, this clause restricts construction and development activity (e.g., use of heavy machinery) that affects jurisdictional areas, since soil constitutes a type of dredge and fill material. Jurisdictional waters are often called "Waters of the United States" (WOTUS). Clean Water Act jurisdiction excludes normal agricultural operations such as plowing and seeding.

Wetlands are sometimes imagined as areas that typically have standing water. In practice, however, many areas that fall under Clean Water Act jurisdiction for some rules are dry for substantial portions of the year and can include former wetlands that are dry due to drainage infrastructure like ditches and culverts and are therefore straightforward to develop. Figure A1 shows several examples of semi-dry wetlands, which differ from the stereotypical image of wetlands as visibly wet.

The EPA and Army Corps implement Section 404 regulations as follows.[5] A landowner wishing to undertake development involving potential water resources may ask the Army Corps for an approved jurisdictional determination (AJD), a ruling whether the Clean Water Act regulates a particular possible water resource on a potential development site. An Army Corps engineer may visit the project site, possibly in multiple seasons to observe different moisture conditions, or use land cover maps and aerial imagery. AJDs remain valid for five years.

If the water resource is regulated, development requires an Army Corps Permit, usually called a Wetland or Section 404 Permit. The permit describes the project and steps required to minimize impacts on regulated waters. Developers often purchase wetland offsets from a mitigation bank, or directly mitigate impacts (i.e., build new wetlands) onsite; the wetland mitigation banking industry, which often makes these investments, generates several billion dollars in annual revenue (BenDor et al. 2023). Since many large development properties contain water features, financing a development project can require demonstrating compliance with Clean Water Act requirements (Strassner et al. 2016). Uncertainty, effort, and delay in each of these steps can increase their costs. These regulations can affect any type of land development, including factories, roads and bridges, airports, ports, oil and gas drilling, and others.

An example may clarify. A road and bridge improvement in Olympic National Park, Washington, affected 0.04 acres of jurisdictional wetlands and 1.35 miles of jurisdictional streams. To mitigate these impacts, the project spent $205,000 to build 0.08 acres of wetlands and an estimated $3,000,000 to build a fish passage intended to mitigate "unavoidable" impacts on streams (U.S. Government Accountability Office 2024). Appendix A.3 provides additional details on the Bridgeland example from the introduction.

Development on regulated waters without a permit violates the Clean Water Act. Upon discovery of a violation, the landowner may be fined and required to remediate the project site to its original state (e.g., demolish the development, then hire environmental consultants and engineers to restore water resources). If a water resource is instead non-jurisdictional, the landowner can proceed without Clean Water Act regulation, though the site may face state or other federal regulation.

[5] The Army Corps is best known for building infrastructure like dams, through the Corps' Civil Works mission. The Army Corps' Regulatory Program instead implements Clean Water Act and related regulations.

2.3 Changes to Clean Water Act Rules

The Clean Water Act does not enumerate which streams, lakes, and other water resources are regulated. The federal government has therefore regularly issued rules describing which waters are jurisdictional.

We focus primarily on two Clean Water Act rules—*Rapanos* and NWPR. Justice Kennedy's 2006 concurring opinion in *Rapanos* stipulates that regulated waters must have a "significant nexus" to navigable waterways, including biological, chemical, and physical connections, potentially including groundwater. *Rapanos* was the main rule enforced before 2020 and after the 2021 judicial stay on NWPR.[6] The 2020 Navigable Waters Protection Rule (NWPR) implemented Justice Scalia's plurality opinion from *Rapanos*. It deregulated isolated wetlands, which may have a biological, chemical, or physical connection to navigable waters, but which lack a continuous surface water connection to such waters. NWPR also required that regulated waters be "relatively permanent." It therefore deregulated ephemeral streams, which flow primarily after rainfall and are common in the western U.S.

The timing of NWPR is relevant to our analysis. The EPA and Army Corps first published an interim version of NWPR on October 22, 2019. Although the 2016 Trump presidential campaign discussed relaxing Clean Water Act regulation, and issued an executive order in 2017 directing the EPA and Army Corps to issue a rule relying on Justice Scalia's plurality opinion, October 2019 was the first date when developers and landowners had precise written guidance on the new rule. The EPA and Army Corps formally repealed the Clean Water Rule on December 23, 2019, which made regulation revert to *Rapanos*. The EPA published the final NWPR rule in January 2020, the Federal Register published it in April 2020, and the Army Corps began implementing NWPR in June 2020. In summary, that precise information about NWPR was available in the fourth quarter of 2019, certainty over NWPR was available in the second quarter of 2020, and implementation of NWPR began in the second to third quarter of 2020.

We primarily interpret the beginning of 2020 as first post-NWPR period, since this covers publication of the final NWPR rule, although event study graphs permit visual inspection of temporal patterns around this period. Given this timing, graphs use the first quarter of

[6] The Clean Water Rule was enforced in parts of 2018–2019, though was primarily intended to clarify rather than modify *Rapanos*. The 2023 Rule was similar to *Rapanos*. Appendix A discusses other rules and aspects of the Clean Water Act that are less directly relevant to our analysis.

2019 as the reference category, which clearly predates NWPR announcements.

NWPR had a complex conclusion. On August 30, 2021, the U.S. District Court of Arizona vacated NWPR, so jurisdiction reverted to *Rapanos* (Grandoni and Dennis 2021). The same month, the U.S. Court of Appeals for the Ninth Circuit ruled in *Sackett* (U.S. Court of Appeals for the Ninth Circuit 2021). In January 2022, the Supreme Court agreed to hear *Sackett*. It was later argued as the first case on the first day of the Court's term in October, 2022.

Developer information and beliefs during and after NWPR was vacated in August 2021 are ambiguous. The Supreme Court had a solid conservative majority and had indicated willingness to decrease federal regulation, and some observers at the time thought the Supreme Court would narrow Clean Water Act regulation. Durable investments like land purchases and investment reflect current and expected future regulation. Thus, while jurisdiction changed from NWPR to *Rapanos* in August 2021, developers in late 2021 may have anticipated deregulation, which *Sackett* ultimately implemented. We therefore interpret the August 2021 court ruling as an increase in regulation, though recognize that developer beliefs may have expected some probability of NWPR-style deregulation.

3 Data

We analyze data spanning the period January 1, 2017 to May 25, 2023. This time period spans the main policy changes we study and has records for our main datasets. The sample period ends on the day the *Sackett* decision was announced, since we have limited land transactions data post-*Sackett*. We choose the beginning of the period to provide roughly equal timespans before and after NWPR's rollout. We deflate all monetary values in the paper to 2024 dollars using the GDP deflator (U.S. Bureau of Economic Analysis 2025).

To measure Clean Water Act regulation, we analyze AJDs (U.S. Army Corps of Engineers and U.S. EPA 2025). These data report the coordinate and jurisdictional determination, separately for each potential water resource within a project. The database has 142,973 AJDs in the contiguous United States within our sample period. The data cover all states and Army Corps districts.[7] Appendix Section B provides more information, including

[7] Michigan and New Jersey assumed administration of Clean Water Act Section 404 for most water resource types before our sample period, so have few (though not zero) Army Corps AJDs. Florida assumed administration in 2020, so has a typical number of AJDs up to that period and fewer afterwards.

spatial patterns in AJDs shown in Figure A2.

We use property transaction data from CoreLogic (2024). The analysis sample includes 4.47 million non-residential property transactions. These represent all U.S. non-residential transactions in our sample period satisfying data quality screening steps that Appendix B describes, such as excluding observations missing key variables or with implausible values. Non-residential land use classifications include vacant, agricultural, commercial, industrial, recreational, rural residential, and public land transactions, typically based on county zoning at the time of transaction; we report results separately for each of these categories. Table A2 describes the distribution of non-residential sites across detailed land use categories (vacant, commercial, agricultural, etc.). Following the same data quality screening steps, we also draw a random sample of 20 million residential properties, yielding 6.9 million transactions in our sample period. Figure A3 shows the spatial distribution of non-residential and residential transactions across the contiguous U.S.

We focus on non-residential properties, given the greater relevance of the Clean Water Act to them, though also discuss results for residential properties. The share of residential properties with an AJD is 0.0006. In other words, over the time period we study, six in 10,000 residential properties had an AJD. This proportion for non-residential properties is 7 times larger than the share of residential properties with an AJD, partly because residential properties often have dwellings already constructed. The few AJDs in residentially zoned areas have extremely different characteristics from the mean transacted residential property. Relative to the mean residential property, residential properties with AJDs have 11 times larger acreage, one-third the value per acre, one-third the buildings per acre, and four times greater water resource share. In addition, single-family homes that are jurisdictional under the Clean Water Act can comply relatively easily through a nation-wide permit, while many non-residential projects have far more complex and costly Individual Permits. This evidence helps motivate our focus on non-residential properties, and interpretation of residential properties as primarily a comparison group.

Ramani et al. (2024) construct zip code-level proxies for the COVID housing boom. We build on their work by constructing these proxies at the property or Census Block levels; Appendix B.3 provides details. We also follow Ramani et al. (2024) by using the Zillow Home Value Index (Zillow.com 2025) starting in March 2020 to construct zip code level indicators for areas with above- or below-median trend breaks in residential home value.

In addition to using the National Wetlands Inventory to proxy jurisdiction, we use an algorithm that estimates property-level probabilities of regulation under both *Rapanos* and NWPR. Appendix C.1 discusses the spatial data on streams, topography, soil characteristics, climate, satellite imagery embeddings, and others used as inputs.

To measure land use change, we derive data on the spatial extent of developed and wetland area from the U.S. Geological Survey (2024) National Land Cover Database (NLCD). This remotely-sensed product provides annual nationwide data on land cover at 30-meter resolution (Brown et al. 2020; Homer et al. 2020). We also use NLCD's fractional impervious surface product, which reports the percentage of each 30m pixel covered by impervious surfaces, such as pavement, concrete, rooftops, and other constructed materials.[8]

For both the National Wetlands Inventory and National Land Cover Database we compute land use within 100m of a property centroid because CoreLogic does not report property boundaries. The 100m radius covers approximately 7.8 acres, which falls between the median (1 acre) and mean (16.5 acres) property size in our non-residential sample. We later empirically estimate the distance from a property centroid at which property values change and find that this effect is concentrated within 100m.

Table 1 reports summary statistics for our analysis sample of non-residential property transactions. In the mean non-residential property, 4.9 percent of area has water resources based on the National Wetlands Inventory,[9] and a little over half of these are (palustrine) wetlands. The mean property has a sale price of around $513,000 and covers 16.5 acres. Properties with and without water resources differ along observed dimensions—properties with water have larger areas, lower values, and less dense populations in their Census Block. Given these cross-sectional differences, we exploit variation in property values over time and provide several assessments of internal validity.

As one proxy for the change in jurisdiction under NWPR, we use the National Wetlands Inventory (U.S. Fish & Wildlife Service 2025), the most comprehensive national dataset describing the area of known water resources. (The next section discusses our other proxy, an algorithm we train.) In a small survey of Army Corps AJDs, 75% used the National

[8] The impervious product provides values only for pixels mapped as developed, with the four developed intensity classes defined by impervious fraction thresholds (<20%, 20–49%, 50–79%, ≥80%). Natural surfaces such as rock outcrops are not captured, and unpaved surfaces such as gravel roads generally do not register.

[9] Across non-residential properties, the standard deviation of the water resource share in percentage terms is 14.4. Conditional on zip code × year × month fixed effects, the standard deviation is 10.5.

Wetlands Inventory, more than any other public data product besides maps (Greenhill et al. 2024). While the National Wetlands Inventory has known errors of inclusion and exclusion (Kudray and Gale 2000; National Research Council 2001; NC Wetlands 2025; U.S. Fish & Wildlife Service 2025), it provides a transparent and simple proxy for where NWPR may change regulation, and it may be the most observable and salient data available to landowners and developers.

4 Econometrics and Algorithms

4.1 Algorithms: Measuring Jurisdiction

We train a ridge regression with close connections to Greenhill et al. (2024) to predict the probability that each site is jurisdictional. The predictors include the share of a 100-meter radius around the site centroid covered by each water resource class (freshwater emergent wetland, estuarine and marine wetland, riverine, lake, etc.), stream classification and flow measures, elevation, soil characteristics, climate measures, land cover, Army Corps administrative districts, pre-period satellite imagery embeddings from AlphaEarth Foundations, and an indicator for whether NWPR was in force at the time of the determination.

The algorithm achieves 79% accuracy at predicting regulatory status on a spatially held-out test set. Accuracy is close for determinations under *Rapanos* (78%) and NWPR (82%). The algorithm outputs a continuous score between 0 and 1, which is well-calibrated to probabilities of regulation. For example, when the algorithm outputs a score between 0.3 and 0.4 for test-set AJDs, 34% of those AJDs are regulated. When it outputs a score between 0.9 and 1, 96% of those AJDs are jurisdictional. We therefore interpret the scores as predicted probabilities of regulation. Figure A4 compares the probabilities of regulation generated by the model used in this paper (Panel A) with those predicted by a deep learning model (Greenhill et al. 2024) (Panel B). It suggests that the model here better captures temporal patterns of changing jurisdiction during NWPR; Appendix C.1 provides details. We use the algorithm to predict how the change between *Rapanos* and NWPR affected the probability that each site is jurisdictional.

4.2 Algorithms: Random Forest To Estimate the Market Value of Non-Transacting Properties

As a control for property quality, we include an estimate of the baseline fair market value in the year 2016. In addition, the analysis of aggregate land market effects of NWPR in Section 8 requires the fair market values of all properties. We therefore train a random forest model to predict the fair market value of each non-residential property, using county assessor records on land use, year assessed, assessed value, and property acres. We compute two versions of this estimate, one for the year 2016 and one for the year 2021. Table A3 shows the results and Appendix C.2 further discusses the random forest model for 2021; 2016 is similar. Nationally, we observe a ratio of transaction price to assessed value of 1.86, so assessments average half of market value. This ratio varies substantially across states and counties, reflecting heterogeneous assessment policies and revaluation frequencies, demonstrating the importance of the algorithm. Comparing the total fair market value estimated via the random forest model to total assessed value for assessed properties implies an average ratio of 2.48. Figure A6 maps spatial heterogeneity in observed and predicted values.[10,11]

4.3 Econometrics: Changes in Jurisdiction

The rest of this section focuses on methods using the wetland map; Appendix C.4 discusses analogous methods using the algorithm. We first assess how NWPR affects Clean Water Act jurisdiction:

$$Y_{ict} = \beta W_i N_{it} + \alpha W_i + \gamma N_{it} + \varepsilon_{ict} \tag{1}$$

Here Y indicates whether AJD i in commuting zone c finalized on day t is jurisdictional. The term W_i measures the share of area within 100 meters of i that has water resources, measured from the National Wetlands Inventory. The indicator N_{it} equals one if the AJD

[10] We release the county-level price-to-assessed ratios as a public good for researchers requiring market value estimates from administrative assessment records—applications include environmental amenity capitalization, conservation cost estimation, property tax equity research, and the construction of wealth estimates.

[11] As external validation, our estimate for agricultural properties aligns closely with the USDA's estimate of U.S. farm real estate value. See Appendix C.2 for more details.

was adjudicated under NWPR and zero otherwise. The coefficient β tests whether NWPR disproportionately deregulates sites with water resources. The equation controls for wetlands W_i rather than site fixed effects because we rarely observe AJDs for the same water resource under different rules. It controls for NWPR rather than year × month fixed effects given our interest in estimating mean differences in jurisdiction across rules, though we also estimate versions with year × month fixed effects. Unless otherwise noted, we cluster all standard errors by commuting zone, given commuting zones' relationship to housing markets and wetland extent.

4.4 Econometrics: Property Values

We then assess how NWPR affects property values:

$$\ln(P_{izct}) = \beta W_i N_t + \alpha W_i + X'_{izt}\gamma_1 + (N_t X_{izt})'\gamma_2 + \eta_{zt} + \varepsilon_{izct} \quad (2)$$

Here P_{izt} represents the transaction price for property i in zip code z sold at year × month t, and N_t is an indicator for the period between February 1, 2020 and August 31, 2021.[12,13] The controls X_{izt} include property size in acres, the property's predicted 2016 transaction value from a random forest model discussed in Section 4.2, and proxies for the COVID housing boom (Ramani et al. 2024). We control for acreage since it is one of few property attributes reported for most non-residential sites. The predicted 2016 transaction value allows comparisons among properties with similar baseline values and helps address the possibility that NWPR disproportionately increased transaction probabilities for wetland properties with higher baseline quality. The five-digit zip code × year × month fixed effects η_{zt} adjust for overall changes in local regulation for all properties, local trends in land market conditions due to the COVID housing boom or any other forces, national effects of NWPR common to all properties, and other unobserved local shocks. Because few properties with AJDs transact, we estimate equation (2) using all properties (see Appendix C.5). The coefficient β describes how the change in log property values between *Rapanos* and NWPR varies with the share of a property's area that has water resources. Finding $\beta > 0$ would

[12] Regressions define the first date of NWPR as February 1, 2020 given that NWPR was finalized on Jan 23, 2020, and that housing transactions take some time due to escrow and other forces.

[13] Unlike the indicator N_{it} in equation (1), N_t does not vary across sites within time. The only variation in N_{it} across sites for a fixed t is due to an injunction in Colorado that delayed the state' s implementation of NWPR.

indicate NWPR disproportionately increases values of properties with water resources.

The identifying assumption for equation (2) to provide an unbiased estimate of the effect of NWPR on land values is that the wetland×NWPR interaction is independent of the regression error:

$$E[W_i N_t \cdot \varepsilon_{izct} | W_i, X_{izt}, (N_t X_{izt})'] = 0 \tag{3}$$

This assumption would fail if sale prices of water resource properties and non-water resource properties would have had different trajectories in the absence of NWPR. We note that this analysis provides comparisons to non-wetland properties, so does not measure aggregate shifts affecting non-wetland properties, though Section 8.4 revisits general equilibrium effects.

We also report corresponding event study graphs:

$$\ln(P_{izcqt}) = \sum_{\tau} \left(\beta_\tau W_i \mathbb{1}[q_q = \tau] + (\mathbb{1}[q_q = \tau] X_i)' \gamma_\tau \right) + \eta_{zt} + \varepsilon_{izcqt} \tag{4}$$

The indicator $\mathbb{1}[q_q = \tau]$ equals 1 if τ represents year×quarter q_q and 0 otherwise. The coefficients β_τ represent the difference in the value of fully wetland relative to non-wetland properties, in year×quarter τ relative to the reference period.

Appendix C.4 discusses extensions, including an extended sample of property transactions, a semi-parametric estimator with bins for wetland share or probability deregulated, distance of a property centroid to the nearest wetland, separating sub-categories of non-residential land use, and direct tests for contribution of the COVID residential housing boom.

4.5 Econometrics: Development

To analyze patterns of development around AJDs, we use Borusyak et al. (2024) (BJS). Let E_i denote the year property i has an AJD; properties that never get an AJD have $E_i = \infty$. We first estimate the evolution of outcomes in the absence of treatment using only observations before an AJD via $L_{ict} = \lambda_{ct} + \eta_i + u_{ict}$ (5) for observations with $t < E_i$. Here L_{ict} represents the land use share (developed or wetland) around site i. We then predict counterfactual outcomes $\hat{L}(0)_{ict} = \hat{\lambda}_{ct} + \hat{\eta}_i$. We residualize the observed outcome as $\delta_{ict} = L_{ict} - \hat{L}(0)_{ict}$.

We then estimate:

$$\delta_{ict} = \sum_{\tau} \Big(\alpha_\tau + \beta_\tau\, D_i + \gamma_\tau\, W_i\Big)\, \mathbb{1}[t=\tau] \;+\; \varepsilon_{ict} \tag{6}$$

The main deregulation treatment $D_i \equiv 1 - Y_i$ equals one if property i is not regulated and zero if regulated. We omit $\tau = -1$ as the reference period. We interpret β_τ as the differential effect of getting an AJD in period τ for non-regulated properties relative to regulated properties. Since properties with different wetland shares may have different counterfactual trajectories, we interact the wetland share W_i with event time indicators. We compute standard errors by bootstrapping this process 100 times. We also report versions of equation (6) which separately estimate the effects of an AJD on land use for regulated versus non-regulated properties:

$$\delta_{ict} = \sum_{\tau} \Big(\beta_{\tau,NR}\, \mathbb{1}[D_i = 1] + \beta_{\tau,N}\, \mathbb{1}[D_i = 0] + \gamma_\tau\, W_i\Big)\, \mathbb{1}[t=\tau] \;+\; \varepsilon_{ict} \tag{7}$$

Finally, we estimate the mean effect of AJDs on development:

$$\delta_{ict} = \beta\, D_i \mathbb{1}[t \geq E_i] + \alpha \mathbb{1}[t \geq E_i] + \gamma\, W_i\, \mathbb{1}[t \geq E_i] + \varepsilon_{ict} \tag{8}$$

where $\mathbb{1}[t \geq E_i]$ is an indicator equal to one in years following an AJD for property i. The coefficient β represents the differential change in land use following an AJD for regulated versus non-regulated properties. We also estimate two extensions. One allows for differential pre-trends between regulated and unregulated properties by including a linear time trend and its interaction with regulation status in equation (8) (τ and τD_i). The other allows for differential trend breaks by additionally including interactions between the time trend, the post-AJD indicator, and regulation status ($\tau \mathbb{1}[t \geq E_i]$ and $\tau D_i \mathbb{1}[t \geq E_i]$), as in Greenstone and Hanna (2014).

5 Results: Effect of the Navigable Waters Protection Rule on Regulatory Stringency

Figure 2 shows the share of AJDs that are jurisdictional, by quarter. The red vertical lines show when NWPR operated, from the beginning of 2020 through the third quarter of 2021. As discussed earlier, NWPR was finalized in January 2020 but implemented in June 2020. In

Panel A, blue circles represent the share of water resources sites in the top quartile ($\geq$ 19% water resource share) and red squares represent sites with no mapped water resources (36% of all AJDs). In Panel B, blue circles describe sites with high probability of deregulation under NWPR, defined as having the top quartile of algorithmically estimated deregulation ($p_{iR} - p_{iN} \geq 0.23$, where p_{iR} and p_{iN} are the algorithmically estimated probabilities of regulation under *Rapanos* and NWPR, respectively), and red squares describe properties below the 36th percentile of estimated deregulation ($p_{iR} - p_{iN} < 0.06$).

Figure 2 shows that NWPR decreased regulation nationally, and especially for properties that the wetland map and algorithm indicate are deregulated most. In panels A and B, before NWPR, regulation has fairly flat trends. After NWPR begins, properties with water resources and properties predicted to be deregulated have especially low probability of regulation. The effect occurs in the second and especially third quarter of NWPR, when NWPR was first implemented, but not in the first quarter of 2020, when NWPR plans were finalized. Panel A shows that NWPR decreased the probability of regulation by about 10 percentage points for sites without mapped water resources but by 20 percentage points for sites with a high share of water resources. The algorithm isolates a larger drop in regulatory probability under NWPR than the wetland maps do.

Table 2 provides corresponding regression estimates. Column (1) shows that the share of AJDs jurisdictional was 36.3% under *Rapanos* but fell by 11.6 percentage points under NWPR. Column (2) finds that for sites with no nearby mapped water resources, NWPR decreased the probability of regulation by 8.3 percentage points. These sites may have nearby water resources that the National Wetlands Inventory excludes. For sites fully covered in water resources, NWPR decreased the probability of regulation by 28.0 percentage points. Column (2) also shows that under *Rapanos*, increasing the share of a site covered in water resources from 0% to 100% increases its probability of jurisdiction by 51.2 percentage points. This coefficient is smaller than 100 both because *Rapanos* does not regulate all water resources and because the National Wetlands Inventory imperfectly measures water resources. Column (3) finds similar results in the held-out test set of AJDs excluded from algorithm training. Column (5) analyzes the algorithm using the test set. Appendix C.4 discusses how a perfect algorithm would estimate coefficients of (1, 0, and -1) for the probability of regulation under *Rapanos*, under NWPR, and for the difference. The column (5) estimates of (1.01, 0.20, and -1.12) are near this benchmark. The coefficient near zero (-0.001) on

NWPR suggests that properties where the algorithm predicts no regulation under NWPR in fact had no additional regulation under NWPR. These estimates provide additional evidence that the algorithm is well-calibrated. Figure A5 shows the estimated probability of regulation under each rule, separately for AJDs, non-residential property transactions, and residential property transactions. On average, NWPR decreased the probability of regulation for non-residential properties by 13.3 percentage points, or 40 percent relative to baseline levels.

6 Results: Effect of the Navigable Waters Protection Rule on Property Values

6.1 Estimated impacts

The event studies in Figure 3 assess how NWPR affects land values. The left panels use the wetland map and the right panels use the algorithm from Section 4.1. The horizontal axis of each graph indexes year×quarters. The vertical axes show coefficients from equations (4) and (19).

Non-Residential Properties

Panel A of Figure 3 shows that NWPR increased values of non-residential properties with water resources. Before NWPR, properties with mapped water resources had somewhat similar trends to properties without water resources. When NWPR began, property values for fully water properties increased by over 20 percent. These point estimates remain large and positive through the third quarter of 2021, while NWPR was in force. The pattern from the algorithm in Panel B has more variability around a similar pattern.

Panels A and B of Figure 3 somewhat suggest that the effect of NWPR on land values attenuated after a court vacated NWPR in late 2021. Most point estimates from quarters after NWPR have smaller magnitude than during NWPR, and more post-NWPR estimates are statistically insignificant. These point estimates suggest that land markets no longer fully incorporated the value of deregulation under NWPR, though they do not completely reverse the land market outcomes under NWPR. As Section 2.3 discusses, stakeholder beliefs in this period are ambiguous, given the conservative Supreme Court majority and procession of *Sackett* through courts.[14] Although a late 2021 court ruling vacated NWPR, land values reflect beliefs about long-run regulation, which may adjust incompletely given expectations of future deregulation.

Panel A of Table 3 shows corresponding regressions, estimated using equations (2) and (17). The coefficient describes how non-residential land values change under NWPR for the properties that NWPR most likely deregulates. Positive effects indicate that deregulated properties had higher transaction values under NWPR. Columns (1) through (3) use the wetland map to measure deregulation; columns (4) through (6) use the algorithm. Columns (1) and (4) control for the log of baseline property value and zip code × year × month fixed effects. Columns (2) and (5) also control for property-level controls for the COVID-19 housing boom (Ramani et al. 2024). Columns (3) and (6) add a control for log property size in acres.

Panel A of Table 3 finds that NWPR increased the value of fully water properties by 11% to 14%, with a standard error of 3%. Controls increase the point estimates' magnitude by about half a standard error. The richest specification in column (3) indicates that NWPR increased the value of fully water non-residential properties by 13.6% ($= e^{0.128} - 1$). As context, we estimate that fully wetland non-residential properties sell for 32.9% lower value, so NWPR decreases the penalty associated with fully wetland non-residential properties by a bit less than half.

Panel A of Table 3 also reports the estimated effects of deregulation on property values using the algorithmic model. Columns (4)-(6) imply that NWPR increased property values by 40% to 54% for properties that decreased probability of regulation by 100%, with standard errors between 16% and 17%. The richest specification, in column (6), indicates that moving from 100% to 0% probability of regulation increases property values by 40.6% ($= e^{0.341} - 1$). This estimate is similar (coefficient on Estimated deregulation × NWPR = 0.314, standard error = 0.079) when using multiple imputation (Proctor et al. 2023) to correct for potential biases in the parameter estimate and standard errors arising from using a machine-learned treatment (see Appendix Section C.6).[15]

[14] We believe that no data from this period describe beliefs about the expected probability of the *Sackett* ruling.

[15] We retain the traditional approach as our preferred specification because we find no evidence that the measurement error in the predicted probabilities of regulation is correlated with our outcome variable (land values).

Residential Properties

The event study graphs in Panels C and D of Figure 3 show mixed evidence on how NWPR affected residential properties. The analysis using the wetland map in Panel C obtains point estimates that vary about zero. The period after the court vacated NWPR is more negative. The analysis using the algorithm in Panel D obtains fairly flat point estimates that are mostly statistically indistinguishable from zero. These graphs echo the qualitative narrative from Section 5 that Clean Water Act land use deregulation primarily has potential to increase the value of non-residential properties. The regression analogs in Panel B of Table 3 echo these findings. The magnitudes are less than a tenth of those of the non-residential regressions from Panel A and are statistically indistinguishable from zero.

Panel C of Table 3 shows a triple-difference regression analyzing changes in values of non-residential versus residential properties. The point estimates are similar to those of the main non-residential estimates in Panel A and are a bit larger for regressions using the algorithm.

6.2 Extensions and Additional Sensitivity Analyses

This subsection discusses five sensitivity analyses and extensions, ordered from those more versus less similar to the main regressions.

Extended housing panel

Although we lack AJDs and land use data far before NWPR, we do have land transactions data back to 2010, so we report event study analyses including this period. This analysis primarily tests whether the appreciation of wetland and deregulated properties under NWPR had precedent in earlier years. It also implicitly tests for responses around the 2016 presidential election or EPA's discussions of NWPR before 2020. The analysis of non-residential properties in Panel A of Figure A8 shows that relative to properties without wetlands, wetland properties have flat price trends and no detectable change in the value of water resource properties through early 2020. These flat estimates over this decade-long pre-period suggest that idiosyncratic forces do not routinely drive changes in values of wetland properties in time periods before NWPR. The NWPR period has the only sustained and significant positive values in this extended panel. Panel B shows more variable results around the same pattern using the algorithm.

Semi-parametric bins

We next use equations (12) and (13) to let the effect of NWPR on property values vary semi-parametrically with bins measuring the share of a property covered in water resources or the algorithmically-estimated deregulation between *Rapanos* and NWPR. Figure 4 finds that the effect of NWPR on a non-residential property's transaction value generally increases with measures of exposure to regulation. In panel A, the blue circles show coefficients on indicators for whether a property is 0% to 10% wetland, 10% to 20% wetland, etc. The circles in Panel B show coefficients on indicators for having an estimated probability of deregulation between 0 and 10%, 10 and 20%, etc. The vertical bars through each circle show 95% confidence intervals. Relative to properties with no water, properties where 0 to 10% of the area is water had values increase only 1.6% ($= e^{0.016} - 1$) under NWPR, and properties where 10% to 20% is water had a significantly greater increase of 5.6%. Effects grow close to linearly up to properties with 50% to 60% water, whose value increases by 11.3%. The pattern somewhat flattens for properties above 60% water, though Panel A of Figure A9 shows that few properties have water shares above 60%. Panel B of Figure 4 shows a monotonic relationship between the probability a site was deregulated and the increase in the site's value under NWPR.

The red squares in Panels A and B of Figure 4 show corresponding estimates for residential properties. Using either the wetland map or algorithm, these estimates are somewhat near zero, all the confidence regions cover zero, and the slope is fairly flat.

Land Supply and Distance to Wetlands

We next examine how NWPR's effects vary flexibly with a property's proximity to wetlands. These estimates have two motivations. First, if NWPR reallocated demand from non-wetland properties toward wetland properties, then non-wetland properties nearer to wetlands, where wetland properties are closer substitutes, may experience a larger relative price decline. Similarly, if deregulation reduced amenity values from nearby wetlands, then the environmental services previously capitalized into nearby land values may diminish, leading to larger price declines for properties nearer to wetlands.

Figure 5 presents two versions of this estimate. Panel A isolates properties within 100 meters of a mapped NWI water feature and then bins the remaining properties into deciles based on distance to the nearest wetland among properties located more than 100 meters away. The positive value of the left-most point indicates that properties with wetlands experience a positive and statistically significant price increase during NWPR. The flat value near zero of the other points indicates that among non-wetland properties, proximity to wetlands does not predict larger price declines.

Panel B instead bins all properties (wetland and non-wetland) by distance to the nearest wetland. The positive value of the three left-most points indicates that price effects are concentrated among properties closest to wetlands. The flat value near zero of points in greater distance deciles also suggests little spillover to nearby properties. These results reinforce the interpretation that NWPR increased the value of properties with proximate wetlands by relaxing development constraints, rather than through spatial reallocation or negative spillovers. These graphs also support the 100m radius we use to measure water resource shares and other property-level values.

Sub-categories of non-residential land use

Appendix Figure A10 reports versions of equation (2) estimated separately by sub-category of non-residential land use. The first entry shows the point estimate for all non-residential properties, mirroring column (3) of Table 3. The next several entries investigate sub-categories of non-residential properties. We obtain a positive point estimate for most sub-categories of land use, though precision varies. Vacant properties, accounting for almost half the sample, have the clearest positive estimates. The bottom of each panel shows the near-zero effect for residential land use.

Size of COVID residential housing boom

Finally, as a test for confounding from the COVID housing boom, we test whether the appreciation of non-residential wetland properties under COVID was concentrated in areas that experienced a large COVID residential housing boom, following equation (15) (See Appendix C.3).

Figure A11 shows the change in the residential home values separately for zip codes that had a trend break in the top quartile (solid blue) and zip codes that had a trend break in the bottom quartile (dashed red) around March 2020. The groups followed similar trends through mid-2020 and clearly diverged in late 2020. The graph shows that the COVID housing boom began in the third quarter of 2020 and took off in the fourth quarter of 2020, which we note is two quarters after Figure 3 shows the effect of NWPR on non-residential housing values begins.

Table A4 uses equation (15) to test for differences in the estimated effect of NWPR on non-residential property between these two groups of zip codes. Column (1) repeats the main estimate from Table 3. Column (2) finds that the effect of NWPR on non-residential properties with wetlands has similar magnitude and is statistically indistinguishable in zip codes that had especially large COVID residential housing booms. Estimates using the algorithm in Panel B have larger magnitude but again are small and statistically indistinguishable from zero. Overall, these estimates suggest that growth in the value of wetland non-residential properties under NWPR is independent of the COVID residential housing boom.

7 Mechanisms: Permitting and Land Use Change

This section investigates how NWPR affected permitting and land use, for two reasons. First, analyzing these outcomes clarifies a mechanism for why the previous section finds that NWPR affects land values. Second, this section estimates some of NWPR's environmental impacts, which Section 8 uses in comparing measured costs and benefits.

Many anecdotes describe how NWPR affected development. The discussion of Bridgeland in Section A.3 provides one example. Appendix Figure A12 depicts two more—the decisions that both a proposed titanium strip mine by Georgia's Okefenokee National Wildlife Refuge and the "last forest in Orlando" were not jurisdictional.

To move beyond these anecdotes, Figure 6 shows the national count of AJDs, by month. The solid black line shows NWPR and the dashed line shows AJDs under other rules, primarily *Rapanos*. AJDs proxy the beginning of development projects.

The number of monthly AJDs jumped under NWPR, suggesting that developers recognized and valued the rule. Before NWPR, developers on average obtained 1,150 AJDs per month. Under NWPR, the mean number of monthly AJDs rose to 3,600. The count remained fairly steady until NWPR was vacated in late 2021. The average number of monthly AJDs then fell to 1,400. This comparison implies that NWPR increased the number of AJDs by about 2.5 years' worth, measured at pre-NWPR levels, since NWPR increased the number of AJDs by 2,450 per month and lasted for 14 months.[16]

Because NWPR changed regulation broadly, we study impacts on development using an event study around AJDs issued under NWPR. Changes in land values likely occur soon after deregulation, since land values reflect both expected future rents from owning a property and the option for future development. Changes in land use may occur gradually after development, as landowners plan, hire contractors, and build. AJDs typically remain valid for five years, so a developer could wait years after an AJD to obtain a wetland permit and then begin development. Following equation (6), we therefore compare development outcomes around the time of an AJD issued under NWPR for regulated versus not regulated sites, controlling for a site's wetland extent or probability of regulation.

Figure 7 shows the result. Panels A and B analyze the share of nearby area that is wetlands, measured from NLCD. In Panel A, red squares show regulated sites and blue circles show non-regulated sites. Panel B shows estimates of the effect for not regulated sites relative to regulated sites. Because these regressions control for interactions of each property's NWI water resource share with event time, this analysis reflects differential changes in wetland share for not regulated versus regulated properties with observably similar characteristics.

Panel A of Figure 7 shows that years before an AJD was issued under NWPR, sites have virtually no differential trend in the share of land that is wetlands. After an AJD issued under NWPR, wetland area decreases around non-regulated sites. Point estimates indicate that wetland area increased around regulated sites, though estimates are imprecise. Panel B shows that after four years, the share of land that is wetlands declines by 0.573 percentage points more in non-regulated sites than in regulated sites.

Panel A of Figure A13 shows estimates of the differential effect on the wetland share of AJD sites using the algorithmically-estimated deregulation rather than NWI water resource share to control for the probability of regulation. The pattern is qualitatively similar to estimates using NWI water resource share from Panel B of Figure 7.

Remote sensing has more measurement error in detecting wetlands than in detecting impervious surfaces (Wickham et al. 2013; Guo et al. 2017), so we show analogous event studies in Panels B and C of Figure A13 that analyze changes in impervious surfaces rather than wetlands. These event studies imply that under NWPR, AJDs expand impervious

[16] We observe a tiny number (<1%) of AJDs adjudicated under *Rapanos* between mid-June 2020 and August 2021 because an injunction in Colorado delayed the state's implementation of NWPR.

surfaces. After four years, the share of land that is impervious increases by 2.6 percentage points more in non-regulated sites than in regulated sites.

Table A5 reports corresponding regressions. Columns (1)–(3) examine the impervious share. Columns (4)–(6) examine the wetland share. Columns (1) and (4) let mean outcomes shift post- versus pre-AJD, as in equation (8). Columns (2) and (5) also control for τD_i, which allow non-regulated sites to have a linear differential pre-trend in outcomes before an AJD project begins. Columns (3) and (6) let this trend have a distinct break in non-regulated sites when an AJD project begins. The fitted effect row beneath the regressions shows the estimated change in outcomes after four years, for non-regulated versus regulated sites.

Table A5 finds moderate effects of projects with AJDs issued under NWPR on impervious surfaces, especially for deregulated sites, and smaller effects on wetlands. The main estimate in column (1) indicates that 4 years after an AJD, a project has caused an additional 3.1% of the area within 100m of a non-regulated site to have impervious surfaces, and an additional 1.7% of the area around a regulated site. The difference implies that deregulation increases impervious surfaces by 1.4 percentage points relative to a baseline mean of 20.9%. Accounting for pre-trends in column (2) does not dramatically change this estimate, though allowing for a trend break in column (3) somewhat increases the estimated effect of deregulation to 2.2%. Column (4) estimates that deregulation decreases the wetland share around sites by 0.53 percentage points relative to a baseline mean of 5.39%. Again, controlling for a linear pre-trend in column (5) does not meaningfully change this estimate, and allowing for a trend break in column (6) modestly increases the estimated effect of deregulation on the wetland share from 0.53 percentage points to 0.59 percentage points.

8 Measured Costs and Benefits

This section discusses total estimated effects of NWPR on land values and ecosystem services.

8.1 Aggregate Effects on Land Values

Column (1) of Table 4, Panel B, aggregates regression estimates from earlier in the paper to find that NWPR increased the mean value of non-residential properties by 0.0056 to

0.0116 in logs.[17] We then scale the estimated price impacts by property values to find that NWPR increased the mean value of non-residential properties by \$1,780 to \$4,630 for transacting properties. In column (2), we find similar changes in value of \$1,820 to \$5,500 after accounting for the estimated value of non-residential properties that do not transact, as predicted from the random forest algorithm that Section 4.2 describes. The similarity of columns (1) and (2) here suggests that non-transacting and transacting non-residential properties have similar values and impacts from NWPR.

We use the following equations to calculate how NWPR affects aggregate property values: $\Delta P_1 = \sum_i (e^{\beta_{m(i)}} - 1)\hat{T}_i$ (9) and $\Delta P_2 = \sum_i (e^{(\beta^N_{m_R(i)} - \beta^N_{m_N(i)})} - 1)\hat{T}_i$ (10). In both equations, $\hat{T}_i$ is the predicted 2021 fair market value of property i. In equation (9), $\beta_{m(i)}$ represents the semi-parametric binned estimate of how NWPR affects log property values in wetland bin m, from equation (12) and Panel A of Figure 4.

Equation (10) is similar but uses the algorithm rather than wetland bins, so $\beta^N_{m(i)}$ represents the estimated impact of NWPR on the log value of properties in regulatory probability bin m from equation (13) and Panel B of Figure 4. Each property has a predicted probability of regulation under both *Rapanos* (p_R) and NWPR (p_N). We assign the property to a regulatory probability bin under each rule and obtain the corresponding estimated effects, $\beta^N_{m_R(i)}$ and $\beta^N_{m_N(i)}$, from equation (13). The difference $\beta^N_{m_R(i)} - \beta^N_{m_N(i)}$ represents the estimated change in log property value resulting from the shift in regulatory status between *Rapanos* and NWPR.

In Panel B of Table 4, column (4) shows our estimate that NWPR increased the value of all non-residential properties by \$51 to \$154 billion.[18]

Figure A14, panel A, shows the impact of NWPR on county-level land values for the wetland map model. The largest price effects occur in counties characterized by both high aggregate non-residential property values and extensive wetlands, including areas such as southern Florida, Massachusetts, and the Seattle metropolitan region.

We interpret NWPR as a shock to the quality of non-residential land, so that our estimates reflect the demand for unregulated versus regulated wetlands. As Section 8.4 discusses, these estimates can be interpreted as a lower bound on the welfare effects of

[17] This calculation uses the semi-parametric binned estimates from Figure 4 rather than the linear estimates from Table 3 to capture the unequal distribution and effects of water resource shares and deregulation across properties.

[18] This result is different than the estimate of total land value NWPR deregulated in Greenhill et al. (2024); Appendix C.3 explains how these estimates differ.

NWPR, accounting for sorting and general equilibrium effects (Banzhaf 2021).

Mitigation Banking Benchmarks of Regulatory Costs

This subsection explores one important reason why removing Clean Water Act regulation from wetland properties increases their value. Many projects that develop wetlands must pay others to build or restore wetlands that offset the wetland loss. The market prices of these wetland offsets therefore provide a useful benchmark for the change in land values that we estimate. National data on offset prices are scarce. Drawing on scattered evidence discussed in Appendix B.4, for this exercise we assume a mean offset price of $150,000 per acre. Sunding and Zilberman (2002) estimated regulatory costs from a 1999 survey of permit applicants, capturing internal staff time and outside experts but abstracting from delays, redesigns, and forgone projects. Our hedonic estimate captures the full revealed cost, of which mitigation banking is one component we can directly quantify from offset prices.

Using equations (9) and (10), we find that NWPR raised the average non-residential property's value by $1,820 to $5,500. To benchmark this against mitigation banking costs, we need the typical wetland area that actually gets developed by a project, since offsets are purchased per acre impacted rather than per acre regulated. The fitted effect from Table A5 column (1) implies that after four years, NWPR increased the share of developed land by 1.4% more in non-regulated than in regulated sites. This estimate uses the wetland map; the corresponding estimate using the algorithm is 1.7%. Evaluated at the non-residential sample average water resource share of 4.9%, NWPR therefore decreased the jurisdictional probability of the average non-residential property by 9.3 percentage points.[19] The algorithm gives a corresponding 13.3 percentage points. Combined, these imply the average project converts 0.035 to 0.061 acres of wetland to impervious surface ($= 0.014 \times 27 \times 0.093$; $0.017 \times 27 \times 0.133$).[20] Dividing the per-property price effect of $1,820 to $5,500 by these developed-wetland areas yields a per-developed-wetland-acre value of $30,000 (algorithm) to $157,000 (wetland map).

[19] Table 2 column (2) implies NWPR decreased the jurisdictional probability of a property without water resources by 8.3 percentage points (coefficient on NWPR), plus an additional 19.7 percentage points for each unit of water resource share ($= 8.3 + 19.7 \times 0.049$).

[20] We use NWI water resource share as opposed to NLCD wetland share because NWI data is higher quality and allows for more precise measurement of NWPR's effect on jurisdiction. We use estimates of wetland loss measured with NLCD because the literature has precise estimates of the value of wetlands, but not water resources under the NWI definition.

Compared to our assumed offset price of $150,000 per acre, mitigation banking could account for all of this per-acre willingness to pay.

8.2 Aggregate Effects of the Navigable Waters Protection Rule on Flood Mitigation

Panels C and D of Table 4 report estimates of how NWPR affects flood mitigation benefits of wetlands. We use the estimated difference in wetland area loss between non-regulated and regulated sites of 0.53 percentage points from column (4) of Table A5. Two considerations suggest that this estimate may be conservative. First, remotely-sensed land cover products generally exhibit poorer classification performance for wetlands than for other land cover types. Second, the 30-meter spatial resolution of these products causes them to miss small water resources.

We multiply these wetland area changes by Taylor and Druckenmiller (2022)'s estimate that one acre of wetlands provides $35,262 in net present value flood protection benefits (3% discount rate). As Panel D of Table 4 shows, this implies that NWPR reduced the value of wetland flood protection services by $8.5 to $13.1 billion. The range in these estimates reflects whether the change in regulatory stringency is estimated using the wetland map or the algorithm.

Many studies estimate value of different ecosystem services using a mix of stated preference, travel cost, and related methods. Many of these studies look at one water resource in a single region. A few meta-analyses quantify the estimated monetized benefits of wetlands through various channels of different ecosystem services. Appendix B.5 and Table A6 summarize these meta-analyses and the share of the estimated value of wetlands that reflect flood damage mitigation versus other channels.

Overall, these meta-analyses find that flood damage mitigation accounts for a fourth to just over a half of the full benefits of wetlands. The most recent meta-analysis (Bilkovic et al. 2025) estimates that prevention of flood damages accounts for 55% of the estimated benefits of wetlands; climate regulation, nutrient removal, biodiversity, and recreation account for the remaining 45%. Including older meta-analyses and averaging across studies would indicate that 25% to 37% of the value of wetlands reflects flood mitigation benefits. The ecosystem services with the largest other estimated benefits are water supply, carbon storage, water quality improvement, waste treatment, erosion protection, nutrient removal and recycling, biodiversity and genetic diversity, and recreation.

8.3 Comparing Flood Mitigation Benefits and Land Values

Panels B and D of Table 4, column (4), summarize our estimates from the last subsection that NWPR increased national land values by $51 to $154 billion. Panel D of Table 4 reports our estimate that NWPR increased downstream flood damages by $8.5 to $13.1 billion.

Panel E of Table 4, column (4), indicates that this ratio of the measured benefits of NWPR to its measured costs ranges from 6.0 to 11.8, depending on whether jurisdiction is measured with the wetland map or the algorithm. This ratio is larger if we use estimates of flood damages per acre of wetland loss from Gourevitch et al. (2026) instead of Taylor and Druckenmiller (2022).[21]

Figure A14, panel B, maps the ratio of NWPR land value benefits to flood protection costs at the county level for the wetland map model. In the vast majority of counties, this ratio exceeds one, indicating that land value benefits from the NWPR exceed the associated flood protection costs. High benefit–cost ratios are especially prevalent in the western United States, the Midwest, the Northeast and Mid-Atlantic, southern Florida, and the Lower Mississippi Basin. In contrast, the ratio falls below one in only 33 counties, primarily concentrated in the central Great Plains.

Panel C of Figure A14 presents a scatter plot of county-level land value benefits against flood protection costs. The two measures have correlation coefficient = 0.45, indicating that counties with larger land value benefits also tend to face higher flood protection costs. This pattern is intuitive, as both land values and the value of human-use ecosystem services tend to be higher in more densely populated and higher-income areas. As a result, there may be limited scope for spatially targeting Clean Water Act land use regulations to achieve large gains in net benefits, since areas with high benefits also tend to have high costs.

[21] Taylor and Druckenmiller (2022), used in our main results, is available at 300m resolution. Gourevitch et al. (2026) reports the median value of flood mitigation for each localized subwatershed (12-digit Hydrologic Unit Code, or HUC12), which is considerably more coarse than 300m. The skewed distribution of wetland flood mitigation values implies that the median incompletely reflects flood mitigation benefits from higher-value wetlands. Applying Gourevitch et al. (2026)'s HUC12 medians here would imply wetland flood mitigation damage values are approximately one-fifth of what our main results estimate, and therefore the ratio of measured benefits to measured costs of NWPR is five times larger than what our main results estimate.

8.4 Social Welfare

This subsection discusses welfare interpretations of land value and flood mitigation estimates. In the classic hedonic model (Rosen 1974), variation in land values can reveal the marginal willingness to pay for amenities. Our setting differs from this classic hedonic model in several ways. NWPR represents a non-marginal policy change. We study longitudinal changes in land values, not a cross-section. Additionally, NWPR may shift out the supply of developed land. These features lightly echo other analyses of U.S. environmental policies and land values (Chay and Greenstone 2005; Greenstone and Gallagher 2008; Gamper-Rabindran and Timmins 2013; Currie et al. 2015; Keiser and Shapiro 2019; Christensen et al. 2023).

In this setting, the change in land values provides a lower bound on the willingness to pay. The tightness of this bound is theoretically ambiguous. In simulations, when half of households receive a public good, differences-in-differences hedonics estimates are 25% below the true willingness-to-pay; when 10% of households receive a public good, the difference is 8% (Banzhaf 2021). While these simulations require strong functional form and parametric assumptions, because wetlands account for 3% to 4.5% of land area in our analysis sample, they suggest that the gap between our hedonic estimates and willingness to pay may not be especially large.

We note other caveats for any welfare interpretation. Because we compare within narrow geographic areas, we abstract from impacts of NWPR on wages, which can account for a portion of willingness to pay (Roback 1982). Our analysis sample excludes properties with missing location, missing or implausible acreage, etc; though the excluded properties account for less than 1% of non-residential land value. We abstract from capitalization of wetlands' environmental benefits. This is loosely in line with findings that changes in water quality and wetland area weakly capitalize into property values (Keiser and Shapiro 2019; Taylor and Druckenmiller 2022), surveys revealing low willingness to pay for wetlands (U.S. EPA and U.S. Army Corps of Engineers 2021), and our lack of estimated local spillovers (Figure 5). These patterns could reflect limited household information on wetland benefits and the accrual of many wetland benefits to other areas, especially downstream.

Additionally, our flood damage estimates reflect flood insurance claims, but some flooded homes are uninsured. The Congressional Budget Office (2019) estimates that the share of flood damages that are insured is 16%, Amornsiripanitch et al. (2025) estimates this share as 30%, and Blickle et al. (2025) as 35%. Also, our flood damage statistics cover residential dwellings, but floods also damage non-residential properties. The Congressional Budget Office (2019) estimates that 25% of flood damages are non-residential, though the Federal Register (2024) reports that only 7% of flood insurance policies are commercial.

Furthermore, wetlands provide ecosystem services besides flood mitigation. The best evidence on other channels seems to be from meta-analyses of stated preference, travel cost, or related studies of individual wetlands; we are unaware of national quasi-experimental valuation evidence beyond flood mitigation. Table A6 summarizes the four meta-analyses that report the estimated monetary value of each ecosystem service from wetlands. The quality of the underlying studies varies widely, so we interpret the results cautiously. The most recent meta-analysis estimates that flood mitigation accounts for 55% of wetlands' ecosystem service values, while averages across meta-analyses range from 25% to 37%, depending on whether one weights by number of underlying observations, number of underlying studies, or takes a simple average.

Overall, our assessment is that the Table 4 finding that NWPR's land market benefits exceed its flood mitigation costs is likely robust to most issues discussed in this subsection. The consequence of accounting for other ecosystem services, however, is ambiguous, given larger uncertainty around the magnitude and value of these other channels.

9 Conclusions

Our analysis shows that changes in environmental land use regulation can have large impacts on land markets and ecosystem services. We focus on the Clean Water Act, the main federal environmental regulation of development involving potential water bodies, wetlands, and streams. We find that the 2020 Navigable Waters Protection Rule (NWPR) substantially decreased wetland regulation, leading to large increases in property values. The land market impacts are concentrated in non-residential properties, which are more subject to Clean Water Act regulation. Properties with federally-mapped wetlands, and which an algorithm estimates had the greatest deregulation, had the largest land market impacts. In aggregate, we estimate that NWPR increased non-residential U.S. land values by \$51 to \$154 billion, relative to the prior Clean Water Act rule. We calculate smaller losses in ecosystem services from this deregulation, though note uncertainty in magnitude and valuation of several important services.

This paper leaves several areas for future research. First, environmental statutes may impact land markets differently. Federal and state land use laws may also interact. *Abundance* (Klein and Thompson 2025), an important motivation for ongoing policy debates around land use regulation, discusses many environmental policies, and we analyze only one.

Second, while we quantify the flood mitigation benefits of wetlands, we have less direct evidence on other ecosystem services from wetlands, including water quality, biodiversity, and others. Carefully measuring these services would help better understand and design policies affecting wetlands.

Finally, we do not distinguish what components of costs reflect delay, uncertainty, regulatory fees, costs of project redesign, or other components. While we discuss available evidence on one important component of the cost, mitigation banking, research strategies to disentangle other costs would be valuable.

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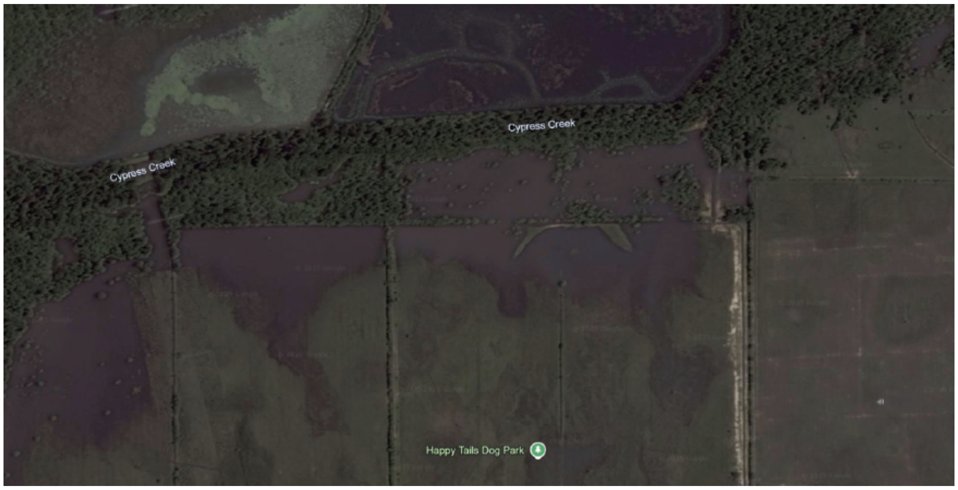
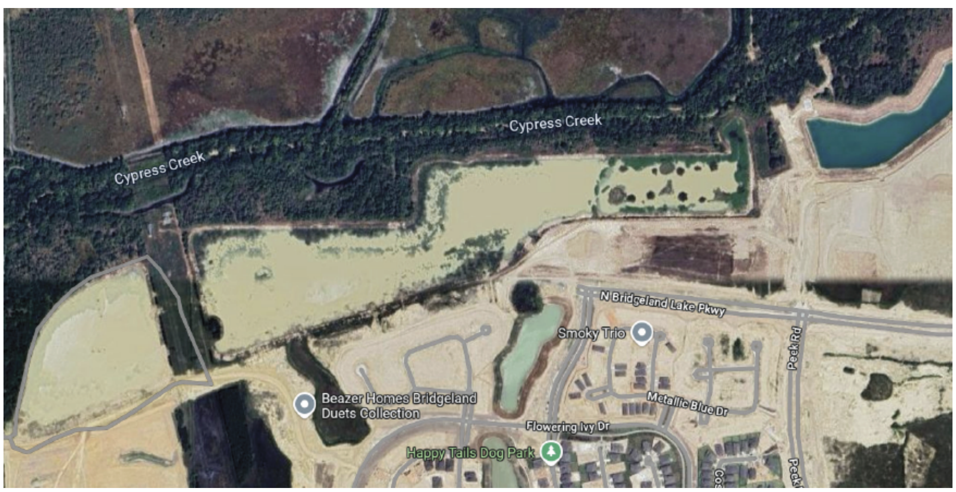
Figure 1: Development Example From the Bridgeland Master Planned Community, Texas

(A) Aerial Image of Flooding, 2016

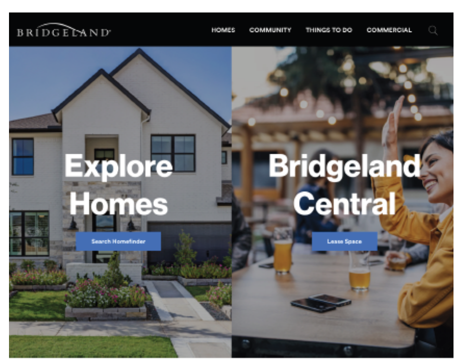


(B) Aerial Image of Development, 2024



(C) Google Street View

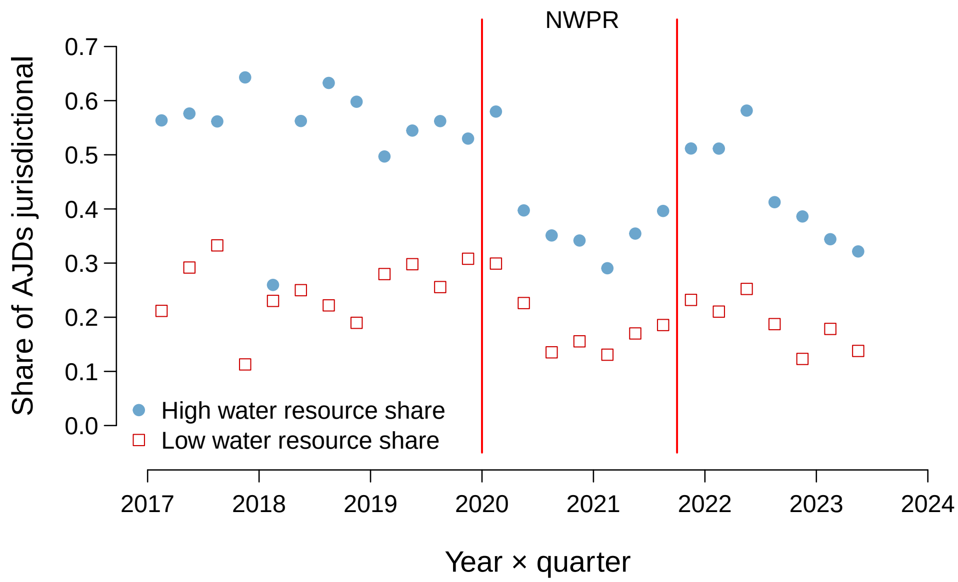
(D) Developer Website



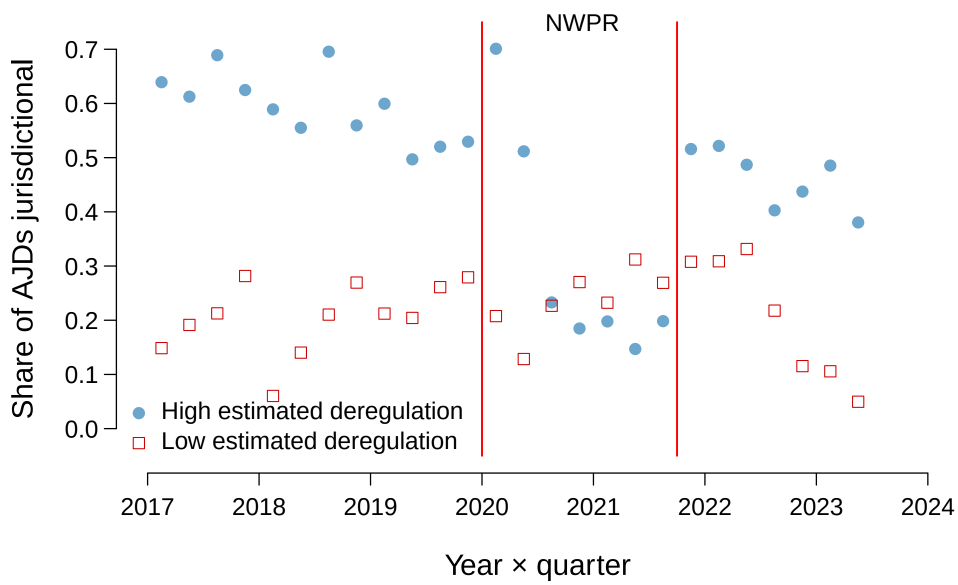
Notes: Panels show imagery of the Bridgeland housing development near Cypress Creek, about 25 miles northwest of central Houston, TX, which received jurisdictional AJDs under the Navigable Waters Protection Rule (NWPR) in October 2020. Panel A shows aerial imagery from Google Earth of flooding in 2016. Panel B shows aerial imagery from Google Earth in the year 2024. Panel C shows Google Street View imagery of one location in the development. Panel D shows a screenshot of the development website, https://www.bridgeland.com/, accessed March 18, 2026.

Figure 2: Share of Approved Jurisdictional Determinations that are Regulated, 2017-2023

(A) Using Wetland Map



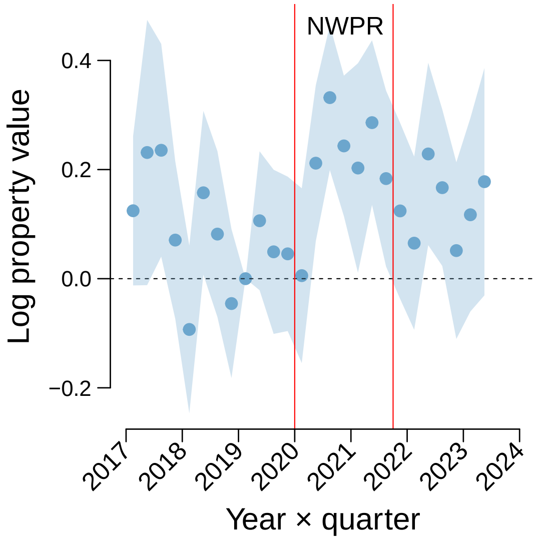
(B) Using Algorithm



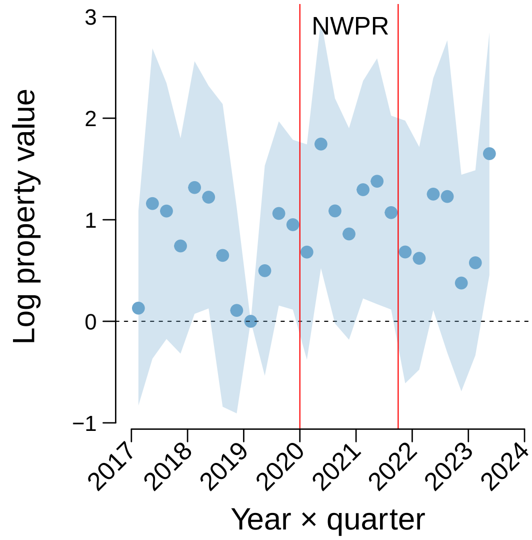
Notes: Graphs analyze approved jurisdictional determinations (AJDs). NWPR is the Navigable Waters Protection Rule. Both panels show the share of AJDs that the Army Corps determines to be jurisdictional in each year × quarter. In Panel A, blue circles describe properties above the 75th percentile of water resource share (where water resources account for more than 19% of surrounding area) and red squares describe properties with zero water resource share (36% of properties). For each site, we calculate the water resource share as the area within a 100 meter radius circle covered by National Wetlands Inventory water features. In Panel B, blue circles describe properties above the 75th percentile of algorithmically-estimated deregulation between *Rapanos* and NWPR. Red squares describe properties below the 36th percentile of estimated deregulation. Vertical lines mark before the first quarter of 2020, when EPA published the final NWPR rule, and after the third quarter of 2021, when a U.S. District Court vacated NWPR. The Army Corps began implementing NWPR in June 2020. Panels A and B each use the entire analysis sample of AJDs; versions of these graphs that use only the test set generally look similar.

Figure 3: Effects of Navigable Waters Protection Rule (NWPR) on Property Values, Event Study Estimates

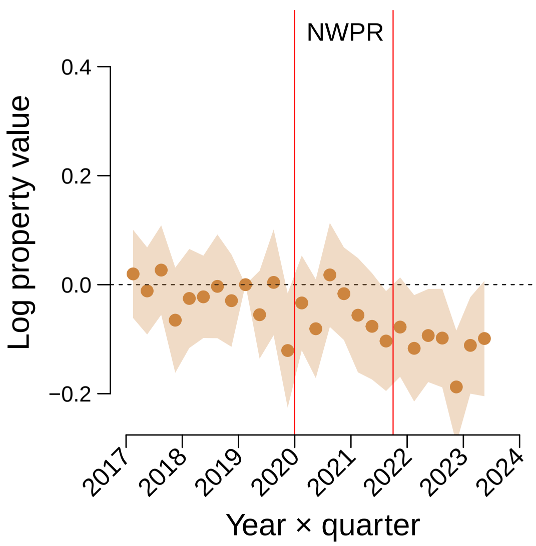
(A) Using Wetland Map, Non-residential



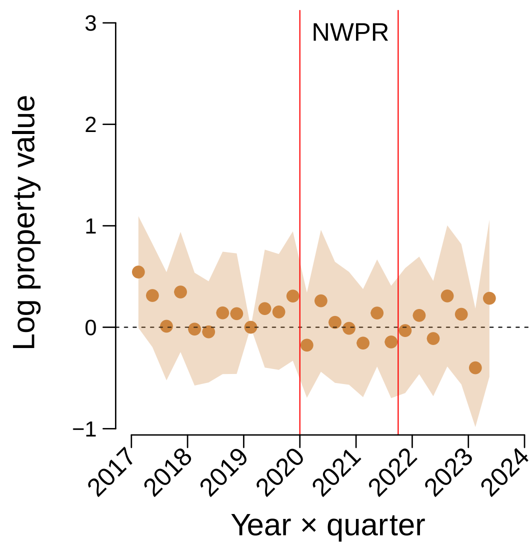
(B) Using Algorithm, Non-residential



(C) Using Wetland Map, Residential



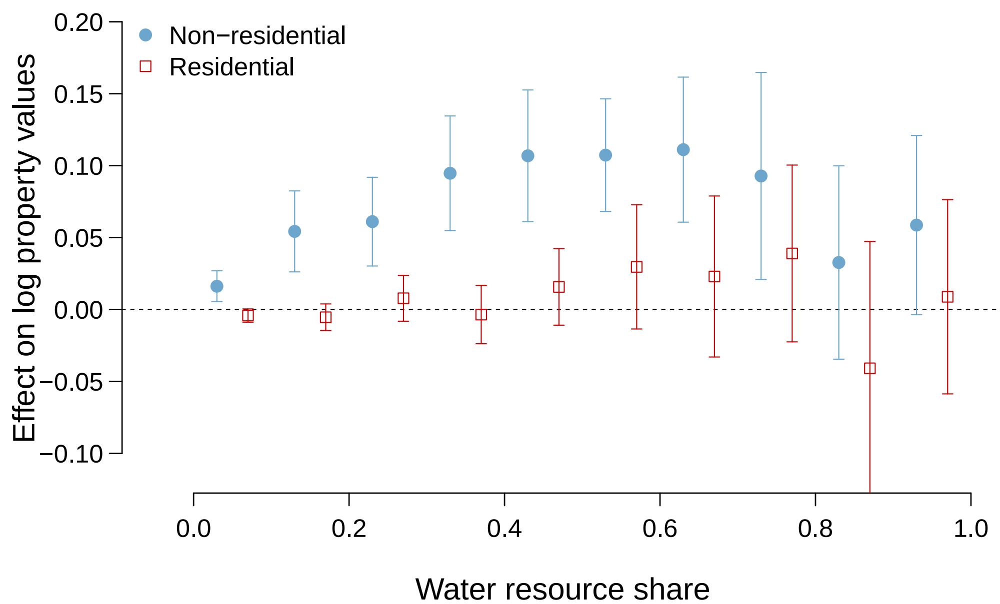
(D) Using Algorithm, Residential



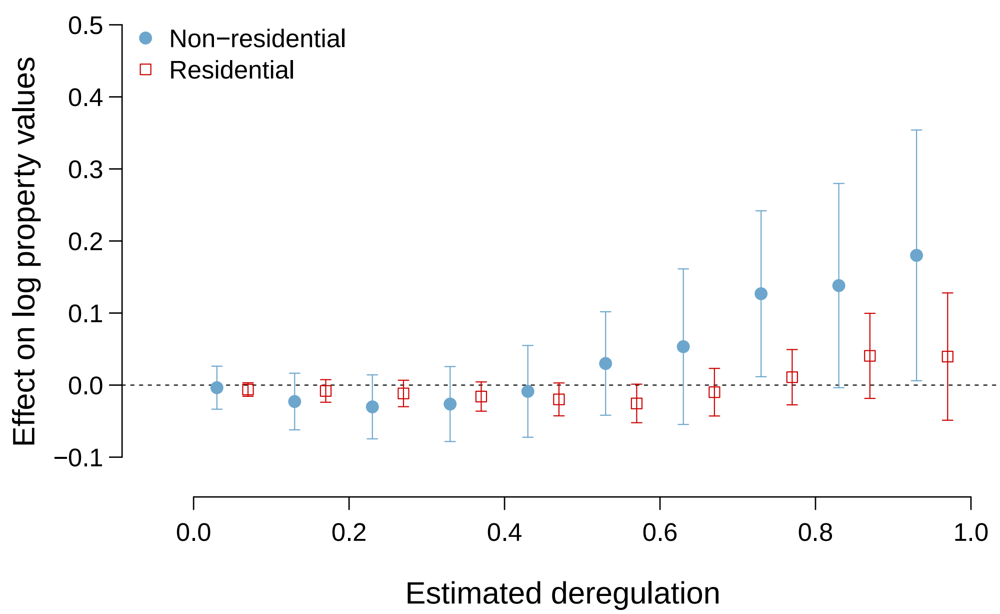
Notes: Wetland map is National Wetlands Inventory (NWI) water resource share. The algorithm is described in Section 4. Panel A shows the effect of water resource share on log values of non-residential properties by year × quarter, from equation (4). Panel B shows the effect of algorithmically-estimated deregulation under NWPR by year × quarter, for non-residential properties. Panels C and D show corresponding values for residential properties. Circles show point estimates and shaded areas show 95% confidence intervals. Standard errors are clustered by commuting zone. Vertical lines mark before the first quarter of 2020, when EPA published the final NWPR rule, and after the third quarter of 2021, when a judge vacated NWPR. All graphs normalize the first quarter of the year 2019 to equal zero.

Figure 4: Effect of Navigable Waters Protection Rule (NWPR) on Log Property Values, Semi-Parametric Bins

(A) Using Wetland Map



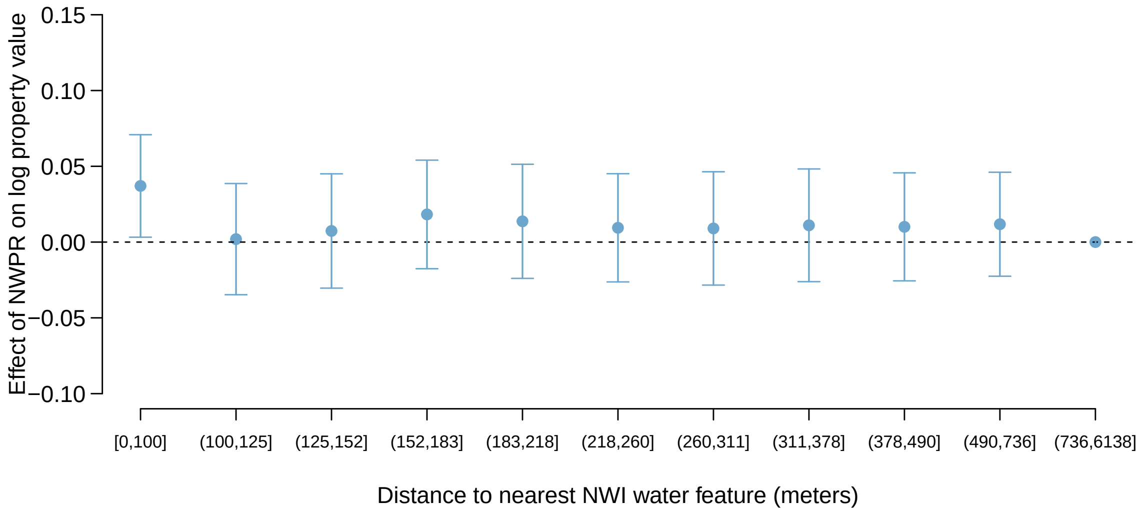
(B) Using Algorithm



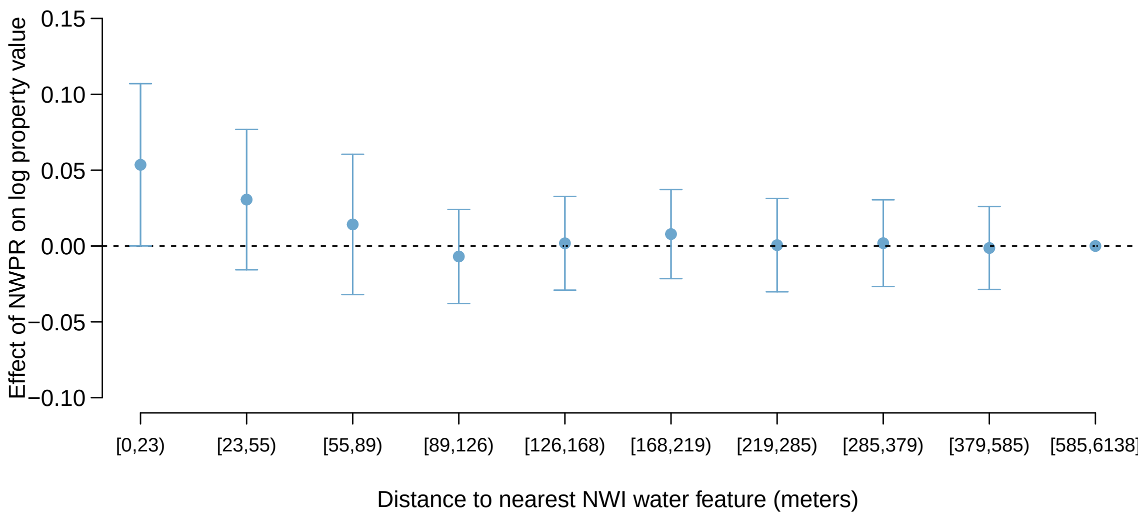
Notes: Wetland map is National Wetlands Inventory (NWI) water resource share. Panel A shows point estimates for the effect of the Navigable Waters Protection Rule (NWPR) on log property values, estimated using equation 12, where NWI wetland share proxies regulation. We separate shares into bins with width of 0.1 from 0 to 1. The reference category is properties with no NWI water resources (share = 0). Vertical lines show 95% confidence intervals. Standard errors are clustered by commuting zone. Panel B instead uses binned estimates of deregulation from the algorithm, following equation (13).

Figure 5: Effects of Navigable Waters Protection Rule (NWPR) on Log Property Values, by Distance to Nearest Wetland

(A) Imposing break at 100 meters

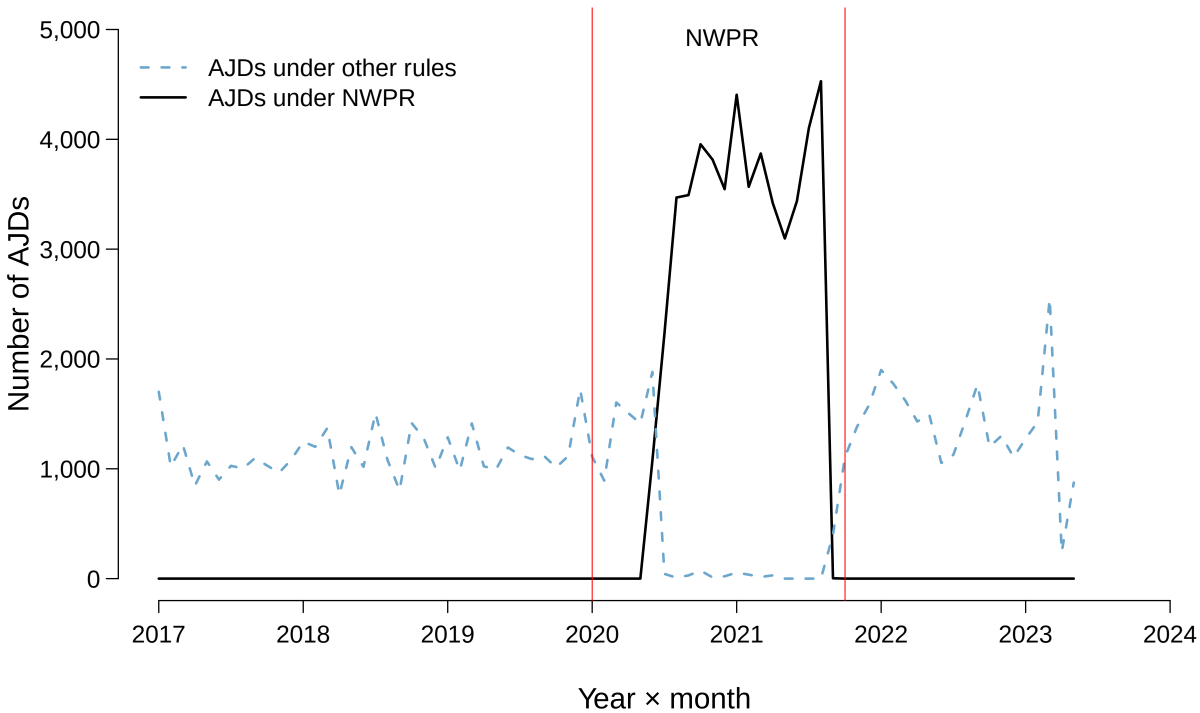


(B) Bins for deciles of distance



Notes: Graphs show results from equation (14), where the effect of NWPR on log property values is estimated for each decile of distance to the property's nearest water feature. Distances are measured using the National Wetlands Inventory (NWI). Panel A separates properties that have an NWI feature within 100 meters versus greater than 100 meters, as in the main analysis. Panel A bins the >100m properties into deciles. Panel B instead calculates deciles of distance to the nearest NWI feature, without imposing a break at 100m. Both graphs use the top deciles as the reference category. Circles show point estimates and shaded areas show 95% confidence intervals. Standard errors are clustered by commuting zone.

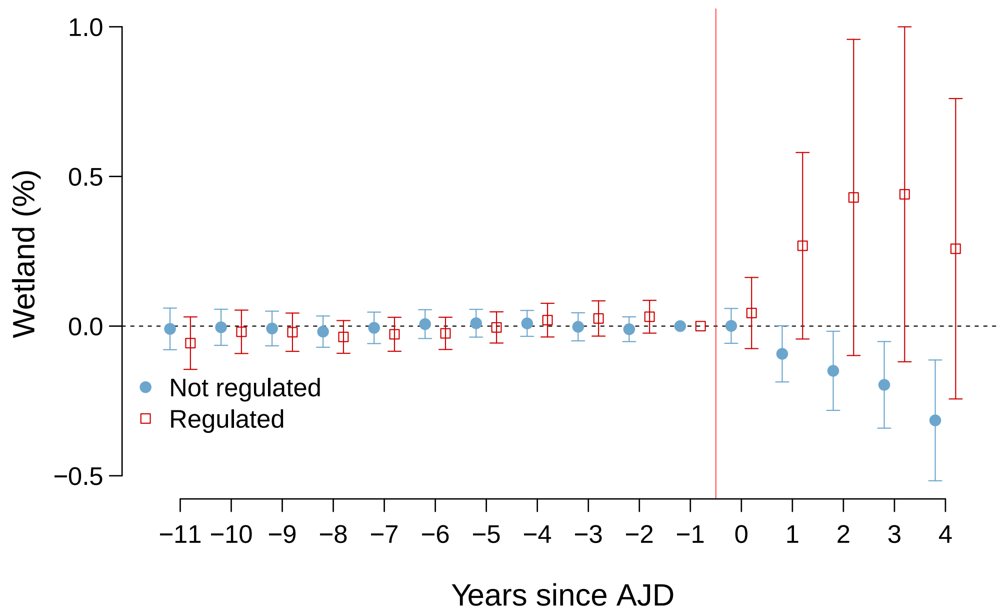
Figure 6: Clean Water Act Approved Jurisdictional Determinations (AJDs), by Rule



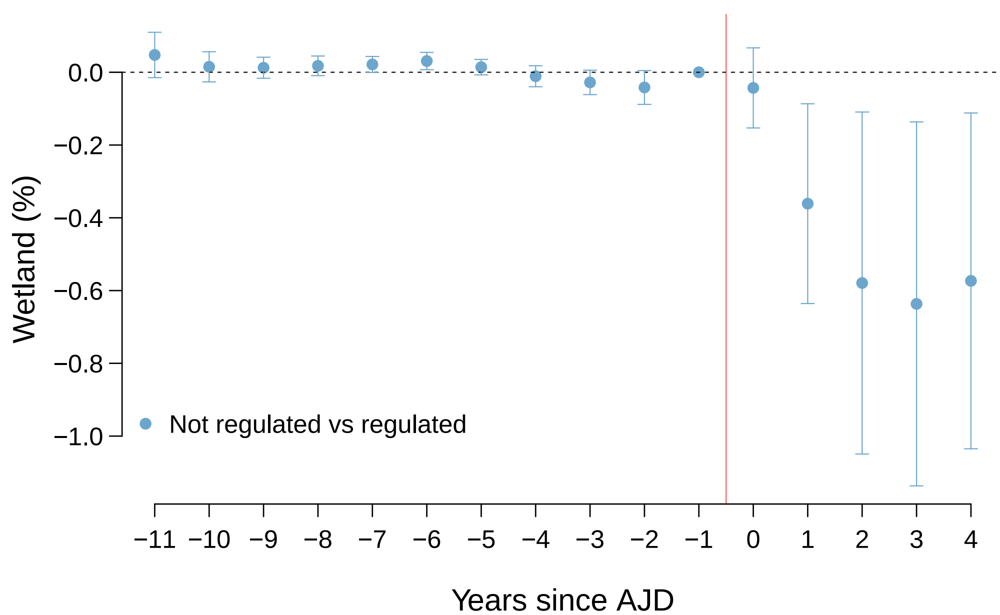
Notes: NWPR is the Navigable Waters Protection Rule. Figure shows the number of Clean Water Act approved jurisdictional determinations (AJDs) each month, separately by rule. The black line shows AJDs under NWPR, and the blue dashed line shows AJDs under *Rapanos* or the Clean Water Rule (CWR). Vertical lines mark before the first quarter of 2020, when EPA published the final NWPR rule, and after the third quarter of 2021, when a U.S. District Court vacated NWPR.

Figure 7: Development Around Approved Jurisdictional Determinations (AJD) Issued Under the Navigable Waters Protection Rule (NWPR), Event Study Graphs

(A) Percent of area that is wetlands, by AJD regulation status



(B) Percent of area that is wetlands, non-regulated versus regulated sites



Notes: Figures show results from equation (6), where the outcome is the share of land that is wetlands within 100m of each approved jurisdictional determination (AJD) site centroid. Regressions use the sample of AJDs issued under NWPR. Wetland area is determined by a binary classification of each 30m pixel, measured from the 2024 edition of the National Land Cover Dataset (NLCD) (U.S. Geological Survey 2024), which covers the years 2010-2024. In Panel A, red squares show point estimates for regulated sites, and blue circles show point estimates for not regulated sites. In Panel B, points show the difference, i.e., the effect of an AJD for non-regulated sites relative to regulated sites. All panels show estimates in the years preceding (negative x-axis values) and following (positive x-axis values) the AJD. Event study regressions include commuting zone × year and site fixed effects, and National Wetlands Inventory (NWI) water resource share × event time. Bars show 95% confidence intervals. Standard errors are clustered by commuting zone.

Table 1: Mean Characteristics of Non-residential Properties

Property area	16.48
	(101.42)
Price	513,048
	(1,098,838)
ln(Price)	11.68
	(1.90)
ln(Predicted 2016 sale price)	11.64
	(2.10)
Water resource share (percent)	4.88
	(14.36)
Wetland share (percent)	3.26
	(12.88)
ln(Distance to town)	3.44
	(1.16)
ln(Distance to metro)	1.14
	(1.12)
Population density decile	5.50
	(2.87)
Work from home share (percent)	34.62
	(9.41)
From algorithm	
Probability regulated under *Rapanos*	0.33
	(0.20)
Probability regulated under NWPR	0.20
	(0.18)
Estimated deregulation: *Rapanos* - NWPR	0.13
	(0.14)
Observations	4,470,365

Notes: Data are from CoreLogic and include US non-residential property transactions in the years 2017 to 2023. The number of unique properties in this sample is 3,587,577. Water resource share is the percentage of land within 100m of the property centroid covered by National Wetlands Inventory (NWI) water features. Wetland share is defined similarly for National Land Cover Database (NLCD) wetlands (U.S. Geological Survey 2024). Property area is in acres. Distances are in kilometers. Population density is measured as the population per square kilometer. Estimated probabilities of regulation are between 0 and 1. Predicted 2016 sale price is a random forest prediction of property sale price in 2016 based on assessor records, used as a control for pre-existing property value. Dollar values deflated to 2024 US$ using the GDP deflator.

Table 2: Effect of the Navigable Waters Protection Rule (NWPR) on Regulatory Stringency

	Dependent Variable: Regulated					
	(1)	(2)	(3)	(4)	(5)	(6)
NWPR AJD	-0.116***	-0.083***	-0.106***	-0.347***	-0.001	-0.069
	(0.022)	(0.022)	(0.026)	(0.129)	(0.017)	(0.051)
Water resource share	—	0.512***	0.579***	0.531***	—	—
		(0.047)	(0.047)	(0.042)		
Water resource share × NWPR AJD	—	-0.197***	-0.173**	-0.150**	—	—
		(0.061)	(0.087)	(0.075)		
Probability of regulation under *Rapanos*	—	—	—	—	1.013***	0.953***
					(0.112)	(0.094)
Probability of regulation under NWPR	—	—	—	—	0.197	0.245**
					(0.126)	(0.108)
Estimated deregulation × NWPR AJD	—	—	—	—	-1.124***	-1.085***
					(0.139)	(0.119)
Constant	0.363***	0.298***	0.297***		-0.069***	
	(0.028)	(0.029)	(0.029)	—	(0.014)	—
Year × month FEs	—	—	—	Yes	—	Yes
Test set	—	—	Yes	Yes	Yes	Yes
Observations	142,973	142,973	29,861	29,861	29,861	29,861

Notes: The dependent variable is an indicator for whether an approved jurisdictional determination (AJD) is jurisdictional. Column (2) uses equation (1). NWPR AJD is an indicator for whether the AJD was adjudicated under NWPR. Water resource share equals the share of area within 100 meters of the property centroid that is covered by any type of National WetlandInventory (NWI) water feature. Probability of regulation and deregulation are established from the ML algorithm, discussed in Section 4.1. Standard errors are clustered by commuting zone. ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

Table 3: Effect of the Navigable Waters Protection Rule (NWPR) on Log Property Values

	Dependent variable: log property value					
	(1)	(2)	(3)	(4)	(5)	(6)
A. Non-residential properties						
Water resource share × NWPR	0.113***	0.117***	0.128***	—	—	—
	(0.027)	(0.028)	(0.028)			
Estimated deregulation × NWPR	—	—	—	0.426***	0.376**	0.341**
				(0.155)	(0.152)	(0.157)
Observations	4,470,365	4,470,365	4,470,365	4,470,365	4,470,365	4,470,365
B. Residential properties						
Water resource share × NWPR	-0.005	0.006	0.010	—	—	—
	(0.017)	(0.017)	(0.017)			
Estimated deregulation × NWPR	—	—	—	-0.106	-0.084	-0.098
				(0.095)	(0.093)	(0.092)
Observations	6,918,722	6,918,722	6,918,722	6,918,722	6,918,722	6,918,722
C. Non-residential vs. residential						
Water resource share × NWPR	0.118***	0.111***	0.117***	—	—	—
× Non-residential	(0.032)	(0.031)	(0.032)			
Estimated deregulation × NWPR	—	—	—	0.584***	0.499***	0.488***
× Non-residential				(0.168)	(0.164)	(0.170)
Observations	11,389,087	11,389,087	11,389,087	11,389,087	11,389,087	11,389,087
Zip × year × month FE	Yes	Yes	Yes	Yes	Yes	Yes
Log predicted 2016 sale price	Yes	Yes	Yes	Yes	Yes	Yes
Log distance to town, metro	—	Yes	Yes	—	Yes	Yes
Population density decile	—	Yes	Yes	—	Yes	Yes
Work from home share	—	Yes	Yes	—	Yes	Yes
Log property acres	—	—	Yes	—	—	Yes

Notes: Columns (1)-(3) use equation (2). Columns (4)-(6) use equation (17). We interact all controls with an indicator for whether NWPR was in force. Water resource share equals share of area within 100 meters of the property centroid that is covered by any type of National Wetlands Inventory (NWI) water feature. Estimated deregulation represents the change in algorithmically predicted probabilities of regulation between *Rapanos* and NWPR, discussed in Section 4.1. Standard errors are clustered by commuting zone. ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

Table 4: Land Value Benefits Versus Flood Protection Costs of Clean Water Act Deregulation

	Mean property		National total	
	(1)	(2)	(3)	(4)
A. Property characteristics				
Number of Properties	—	—	4,470,365	27,942,084
Property Value ($M)	0.513	0.551	2,293,510	15,388,858
Property Acres	16.481	27.047	73,676,761	755,747,059
Wetland Acres	0.956	1.527	4,272,226	42,663,100
Water resource acres	1.212	2.009	5,416,332	56,124,733
B. Effect of NWPR on land values				
Using wetland map (logs)	0.0116	—	—	—
Using algorithm (logs)	0.0056	—	—	—
Using wetland map ($M)	0.0046	0.0055	20,682	153,705
Using algorithm ($M)	0.0018	0.0018	7,975	50,563
C. Effect of NWPR on wetland area				
Using wetland map (acres)	-0.008	-0.013	-36,161	-370,927
Using algorithm (acres)	-0.005	-0.009	-23,457	-240,613
D. Effect of NWPR on wetland flood protection				
Flood mitigation value ($/acre of wetlands)				
Annual	1,057	—	—	—
Present value	35,261	—	—	—
Effect on flood damages ($M, present value)				
Using wetland map	—	—	-1,275	-13,079
Using algorithm	—	—	-827	-8,484
E. Ratio of NWPR land value benefits to flood protection costs				
Using wetland map	—	—	16.2	11.8
Using algorithm	—	—	9.6	6.0
Transacted Properties	Yes	—	Yes	—
All Properties	—	Yes	—	Yes

Notes: Columns (2) and (4) show all non-residential properties from CoreLogic assessor data, in which transaction values are predicted from assessed values by a random forest model (see Section 4.2 and Appendix C.2). Wetland acres represent the share of land within 100m of the property centroid covered by National Wetlands Inventory (NWI) water features, multiplied by property acreage. Wetland map is NWI water resource share. Panel B computes the aggregate effect of the Navigable Waters Protection Rule (NWPR) on property values following equations (9) and (10). Panel C shows the effects of NWPR on wetland area four years after an AJD using the fitted effect difference from column (4) of Table A5. Aggregate estimates in Panel D multiply estimates in Panel C by the present value under a 3% discount rate of wetland flood protection from Taylor and Druckenmiller (2022) and scale by the effect of NWPR on probability of regulation, using either estimates from equation (1) or algorithmically estimated deregulation. Panel E divides estimates in Panel B by the corresponding estimates in Panel D and multiplies by -1.

A Background: Additional Details

A.1 Clean Water Act

As the introduction mentions, Section 404 and wetland permits are largely separate from two other main Clean Water Act (CWA) activities: the State Revolving Fund, which provides low-interest loans to municipal wastewater systems to improve abatement technology; and Section 402, which creates the National Pollutant Discharge Elimination System (NPDES) that sets emission limits and requires abatement technology investments for industrial and municipal plants.

The legal changes we analyze apply to all parts of the CWA. However, as mentioned in the introduction, the changes in the definition of regulated waters (WOTUS) we analyze primarily affected water resources that are small, isolated, non-flowing, or non-permanent. The industrial and municipal plants that are regulated under non-Section 404 CWA provisions generally discharge polluted wastewater directly into permanent water resources which always flow—and thus are always regulated. As such, the rule changes we analyze have generally not affected industrial regulation or wastewater treatment under these other sections of the CWA.

A.2 Other CWA Rules

The main text focuses on two CWA rules (*Rapanos* and NWPR), but several other rules similar to these two have applied in the last decade.

The 2015 Clean Water Rule sought to clarify jurisdiction under *Rapanos*, though not to change it substantially. The Clean Water Rule applied beginning in 2018, though only in 23 U.S. states. Litigation delayed and then stopped its implementation in the other 27 states due to litigation. The Clean Water Rule has substantial similarity to *Rapanos*. The 2023 rule was essentially *Rapanos*, with minor differences.

Sackett has similarities to NWPR. It strikes down Justice Kennedy's significant nexus standard. *Sackett* also applies the relatively permanent standard—both deregulate isolated wetlands and ephemeral streams.

A.3 Case Study of Wetland Development

Detail on the Texas development project mentioned in the introduction can clarify our setting. The master planned community called Bridgeland covers 11,500 acres on the Houston periphery, about 25 miles northwest of central Houston, TX. This development is planned to include 20,000 homes and is among the country's top-selling master-planned communities (Groves 2021; Mizan 2023; Bridgeland 2025). Bridgeland is just south of Cypress Creek, a perennial stream prone to flooding that flows downstream through Houston. The Bridgeland development began in 2011 but initially avoided developing some areas near Cypress Creek.[22]

In October 2020, the Army Corps provided approved jurisdictional determinations (AJDs) under NWPR for 90 water features on the Bridgeland property surrounding Cypress Creek, collectively covering 80 acres of wetlands and basins plus 20 linear miles of ditches and streams (U.S. Army Corps of Engineers 2020). The Army Corps concluded that none of the sites were regulated under NWPR.[23] Many of the water resources under consideration were near Cypress Creek but lacked a continuous surface water connection. *Rapanos* might have regulated these sites but NWPR did not.

This case study illustrates the tradeoffs we analyze. By expanding impervious surfaces on historically wet areas near perennial streams and floodplains, this development may decrease other ecosystem services. At the same time, Bridgeland demonstrates strong demand for wetland development and suggests the potential costs of regulations restricting such development.

B Data: Additional Details

B.1 CoreLogic

We use property transaction data from CoreLogic (2024). We use CoreLogic's property-level data product, `property_basic2`, which includes information on property location, acreage, and land use. We link this to its ownership transfer product, `ownertransfer_v3`, which

[22] The county assessor data that we use to identify land use indicate that at the time these properties transacted, before Bridgeland developed them, they were classified as non-residential and vacant.

[23] Because the sites were not jurisdictional, Bridgeland did not obtain a wetland permit for this development, although it had obtained AJDs and permits for earlier development elsewhere on the property.

includes information on property sales like sales price and date.

Our CoreLogic extract includes approximately 4.5 million non-residential and 6.9 million residential sales transactions spanning January 1, 2017 to May 25, 2023. This period covers three years on either side of the 2020 NWPR rule change and ends with *Sackett*'s announcement. Residential properties have land use codes ($LUSE$) below 200 and non-residential properties have codes of 200 or greater. Sensitivity analyses examine several sub-categories of non-residential vacant ($LUSE$ in the 400s), commercial (200s), agricultural (500s), industrial (300s), public (600s), recreational (700s), noncoded (998, 999 or missing), residential rural (109, 160), and transport energy (800s).[24] Table A2 reports the number of observations in each category.

We note one nuance in how we categorize residential vs non-residential: "residential rural" involves land use codes for cabins (109) and rural homesites (160), which we classify as non-residential despite having codes below 200. These properties typically represent larger rural properties with minimal housing structures, making them more similar to non-residential land in their exposure to CWA regulation. About 6,900 of our sample of 4.5 million (0.2%) non-residential properties are classified as "residential rural." We classify transactions based on the land use code at the time of sale from ownership transfer records (`landuse_code.ot`) rather than the most recent assessment.

To locate properties, we use the listed coordinates of each property centroid that CoreLogic calculates. For the few properties with missing coordinates, we instead use coordinates that USPS derives from mailing addresses, which CoreLogic also provides.

Our main analysis sample excludes the following groups of observations as representing erroneous or incorrect records:

1. Observations missing a CoreLogic property identifier (`clip`), since we use this identifier to link property details to transaction records.
2. Non-arm's length, non-third-party transactions (`primary category code` $\neq$ A and `interfamily related indicator` $\neq 0$).
3. Transactions with missing values for sale amount, sale date, or latitude/longitude.
4. Transactions with missing or zero property acreage, or with acreage $\geq$ 100,000.
5. Duplicate transactions that share the same property identifier (`clip`), transaction ID

[24] Examples of properties for less familiar categories: Public includes non-privately owned land, e.g., schools, churches, NGOs); recreational includes golf courses, casinos, marinas, parks; transport energy includes airports, power stations, waste disposal, ports.

(`transaction_id`), sale amount, latitude, and longitude.

6. Transactions where the transaction price is $\leq$ \$1,000 or $\geq$ \$10,000,000, or the price per acre is $\leq$ \$100.
7. Transactions with ratio of assessed value-to-price or price-to-assessed value $\geq$ 50.

We use these same cleaning rules to construct an extract of non-residential transactions spanning 2010–2023.

CoreLogic transaction coverage is incomplete in eleven contiguous U.S. states where buyers and sellers are not required to file the sale price on the deed (the "non-disclosure" states): Idaho, Kansas, Louisiana, Mississippi, Montana, New Mexico, North Dakota, South Dakota, Texas, Utah, and Wyoming. CoreLogic typically records the deed transfer event in these states but lacks a recorded price, so the parcel cannot enter our transaction sample. South Dakota is the most affected: 40 of its counties have zero CoreLogic nonresidential transactions in any year. Montana, Wyoming, and Utah have positive but sparse county-level coverage. In Kansas, annual nonresidential transactions are absent post-2010. However, these missing counties, visible in Figure A6, collectively house under 1% of the U.S. population. Similar coverage limitations in the ZTRAX dataset have been documented (Nolte 2020).

Our benefit-cost comparison uses the CoreLogic assessor data (`property_basic2`). These assessor records cover most non government-owned properties, including properties that did not transact in our analysis sample. As above, we limit the assessor sample to non-residential properties (land use code $\geq$ 200, plus "residential rural" properties with land use codes 109 and 160). We exclude properties with assessed value $\leq$ \$1000 or $\geq$ \$9,999,999 (to account for some missing values that were encoded with a sequence of nines), and the assessed value per acre $\leq$ \$100. The resulting data describe 27.9 million nonresidential properties. Among these, 44% have at least one recorded transaction ever. The mean property size in the assessor sample is 27.0 acres, and the total covered acreage is 756 million acres.[25] The mean U.S. property value is \$222,000.[26]

We use a sample to calculate summary statistics like wetland share and probability regulated for the average property overall. We randomly select 1 million properties from this

[25] For reference, the total land area of the continental U.S. is 1.9 billion acres, of which about 1.3 billion are privately held.

[26] Our national statistics include only assessed properties, which excludes public lands, properties missing coordinates, properties that assessors or county data miss, etc. We refer to these national statistics as "U.S. properties" or "national properties."

set of 27.9 million nonresidential properties in the assessor sample. Following the procedure from the main transaction sample, we compute the share of land within a 100m radius of the property centroid that contains NWI water resources (mean = 5.3%) or wetlands (mean = 3.6%). Applying the wetland share to the average U.S. property (27.0 acres) results in an estimated 1.5 acres of wetlands per property, and 42.7 million acres of wetlands total.

The composition of non-residential property transactions differs from the full stock of non-residential properties (Table A2). Commercial properties are relatively more likely to transact (25% of transacted properties versus 18% of U.S. properties), reflecting liquidity in commercial real estate. Conversely, agricultural and residential rural properties are relatively less likely to transact, reflecting longer holding periods of farmland and rural properties. Vacant land is particularly likely to transact (48% of transactions versus 39% of U.S. properties).

B.2 Approved Jurisdictional Determinations (AJDs)

We use records of AJDs from U.S. Army Corps of Engineers and U.S. EPA (2025). The data cover all states and USACE districts. Florida, Michigan, and New Jersey have state authority to manage AJDs, so have few (though not zero) AJDs.

Wetland development can occur without an AJD. Some developers provide a preliminary jurisdictional determination (PJD), which assumes water resources are jurisdictional. Developers may choose a PJD if a site is obviously jurisdictional or if they have strong demand to expedite the regulatory process. Other developers directly obtain a wetland permit without a jurisdictional determination. Still others may develop properties without a jurisdictional determination or a wetland permit, under the assumption that either they are not violating the CWA or will not get caught.

Figure A2 maps AJDs. The AJDs cover most of the continental US, including all 48 states. They are more common in major metro areas, where development is prevalent, and less common in sparsely populated rural areas, which have less development. AJDs are more common in the wetter areas of the eastern U.S., which have more water resources and development, and less common west of the 100th meridian, where more arid climate and less population means fewer water resources and development projects require AJDs.

Figure A2 also reveals spatial patterns of regulation. Red points are jurisdictional and blue points are not. In our sample, 32% of AJDs are regulated. Some spatial patterns in regulation reflect geophysical features. For example, many coastal wetlands in the South and Mid-Atlantic are regulated, while few ephemeral streams in the arid West are regulated. Other patterns reflect USACE district boundaries—few AJDs in the St. Paul USACE district, which covers Minnesota and Wisconsin, are regulated, while many AJDs in the Chicago district are regulated.

B.3 Property-level controls

Several regressions add property-level controls: log property acres, log distance to nearest town center, log distance to nearest metro area, population density decile, and work from home share.

We compute the straight-line distance from each property's centroid to the nearest Census "place" (city or town) center using point shapefiles from the National Historical Geographic Information System (U.S. Census Bureau 2015). We calculate distances to the nearest major metropolitan area by matching properties to the closest of the 400 largest U.S. cities using the SimpleMaps.com (2023) U.S. Cities Database, which uses several U.S. Census Bureau and U.S. Geological Survey datasets. We define population density as 2020 block population (U.S. Census Bureau 2020) divided by land area in square kilometers. Because the United States has 8,132,968 Census blocks and 33,642 Zip Code Tabulation Areas (ZCTAs) (U.S. Census Bureau 2020), our data have on average about 240 Census blocks per zip code. We compute the block-level work-from-home (WFH) share by weighting Longitudinal Employer-Household Dynamics (LEHD) (U.S. Census Bureau 2020) employment shares in each NAICS sector by teleworkability rates (Dingel and Neiman 2020) and summing across sectors.

We measure property acres from the CoreLogic assessor records and link to transactions data using unique property identifiers ("CLIP").

We calculate the distance of each property to the nearest town center using Census Place Points obtained from the NHGIS place point GIS files (U.S. Census Bureau 2015). These Place Points report the locations of approximately 30,000 incorporated, unincorporated, and census-designated places identified in the U.S. Census Bureau's published datasets and volumes.

We calculate distances to the nearest metro area using the 400 metropolitan areas with greatest U.S. population, from SimpleMaps.com (2023). This sample includes cities with populations exceeding 115,330 and has coverage across all 48 states in the contiguous U.S. and Washington, DC.

We measure population density by census block using data from the 2020 Census (U.S. Census Bureau 2020). We intersect the latitude and longitude coordinates for each Corelogic property with the census block shapefile, then merge in block-level population count and land area. We control for population density decile, with density measured in persons per square kilometer.

We also measure work from home shares by Census block using the same methodology from Ramani and Bloom (2021).

B.4 Measures of mitigation costs

Several sources report typical mitigation costs (i.e., the market price of paying another party to build a wetland that offsets area developed under a wetland permit). Coleman (2015) estimates a mean price of $144,000 per acre in the year 2015, and Madsen et al. (2010) report a price of about $75,000 per acre in the year 2008. EASI (2025) reports that nominal prices in two large states doubled between the years 2008 and 2023. The U.S. EPA and U.S. Army Corps of Engineers (2022) Economic Analysis of NWPR does not list the average mitigation price they assume, but $150,000 is consistent with national aggregate value and quantity results they list.

B.5 Extrapolating Ecosystem Service Value from Flood Control

Differences-in-differences regressions exploiting spatial and temporal variation in wetland extent find that wetlands provide substantial protection against flood damages (Taylor and Druckenmiller 2022; Aronoff and Rafey 2026; Gourevitch et al. 2026). A vast literature of wetland valuations may provide a comparison of the value of flood control to the values of other ecosystem services provided by wetlands. Comparison in this literature is challenging, however, because studies are conducted across diverse ecological settings and methodological frameworks. A few examples of wetland valuation studies highlight this methodological heterogeneity.

Bergstrom et al. (1990) combine on-site interviews with a follow-up contingent valuation survey to estimate the value of wetlands-based recreation in Louisiana coastal marshes. Using dichotomous-choice logit models with varying payment amounts, they recover mean willingness to pay for wetland protection, thereby measuring consumer surplus directly through stated preferences. Samonte-Tan et al. (2007) employ market-based methods to value coastal wetlands in the Bohol Marine Triangle, Philippines. For provisioning services such as fishing and gleaning, they collect survey data on output quantities, ex-vessel prices, and production costs, and compute annual net revenues (producer surplus). Bell (1997) uses a production function approach. He estimates fishing output as a function of fishing effort and coastal marsh area using state-level data. The coefficient on marsh area identifies the marginal contribution of wetlands to fishing output under the assumed production structure, which is then monetized using observed fish prices. Breaux et al. (1995) illustrate cost-based valuation. They estimate nutrient removal by wetlands and use Army Corps engineering cost data to calculate the per-acre cost of achieving equivalent wastewater treatment through constructed filtration systems. The avoided treatment cost per acre is interpreted as the value of wetlands' water purification services. Hein et al. (2006) estimate recreational values using revealed preferences based on travel costs. Combining survey data on visitation rates with estimated transportation and time costs, they recover a demand function for wetland recreation and compute consumer surplus per visit.

Meta-analyses synthesizing this literature provide a useful, albeit imperfect, benchmark for the value of flood mitigation as a proportion of total wetland ecosystem service value (Brouwer et al. 1999; De Groot et al. 2012; Brander et al. 2013; Bilkovic et al. 2025). These meta-analyses compile monetary value estimates from underlying primary studies and standardize them to common, inflation-adjusted per-hectare annual values, treating each reported valuation estimate as an observation. For a given ecosystem service (e.g., flood control), they compute the mean value across observations in which that service is identified as being provided.

A key challenge in estimating the broader ecosystem service costs of wetland loss is monetization. Biophysical ecosystem service models such as InVEST (Tallis and Polasky 2009) can map ecosystem services at fine spatial resolution, but their outputs are typically expressed in physical units (e.g., avoided runoff or nutrient retention), requiring additional assumptions to convert them into dollar values. Because our welfare analysis requires monetized estimates that are comparable across ecosystem services and scalable to a national analysis, we instead rely on meta-analyses that aggregate valuation evidence across many settings. While this approach abstracts from spatial heterogeneity in ecosystem service provision, it is suited to our setting, which studies policy changes affecting wetlands across the entire United States rather than a specific wetland system where detailed site-level ecological modeling would be more informative.

We leave some meta-analyses of wetland valuation studies out of consideration, such as Woodward and Wui (2001), Brander et al. (2006), Ghermandi et al. (2010), He et al. (2015), and Moeltner et al. (2019). These studies estimate meta-regressions of wetland value but do not report mean value breakdowns by ecosystem service. The 2022 EPA WOTUS Economic Analysis (U.S. EPA and U.S. Army Corps of Engineers 2022) adopts a related meta-analytic framework, using meta-regression estimates to predict willingness-to-pay per acre of wetlands for policy-relevant changes in wetland provision. However, the WTP measure reflects average household welfare gains from wetland preservation or expansion, not the marginal value of a specific ecosystem service such as flood control. We describe the four meta-analyses considered below.

Brouwer et al. (1999) restrict attention to contingent valuation studies and analyze four services: flood control, water generation, water quality, and biodiversity. Mean willingness-to-pay estimates imply that flood control accounts for approximately 38% of total ecosystem service benefits in their sample. However, the study relies exclusively on stated preference methods and draws from a relatively early literature.

De Groot et al. (2012) aggregate ecosystem service value estimates from all studies included in the Ecosystem Services Valuation Database (ESVD) at the time of their analysis. They report mean per-hectare annual values separately for coastal and inland wetlands, with disturbance regulation serving as the closest proxy for flood mitigation. However, these mean estimates are highly sensitive to a small number of extreme observations. In particular, the wastewater treatment category accounts for approximately 84% of total reported coastal wetland value, but this share falls to roughly 12% after removing two clear outliers—one nearly two orders of magnitude larger and another roughly three orders of magnitude smaller than the mean wastewater treatment value calculated without them. After excluding these observations, flood control accounts for approximately 15% of total coastal wetland ecosystem service value (and about 12% for inland wetlands).

Brander et al. (2013) critique earlier meta-analyses for including overly broad sets of ecosystem services that may interact or offset one another. To address this tradeoff, they focus on only three regulating services—flood control, water supply, and water quality (via nutrient recycling)—and restrict their sample to agricultural wetlands. Their estimates imply that flood control accounts for approximately 43% of total wetland value in agricultural landscapes.

Bilkovic et al. (2025) synthesize coastal wetland studies to conduct a site-specific benefit transfer, averaging normalized ecosystem service values and adjusting them to local geospatial characteristics. Although this context-specific approach limits external validity, it may produce more internally consistent service comparisons. In their estimates, storm risk reduction—closely analogous to flood mitigation—accounts for approximately 55% of total coastal wetland ecosystem service value across storm risk reduction, fish habitat, nutrient removal, carbon storage, and fishing benefits.

Table A6 reports, for each meta-analysis, the mean value of each ecosystem service as a proportion of the sum of mean service values within that study. Because each meta-analysis applies different inclusion criteria, estimates vary substantially. Across studies, the simple average flood-mitigation share is approximately 37%; weighting by number of studies yields roughly 30%, and weighting by number of observations yields approximately 25%.

Despite substantial heterogeneity in valuation methods and ecological settings, the meta-analytic evidence consistently suggests that flood mitigation is among the most economically important services provided by wetlands. Under a conservative assumption that flood control represents roughly 25% of total wetland value, property value gains from wetland deregulation exceed associated ecosystem service losses in most scenarios considered in this paper.

A further, distinct caveat concerns the type of land to which our benefit and cost measures apply. Our land-value estimates reflect deregulation of water resources as measured by the National Wetlands Inventory, a category that includes wetlands together with lakes, ponds, rivers, and streams, including the ephemeral streams that NWPR specifically deregulated. The flood-mitigation values we use, by contrast, are estimated per acre of wetland and applied only to the change in wetland area following an AJD (Table A5). Our reported flood-mitigation cost therefore omits any increase in flood damages from deregulating non-wetland water resources such as ephemeral streams. Together with the fact that flood mitigation accounts for only a portion of wetlands' total ecosystem-service value, this implies that the cost we measure is best interpreted as a lower bound on the full ecosystem-service consequences of NWPR, and the benefit-cost ratios in Table 4 as upper bounds.

B.6 Marginal Value of Public Funds

One could ask how CWA deregulation affects government revenue. This question is important for calculating the marginal value of public funds (Hahn et al. forthcoming). It is also important for scoring government legislation like the PERMIT Act, which passed the U.S. House in December 2025. The Congressional Budget Office (CBO) is evaluating how to estimate the effects of that Act on investment and government revenue. NWPR decreased the set of waters regulated under the CWA, so likely decreased the number of individual and nationwide permits required for development. These permits require modest fees and staff effort from regulatory agencies. In line with most environmental research on regulations that are not subsidies, we do not directly report the marginal value of public funds. The CBO could use a version of this logic to model effects of Clean Water Act regulation on investment and government revenue.

C Algorithms and Econometrics

C.1 Algorithms: probabilities of regulation

As Section 3 discusses, we use a machine learning algorithm to estimate property-level probabilities of regulation under both *Rapanos* and NWPR. We employ a ridge regression with close connections to Greenhill et al. 2024. It is trained and evaluated on the same sample of AJDs used in our analysis of regulatory stringency.

The algorithm is trained to predict regulatory status. Specifically, the outcome is a binary indicator equal to one if USACE determined that the site is regulated by Section 404. The predictors include a set of local geophysical and administrative characteristics: the share of a 100-meter radius around the site centroid covered by each NWI class (e.g. freshwater emergent wetland, estuarine and marine wetland, riverine, lake, etc.) (U.S. Fish & Wildlife Service 2025), stream classification and flow measures from the National Hydrography Database (U.S. EPA 2015), elevation from USGS (U.S. Geological Survey 2022), soil characteristics from the Gridded National Soil Survey Database (U.S. Department of Agriculture 2023), climate measures from PRISM (PRISM Climate Group 2025), land cover from NLCD (U.S. Geological Survey 2024), USACE administrative districts (U.S. Army Corps of Engineers 2016), satellite imagery embeddings from AlphaEarth Foundations,[27] and an indicator for whether NWPR was in force at the time of the determination.

The algorithm is trained on 80% of the AJD observations and evaluated on a spatially held-out test set of 20% of observations. Specifically, we assign train/test on a 0.1 degree grid.

To prevent spatial leakage, we group data so AJDs in the same project or with geographically overlapping footprints are in the same fold. AJDs in the same project are evaluated by the same USACE engineer at the same time, so have correlated outcomes. Grouping by aerial imagery footprint ensures the test set does not partially include images and other input layers used to train the model.

The model achieves 79% accuracy at predicting regulatory status on the held-out test set. Accuracy is comparable for determinations made under *Rapanos* (78%) and NWPR (81%).

The algorithm outputs a continuous score between 0 and 1, which is well-calibrated to probabilities of regulation. For example, when the algorithm outputs a score between 0.3 and 0.4 for test-set AJDs, 34% of those AJDs are regulated. When it outputs a score between 0.9 and 1, 96% of those AJDs are jurisdictional. Hence, following Greenhill et al. (2024), we interpret the scores as probabilities of regulation.

The probabilities of regulation among the AJDs are shown in the left column of Figure A5. The top row corresponds to the probability of regulation under the rule in force at the time of the determination. The mean probability of regulation is 0.31. The second row plots the site-level probabilities if all AJDs were decided under *Rapanos*, p_{iR}. The third row shows the site-level probabilities if all decisions were made under NWPR, p_{iN}. As expected, the probabilities of regulation tend to be higher under *Rapanos* (mean = 0.37) than under NWPR (mean = 0.26). The fourth row shows the site-level change in probability of regulation when moving from *Rapanos* to NWPR, which we define as Estimated deregulation $= p_{iR} - p_{iN}$. Most sites (>80%) are predicted to have lower probabilities of regulation under NWPR, with a mean estimated deregulation of 0.11.

While Greenhill et al. (2024) use a Convolution Neural Network (CNN) to predict regulatory probabilities, we find that a ridge regression with two-way interactions between features achieves comparable accuracy and can be deployed at fraction of the computational

[27] Imagery embeddings are for 2017.

cost, allowing us to apply this procedure to our sample of millions of real estate transactions.

Moreover, the ridge regression model is better suited to our downstream application of estimating the impact of NWPR deregulation on property values. We rely on detecting sharp changes in the probability of regulation at the time NWPR was implemented. We use an event study to test the two models' ability to detect these sharp changes:

$$Y_{id} = \alpha p_{iR} + \sum_{\tau} \Big(\beta_\tau \left(p_{iR} - p_{iN} \right) \mathbb{1}[q_q = \tau] + \gamma_\tau \mathbb{1}[q_q = \tau] \Big) + \delta_d + \epsilon_{id} \tag{11}$$

where Y_{id} is the true regulatory status (AJD outcome) for site i in district d. p_{iR} is the probability of regulation under *Rapanos*, and p_{iN} is the probability of regulation under NWPR. The term $\mathbb{1}[q_q = \tau]$ is an indicator function for whether the AJD was determined in year-quarter τ. δ_d are USACE district fixed effects. The error term is ϵ_{id}.

Equation (11) allows us to estimate the relationship between the predicted change in probability of regulation under NWPR and actual regulatory outcomes. If the model were perfect, the β_τ terms would be 0 in year-quarters when NWPR was not in force (because the p_{iR} term would fully absorb the relationship between regulatory status and predicted probabilities) and would equal 1 when NWPR was in force.

Figure A4 shows the resulting event study graphs for the probabilities of regulation generated using our tabular ridge regression model (panel A) and the WOTUS-ML model used in Greenhill et al. 2024 (panel B). We find that the Greenhill et al. (2024) CNN model and our ridge regression have the same accuracy at predicted regulatory status (79%), and the tabular model employed in this paper is better able to detect sharp changes in regulatory status at the time NWPR was implemented.

C.2 Algorithms: fair market value for non-residential properties

Estimating the impact of the NWPR on non-residential property values requires an estimate of the aggregate fair market value of all non-residential properties in the United States. Although administrative assessor records provide assessed values for the near-universe of non-residential properties, many properties have not transacted recently, and thus lack an observable sales price. Moreover, transacted properties are not representative of the full stock of non-residential properties: they tend to be smaller (16.5 vs. 27 acres on average), have higher value per acre, and may differ systematically in ways that affect the relationship between assessed and market values. We therefore develop a machine learning model to impute transaction prices for all non-residential properties in the United States.

Rather than applying a uniform price-to-assessed ratio or restricting analysis to transacted properties, we develop a random forest model to impute transaction prices for all non-residential properties. This approach captures heterogeneity in the relationship between assessed and market values across property types, locations, and assessment regimes, addressing a fundamental challenge in land economics: assessed values from administrative records provide comprehensive coverage but systematically diverge from market prices (Dray et al. 2023) due to variation in assessment practices (Chen and Cohen 2024), infrequent reappraisal cycles (Hou et al. 2025), and assessment ratio heterogeneity across jurisdictions (Avenancio-León and Howard 2022).

We train the model using our primary estimation dataset of 4.5 million non-residential properties that have both a recent arm's-length transaction (2017–2023) and corresponding CoreLogic assessor characteristics. The outcome variable is the observed sales price. Predictor variables include assessed value, assessment year, property acreage, land-use category, and county fixed effects. To produce a consistent estimate of fair market value across properties, we generate predictions under the assumption that all properties transact in 2021.

The model is trained on 80% of the sample and evaluated on a 20% held-out test set. We assess performance using (i) property-level predictive accuracy, measured by the R-squared between observed and predicted sales prices, and (ii) accuracy in predicting the aggregate sales value of all properties in the test set, which is the quantity relevant for our NWPR cost analysis.

Our best-performing model achieves an R-squared of 0.57 on the test set of 566,983 transactions and predicts the total sales value to within 2.7% of the observed aggregate ($299 billion predicted vs. $291 billion observed). Because property values are heavily right-skewed, it is not obvious a priori whether the outcome should be modeled in levels, logs, price per acre, or log price per acre. We estimate all four variants and find that the levels-based specification delivers superior predictive performance on both metrics.

While the property-level R-squared reflects the inherent heterogeneity of non-residential assets, the low aggregate error suggests that prediction errors are approximately symmetric and cancel in aggregation. For the purpose of estimating total market value, this portfolio-level accuracy is the relevant metric.

To facilitate comparison with other approaches, we also evaluate how well the levels-based model recovers related transformations of the outcome (Figure A7). For instance, when we compute price-per-acre predictions implied by our preferred model, it attains an R-squared of 0.78, exceeding the performance of models reported in Nolte (2020), which range from 0.08 to 0.72.

Importantly, the ratio of transaction value to assessed value differs widely across states and counties. This is driven by explicit differences in assessment policies in different states (e.g., Louisiana requires commercial properties to be assessed at 15% of market value, Mississippi at 15% of true value, Alabama at 20% of fair market value, and Arizona at 18% of full cash value), across land-use types, and variation in the time between the most recent assessment and the transaction date. Our model is designed to help recover these heterogeneous ratios (Figure A6) because the spatial distribution of transacted non-residential properties differs from that of all non-residential properties.

One potential concern is "sales chasing," whereby assessors update assessed values following a transaction to reflect the sale price. This could inflate the correlation between assessed values and prices in the training sample of transacted properties. However, our model includes assessment year as a predictor, allowing it to account for the recency of assessments, and the strong out-of-sample performance on held-out transactions suggests the relationship generalizes beyond recently reassessed properties.

On aggregate, we estimate that the value of non-residential properties in the U.S. is \$15.39 trillion, or 2.48 times the assessed value (\$6.20 trillion) of this sample—implying that assessments capture less than half of market value on average. Yet this headline price-to-assessed ratio overlooks the extreme heterogeneity across space (Figure A6) and land use category (Table A3). The ratio is lower for commercial and industrial properties and higher for vacant and agricultural properties.

As external validation, our estimate for agricultural properties is \$3.85 trillion, which somewhat aligns with the USDA's estimate of U.S. farm real estate value of \$3.4 trillion (USDA National Agricultural Statistics Service 2024).

As a public good, we release county-level estimates of price-to-assessed value ratios for non-residential properties, stratified by land use type. These ratios address a practical challenge for applied economists: while assessed values are available for the near-universe of U.S. properties, transaction prices are limited to recorded sale events. Our ratios enable researchers to convert time-varying assessed values to estimated market values for applications including environmental amenity capitalization studies (Keiser and Shapiro 2019), property tax equity research (Avenancio-León and Howard 2022), construction of wealth estimates (Dray et al. 2023), and conservation cost estimation (Nolte 2020; Bahrami et al. 2025). Our county-level ratios provide a transparent, externally validated tool for such imputations.

C.3 Econometrics: Extensions and Sensitivity Analyses

We report several other sensitivity analyses. One repeats the event study equation (4) with an extended sample of property transactions back to 2010.

Another uses a semi-parametric binned regression that allows the effect of NWPR on property values to vary nonlinearly with the extent to which NWPR deregulates a property, measured by either the wetland map or algorithm:

$$\ln(P_{izct}) = \sum_m \beta_m \mathbb{1}[W_i \in m] + X'_{izt}\gamma_1^B + (N_t X_{izt})'\gamma_2^B + \eta_{zt}^B + \varepsilon_{izt} \tag{12}$$

$$\begin{aligned}\ln(P_{izct}) = \sum_m \Big(&\alpha_{1m}\mathbb{1}[p_{iR} \in m] + \alpha_{2m}\mathbb{1}[p_{iN} \in m] + \beta_m^N \mathbb{1}[p_{it} \in m]\Big) \\ &+ X'_{izt}\gamma_1^N + (N_t X_{izt})'\gamma_2^N + \eta_{zt}^N + \varepsilon_{izt}^N\end{aligned} \tag{13}$$

Here the indicator $\mathbb{1}[W_i \in m]$ equals one if property i's water resource share at the time of sale is in bin m. We use ten bins of width 0.1, ranging from 0 to 1, then graph the coefficients β_m. In equation (13), the indicators $\mathbb{1}[p_{it} \in m]$, $\mathbb{1}[p_{iR} \in m]$, and $\mathbb{1}[p_{iN} \in m]$ equal one if property i's probability of regulation at time t, its probability under *Rapanos*, and its probability under NWPR are in bin m. We graph the coefficients β_m^N, which represent the effect of having regulatory probability m on log land values. The semi-parametric analysis sheds some light on the marginal effect of deregulation at different levels of wetland concentration or at different probabilities of regulation.

Another sensitivity analysis tests whether the effects of NWPR vary with a property's distance to the nearest wetland. We conduct this test with the following equation:

$$\ln(P_{izct}) = \sum_{m\neq 10} \beta_m\, 1[D_i \in m] + \sum_{m\neq 10} \gamma_m\, 1[D_i \in m] \cdot N_t + X'_{izt}\delta_1 + (N_t X_{izt})'\delta_2 + \eta_{zt} + \varepsilon_{izct} \tag{14}$$

where $1[D_i \in m]$ equals one if property i's distance to the nearest wetland is in bin m. The tenth bin, i.e., the greatest distance decile, is omitted. The bin coefficients allow us to assess potential spillovers from reallocation of demand from non-wetland properties to wetland properties.

Additionally, we estimate the effects of NWPR on log property values for different sub-categories of non-residential land use. Appendix B.1 discusses land use subcategories observed in the CoreLogic data.

Finally, we test for confounding from the COVID housing boom by measuring whether NWPR disproportionately affected non-residential property values in areas that had an above-median trend break in residential property values in March 2020:

$$\begin{aligned}\ln(P_{izct}) = \kappa W_i C_z N_t + X_i' \gamma_1^C + \alpha W_i + \rho C_z + \phi W_i C_z + \beta W_i N_t + \psi C_z N_t \\ + (N_t X_i)' \gamma_2^C + \eta_{zt}^C + \varepsilon_{izct}^C\end{aligned} \tag{15}$$

Here C_z represents the March 2020 trend break in residential property values in zip code z and other variables are as defined above. The coefficient κ tests whether wetland properties appreciated more under NWPR in areas that had a residential home price boom. The comparison group is wetland properties under NWPR in non-COVID-boom areas.

We also note here that our approach to estimating the effect of NWPR on land values differs from the approach taken by Greenhill et al. 2024, who estimate the value of all land that NWPR deregulated. The Greenhill et al. (2024) calculation combines residential and non-residential land, counts whether a property had the probability of jurisdiction change from above to below 50% (by not how extensively each property was deregulated), and uses an estimate of the fair market value of vacant land from Nolte 2020. Our estimate reflects the *change* in land values that we estimate NWPR caused, which is a related, but different object.

C.4 Econometrics: Alternative Specifications

Regulation

We also use the algorithm to assess how NWPR affected regulation:

$$Y_{ict} = \beta(p_{iR} - p_{iN})N_{it} + \alpha_1 p_{iR} + \alpha_2 p_{iN} + \gamma N_{it} + \varepsilon_{ict} \tag{16}$$

Here Y and N are as in (1). The algorithm estimates the probabilities p_{iR} and p_{iN} that *Rapanos* and NWPR regulate site i. The term $p_{iR} - p_{iN}$ equals the algorithmically-estimated deregulation between *Rapanos* and NWPR. For example, a site with $p_{iR} - p_{iN} = 0.2$ has 20% lower estimated probability of regulation under NWPR than under *Rapanos*. We estimate equation (16) on a held-out test set of AJDs excluded from model training.

The coefficients in equation (16) have simple interpretations. The term α_1 represents the relationship between algorithmically-estimated probability of regulation and true regulation under *Rapanos*. With a perfect algorithm and large sample, $\alpha_1 \approx 1$. Also, α_2 represents the effect of a site's probability of regulation under NWPR on its actual regulation under *Rapanos*; we expect $\alpha_2 \approx 0$. The parameter β represents the relationship between algorithmic estimates of the difference in jurisdiction between *Rapanos* and NWPR and the actual difference in jurisdiction. We expect $\beta \approx -1$.[28]

Land Values

We estimate analogous results that use the algorithmic estimate of regulatory probabilities rather than the wetland map to proxy jurisdiction:

$$\ln(P_{izct}) = \beta^A (p_{iR} - p_{iN}) N_t + \alpha_1 p_{iR} + \alpha_2 p_{iN} + X_i' \gamma_1^A + (N_t X_i)' \gamma_2^A + \eta_{zt}^A + \varepsilon_{izct}^A \tag{17}$$

Here $p_{iR} - p_{iN}$ is as in (16), we control for the probabilities of regulation p_{iR} and p_{iN} under *Rapanos* and NWPR. As in equation (2) we add property-level observable characteristics (X_{izt}) and zip × year × month fixed effects η_{zt}^A. The coefficient β^A represents the effect of deregulation on property values. Finding $\beta^A > 0$ would imply that deregulation increases property values. Since we expect NWPR to deregulate most properties (i.e., $p_{iR} - p_{iN} > 0$), finding $\beta^A > 0$ would imply that NWPR increased property values for the properties it deregulated.

We note that equation (17) is equivalent to

$$\ln(P_{izct}) = \tilde{\alpha}_1 p_{iR} + \alpha_2 p_{iN} - \beta^A p_{it} + X_i' \gamma_1^A + (N_t X_i)' \gamma_2^A + \eta_{zt}^A + \varepsilon_{izct}^A \tag{18}$$

[28] Because the dependent variable Y_{ict} is regulation while $p_{iR} - p_{iN}$ is estimated deregulation, the two should be negatively related. If the algorithm perfectly measures the change in regulatory status between *Rapanos* and NWPR, this relationship will be one-to-one, implying $\beta \approx -1$.

where $p_{it} \equiv p_{iR}(1 - N_t) + p_{iN} N_t$ represents the probability of regulation at the time of the property transaction, and $\tilde{\alpha}_1 = \alpha_1 + \beta^A$ with α_1 as in equation (17). Equation (18) allows the simple interpretation that $-\beta^A$ is the effect of regulation on property values, so that $\beta^A > 0$ implies regulation reduces property values.

We also use the algorithm to report an event study analysis of how NWPR affects log property values:

$$\ln(P_{izcqt}) = \sum_{\tau} \Big(\beta_\tau \mathbb{1}[q_q = \tau](p_{iR} - p_{iN}) + (\mathbb{1}[q_q = \tau] X_i)' \gamma_\tau \Big) + \alpha_1 p_{iR} + \alpha_2 p_{iN} + \eta_{zt} + \varepsilon_{izcqt} \quad (19)$$

Land Use

We use the following alternate version of the event study second stage equation (6) to estimate NWPR's land use impacts:

$$\delta_{ict} = \sum_{\tau} \Big(\alpha_\tau + \beta_\tau \, D_i + \gamma_\tau \, (p_{iR} - p_{iN}) \Big) \, \mathbb{1}[t = \tau] \; + \; \varepsilon_{ict} \quad (20)$$

$\delta_{ict} \equiv L_{ict} - \hat{L}(0)_{ict}$, where L_{ict} is the share of a given land use (developed or wetland) within a 100m radius of site i in commuting zone c in year t, and $\hat{L}(0)_{ict}$ is the estimated counterfactual from the first stage equation (5). D_i equals 1 if AJD i is nonjurisdictional and 0 if AJD i is jurisdictional. $p_{iR} - p_{iN}$ is the algorithmically-estimated deregulation between *Rapanos* and NWPR. The event year indicators $\tau \in \{-11, -10, \ldots, -3, -2, 0, 1, 2, 3, 4\}$ omit $\tau = -1$ as the reference period. Point estimates and 95% confidence intervals are shown in Figure A13.

We also use the following analogous extension of the richest specification of equation (8):

$$\begin{aligned} \delta_{ict} = & \alpha \mathbb{1}[t \geq E_i] + \beta \, D_i \mathbb{1}[t \geq E_i] + \gamma \, (p_{iR} - p_{iN}) \, \mathbb{1}[t \geq E_i] \\ & + \phi\tau + \psi\tau \mathbb{1}[t \geq E_i] + \mu\tau D_i + \nu\tau D_i \mathbb{1}[t \geq E_i] + \varepsilon_{ict} \end{aligned} \quad (21)$$

which replaces W_i in equation (8) with $p_{iR} - p_{iN}$ and allows for differential pre-trends and differential trend breaks by regulation status.

C.5 Econometrics: Land Market Impacts

The main analysis investigates how NWPR changes land market outcomes for all properties by using the wetland map or algorithm to determine changes in jurisdiction. We considered an alternative analysis which investigates changes in property values for only properties with an AJD. Our investigation of this alternative analysis found that only about 200 properties had a transaction before and after an AJD. The main text focuses on all properties rather than only properties with an AJD because this severely limited sample size lacks statistical power to permit an informative analysis of the CWA's impacts on land markets.

C.6 Econometrics: Correcting for Measurement Error in Algorithmic Predictions of Regulation

Our algorithmic model uses predictions of Clean Water Act jurisdiction to measure the change in regulation under NWPR. Because these predictions are generated by a machine learning model rather than directly observed, they may contain systematic measurement error. When such predicted variables are used in downstream regressions, measurement error can bias both coefficient estimates and associated measures of uncertainty. In particular, machine learning predictions often exhibit structured errors, such as mean reversion or differential measurement error, that can lead to biased parameter recovery if the predicted variable is treated as observed without correction (Proctor et al. 2023).

To address this issue, we implement the multiple imputation correction procedure proposed by Proctor et al. 2023. We construct a calibration sample using properties for which we observe both the algorithmic predictions of regulation and the true regulatory status from AJDs. Because the regulatory criteria differ under the Rapanos and NWPR rules, we estimate separate calibration models for each rule. Specifically, we estimate linear models of the form

$$Y_i = \alpha + \beta\,\widehat{p}_i + \gamma Z + \varepsilon \tag{22}$$

where Y_i is the observed regulatory status under either *Rapanos* or NWPR for property i, $\widehat{p}_i$ is the algorithmic prediction of regulation under the same rule, and Z_i is the residualized outcome variable (log property value after removing zip-year-month fixed effects). Including the residualized outcome addresses differential measurement error that may correlate with the regression outcome.

The estimated coefficients and covariance matrix from each calibration regression summarize the joint distribution of the true and predicted regulatory variables. We generate $M = 30$ draws of the true regulatory variable using the calibration model. For each draw m, we sample a coefficient vector from the estimated multivariate normal distribution of the calibration parameters and use it to construct imputed values of regulatory status for every property in the main analysis sample. These imputations yield alternative predicted regulatory probabilities under both rules for each observation, and from these values we compute the corresponding change in regulation under NWPR for each imputation.

Then, for each imputed dataset m, we re-estimate equation 17 using the imputed regulatory change. This produces a set of M estimates of the coefficient of interest. We combine these estimates using Rubin's rules, which account for both within-imputation sampling variance and between-imputation variation across imputations.

The corrected estimate of the effect of NWPR deregulation on log property values is 0.314 (se = 0.079), compared to 0.341 (se = 0.157) in the baseline specification that directly uses the algorithmic prediction of regulatory status. The corrected coefficient therefore lies well within one standard error of the baseline estimate and is slightly larger in magnitude. Importantly, despite the larger standard error produced by the correction procedure, the estimate remains statistically different from zero at the 5 percent level.

The increase in the standard error is expected. The multiple-imputation procedure accounts for two additional sources of uncertainty that are ignored when the predicted regulatory variable is treated as observed: (i) sampling uncertainty in the calibration model that links the algorithmic prediction to the true regulatory status, and (ii) measurement error in the predicted treatment variable itself. As shown by Proctor et al. (2023), ignoring these sources of uncertainty can lead to biased parameter estimates and overstated statistical precision when predicted variables are used in regression analysis.

In principle, measurement error in the predicted regulatory variable could bias the estimated treatment effect in either direction. Classical measurement error in a treatment variable would tend to attenuate coefficients toward zero, while differential measurement error—errors correlated with the outcome or other regressors—could lead to either attenuation or exaggeration of the estimated effect. The multiple-imputation procedure corrects for both sources of bias by using the calibration sample to recover the joint distribution of the true and predicted variables and propagating that uncertainty into the second-stage regression.

Notably, the calibration sample used to estimate the correction is relatively small. For each rule, we observe fewer than 5,000 observations in which both the true regulatory status (from an AJD) and a property transaction are available. Because the precision of the calibration model depends on the size of this sample, the resulting correction represents a conservative test of robustness. Even under this limited calibration sample, the corrected estimate remains similar in magnitude to the baseline result and statistically significant. Taken together, these findings indicate that our estimates of the effect of Clean Water Act deregulation on property values are robust to potential biases arising from measurement error in the machine-learned treatment variable.

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Figure A1: Examples of Semi-Dry Wetlands

(A) Isolated Wetland

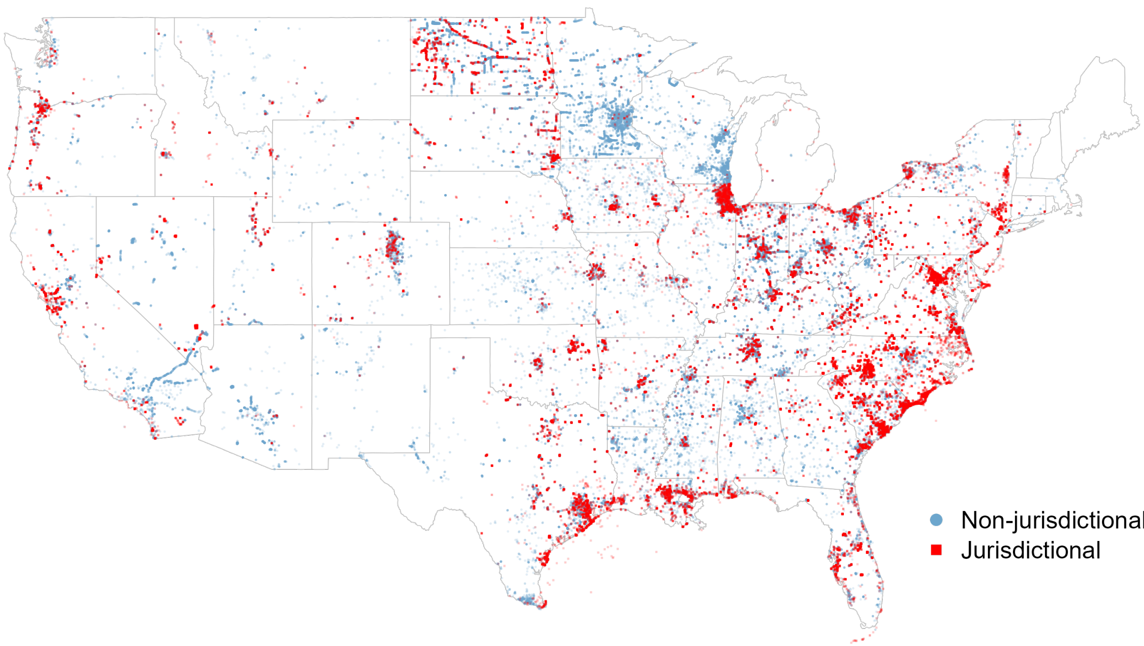
(B) Google Data Center

(C) Moapa Solar Project Satellite Image

(D) Moapa Solar Project Development

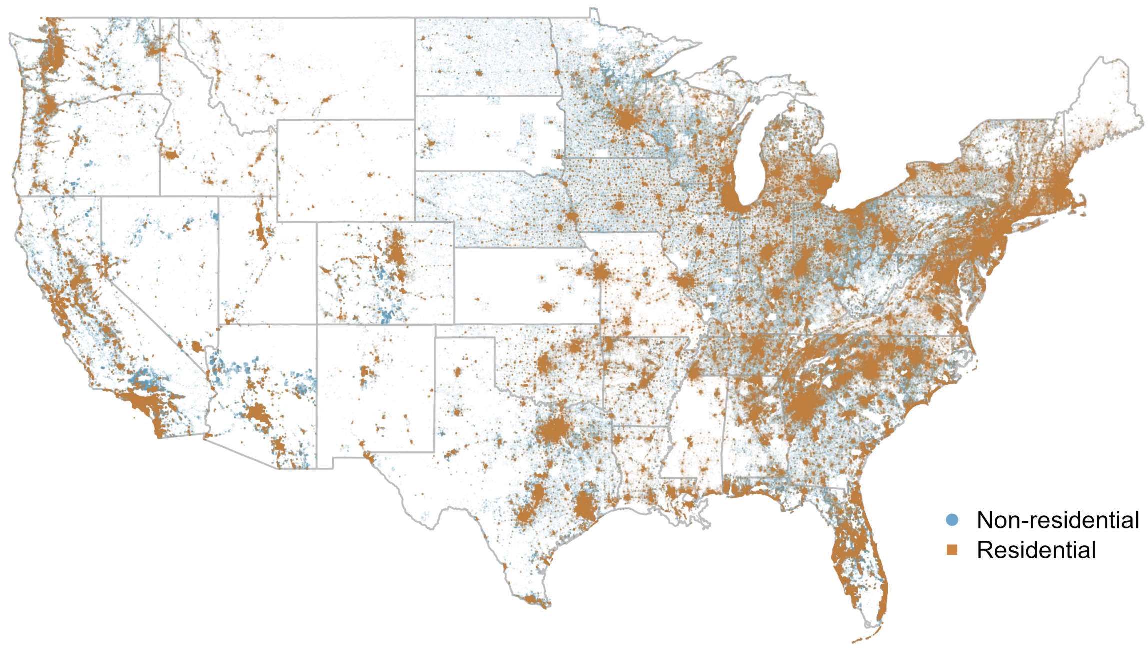
Notes: Panel A shows an isolated wetland (Wetlands Professional n.d.). Panel B shows a Google data center constructed on an isolated wetland (Google Earth n.d.). Panel C shows a satellite image of the land surrounding the Moapa Southern Paiute Solar Project (Google Maps n.d.). Panel D shows a snapshot of Moapa Solar Project development (Google Earth n.d.).

Figure A2: Locations and Outcomes of Approved Jurisdictional Determinations



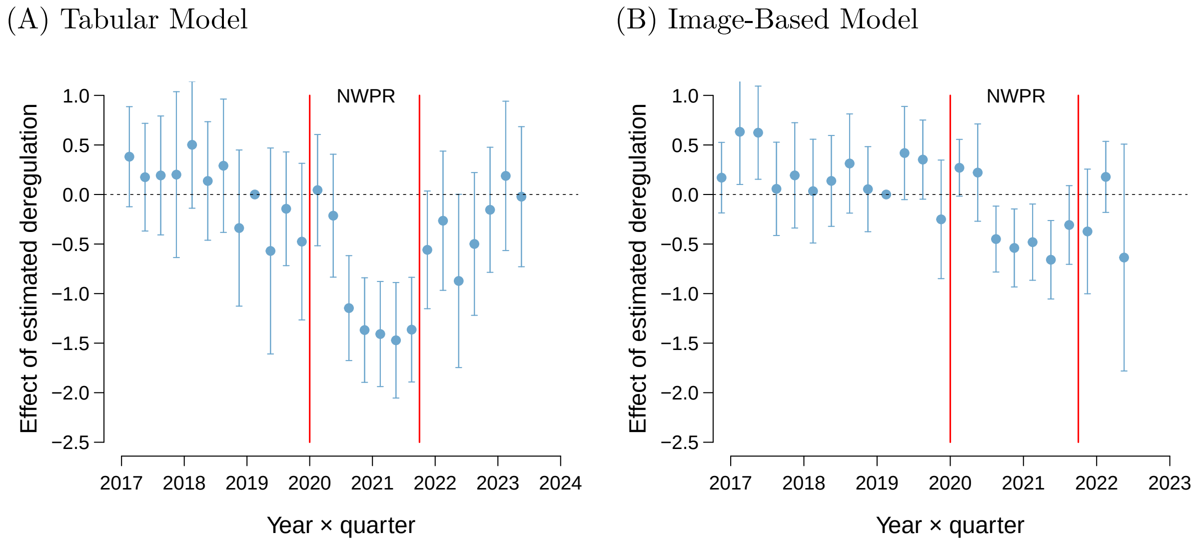
Notes: Map shows the Contiguous United States overlaid with the locations and outcomes of approved jurisdictional determinations (AJDs). Blue dots show non-jurisdictional sites (N = 97,606). Red squares show jurisdictional sites (N = 45,367). Jurisdictional sites are plotted on top of non-jurisdictional sites with a high degree of transparency.

Figure A3: Transaction Locations from CoreLogic



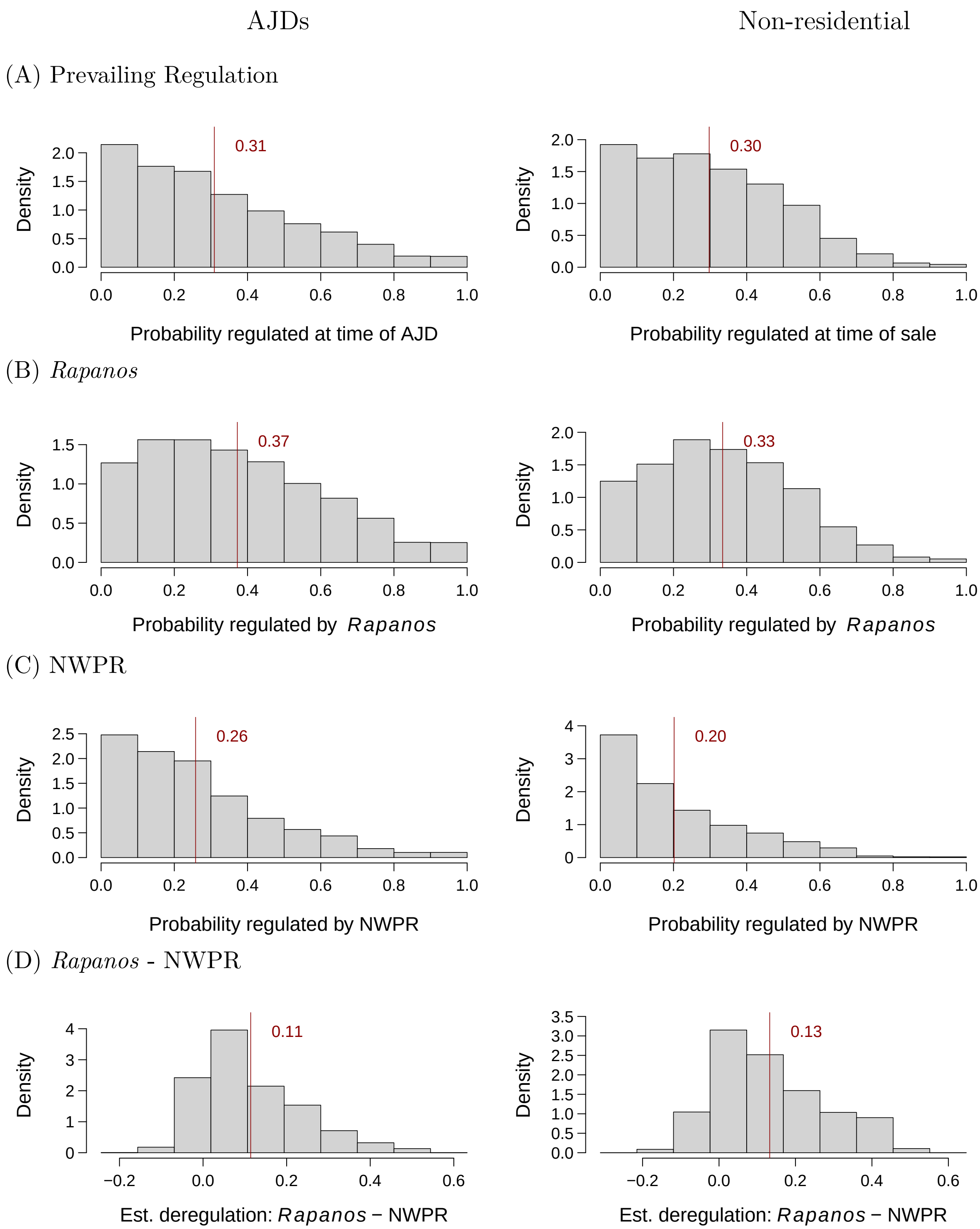
Notes: Map shows the Contiguous United States overlaid with the locations of CoreLogic non-residential and residential transactions from our analysis sample. Blue dots are non-residential properties (N = 4,470,365). Tan squares are residential properties (N = 6,918,722). Residential properties are plotted on top of non-residential properties with a high degree of transparency.

Figure A4: Algorithm for Predictions of Changes in the Probability of Regulation



Notes: NWPR is the Navigable Waters Protection Rule. Graphs show the effect of estimated deregulation $= p_{iR} - p_{iN}$ on jurisdiction, following equation (11). The graphs use approved jurisdictional determinations (AJDs). The outcome is an indicator for whether a site is regulated. We estimate a coefficient (blue circles) for each year×quarter, where the first quarter of 2017 is used as the reference category. Blue bars show 95% confidence intervals for standard errors clustered at the USACE district level. Panel A uses the predicted probabilities of regulation from the algorithm from Section 4.1. Panel B uses the predicted probabilities from Greenhill et al. (2024). Appendix C.1 discusses details of each model.

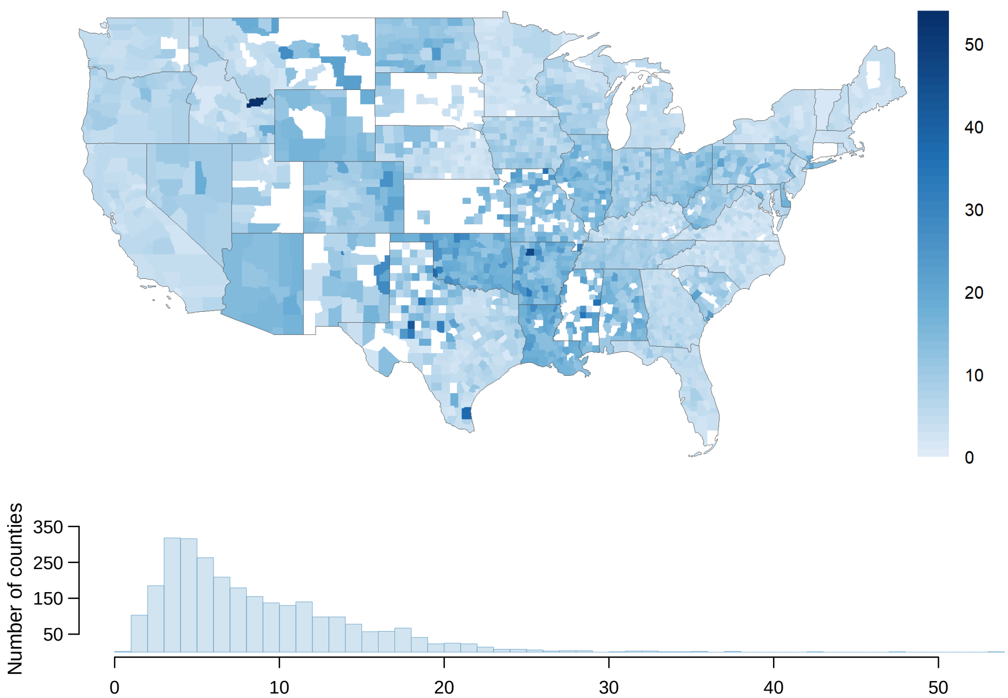
Figure A5: Predicted Probabilities of Regulation, by Sample



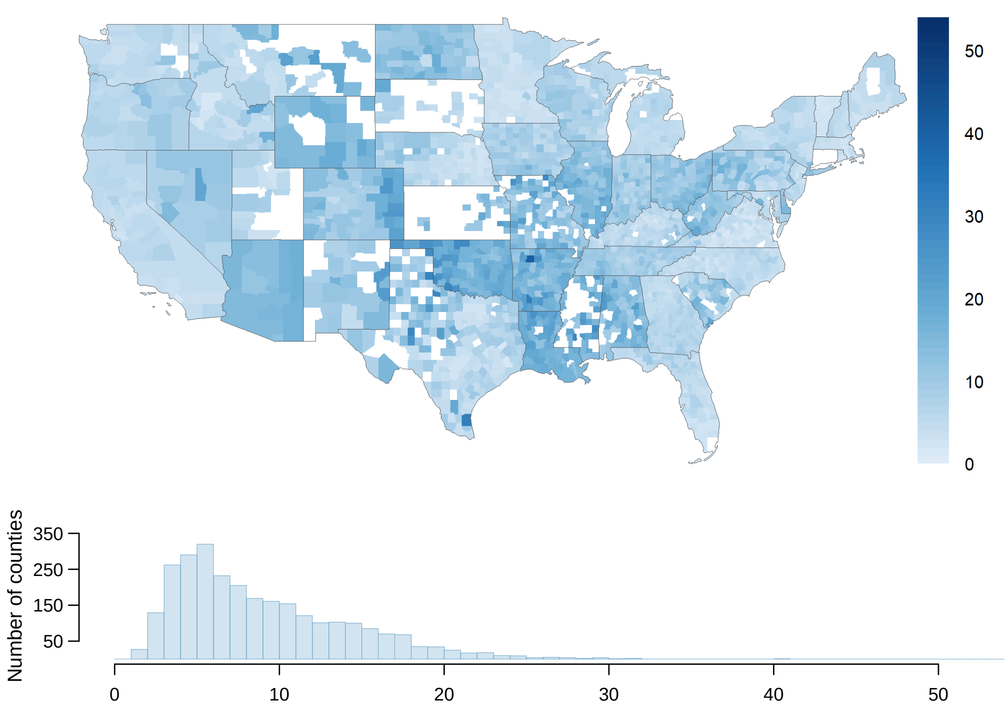
Notes: NWPR is the Navigable Waters Protection Rule. Predicted probabilities of regulation are from the algorithm described in Section 4.1. Panel A shows the probabilities under the rule in force at the time of the approved jurisdictional determination (AJD) or property sale. Panel B shows the probabilities under *Rapanos* (p_{iR}). Panel C shows the probabilities under NWPR (p_{iN}). Panel D shows the algorithmically-estimated deregulation ($p_{iR} - p_{iN}$). The first column shows probabilities among AJDs, and the second column shows probabilities among non-residential property transactions.

Figure A6: Ratio of Mean Sales Price to Assessed Value, by County

(A) Observed ratio of price to assessed value



(B) Ratio of predicted price to assessed value



Notes: Graphs show the ratio of sales price to assessed values in each county, as computed in our analysis sample of non-residential properties. Panel A shows the observed ratios. Panel B shows the ratios predicted using a random forest (Section 4.2 and Appendix C.2).

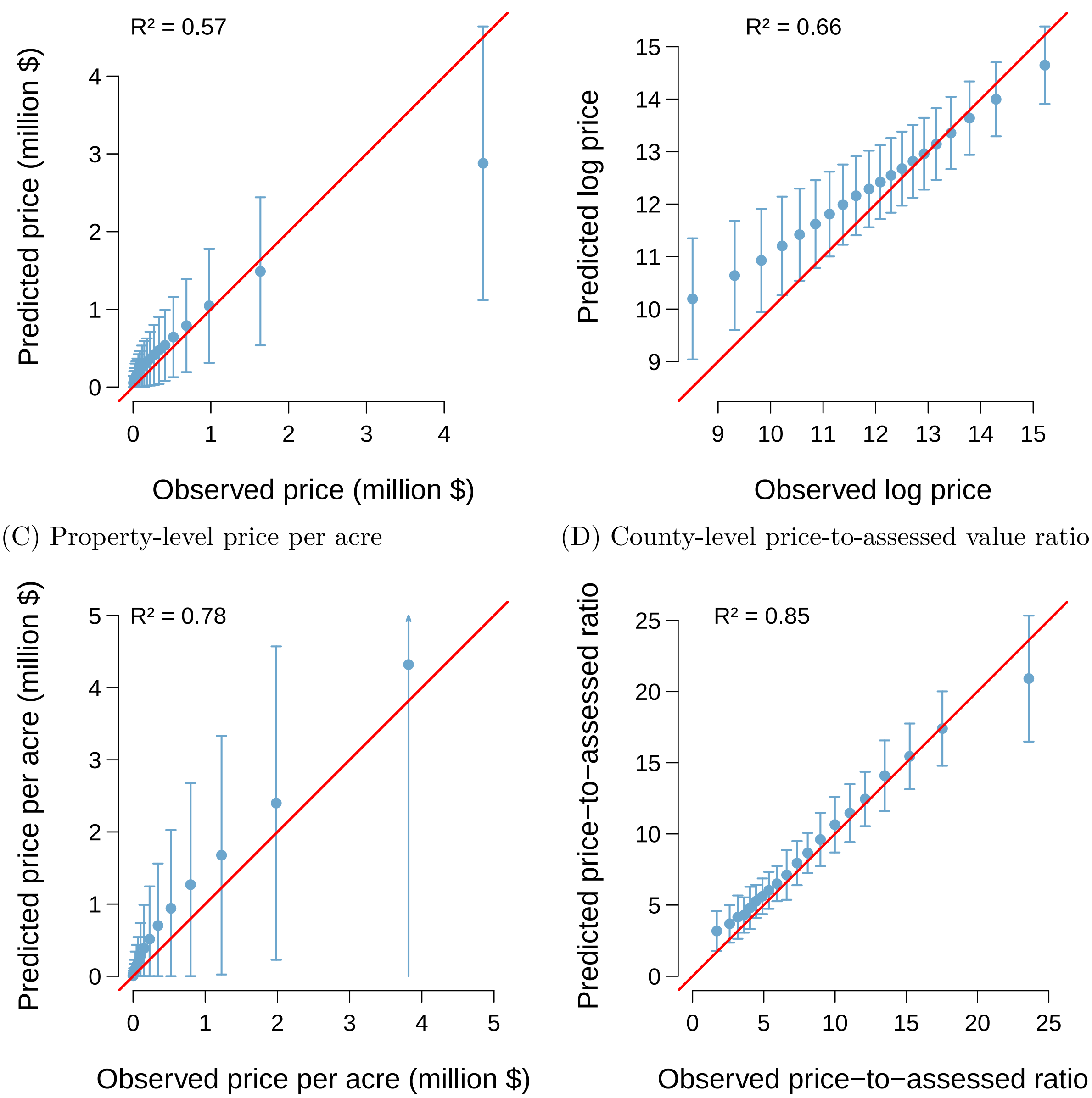
Figure A7: Model Performance for Predicting Fair Market Value

(A) Property-level price

(B) Property-level log price

(C) Property-level price per acre

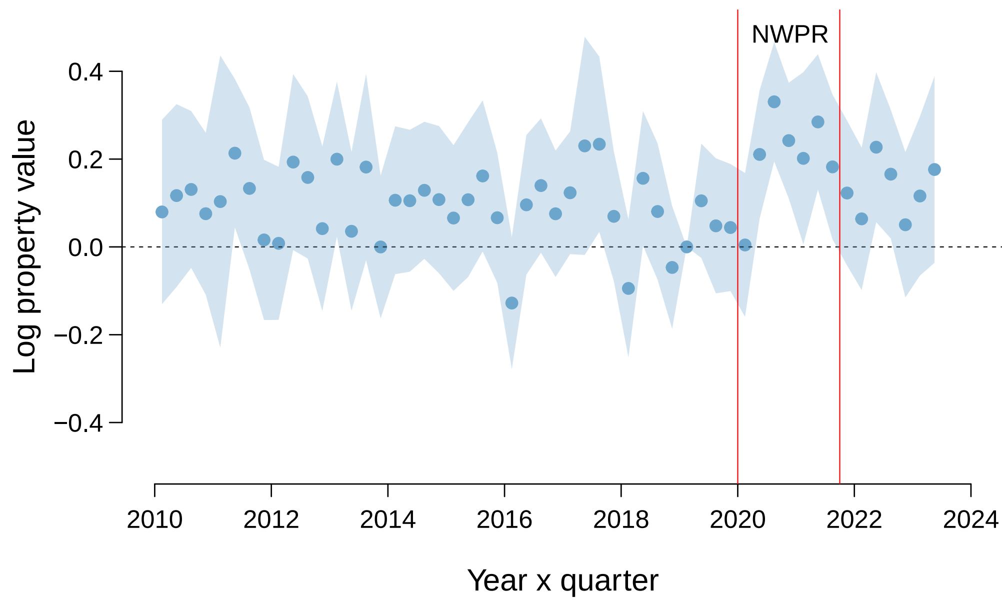
(D) County-level price-to-assessed value ratio



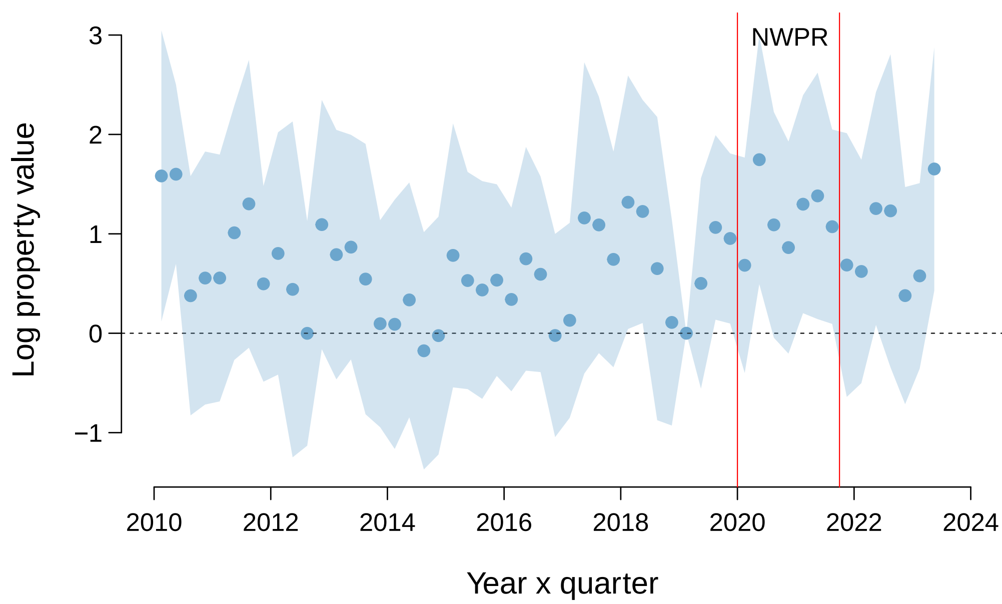
Notes: Plots show bin scatters of observed values (x-axis) against predicted values (y-axis) from the random forest model that predicts property sales price as a function of assessor records (Section 4.2 and Appendix C.2). Circles are means, bars are standard deviations. All Panels show a model trained to predict property sales prices in levels. Panel A shows the correspondence between observed values and predictions for property-level prices, B shows log price, and C shows price per acre. Panel D shows the correspondence between predicted and observed county-level price-to-assessed value ratios.

Figure A8: Effect of Navigable Waters Protection Rule (NWPR) on Property Values, Extended Panel

(A) Wetland Map Model



(B) Algorithmic Model

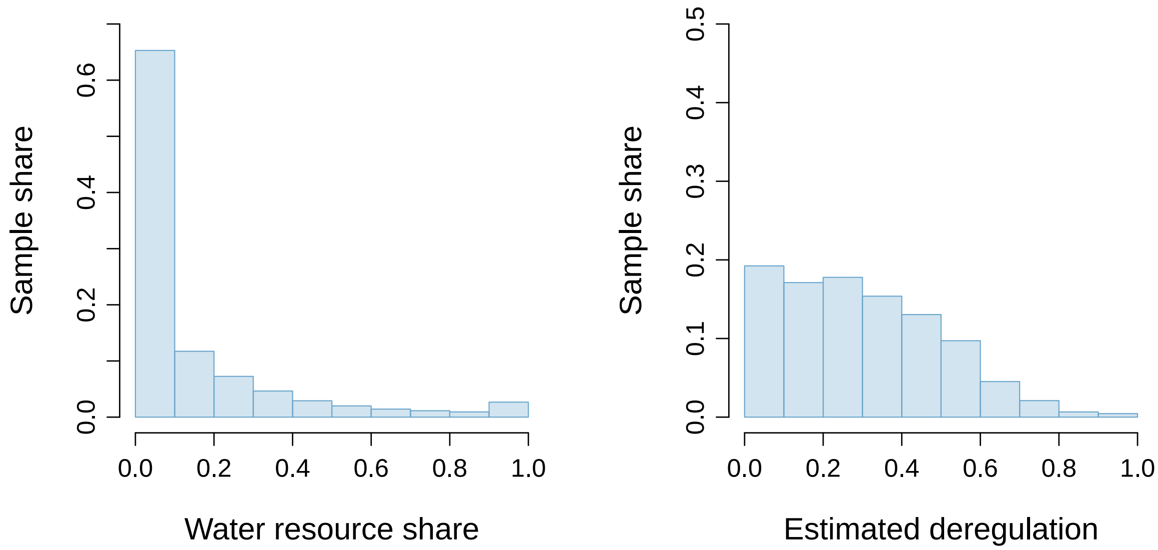


Notes: Wetland map is National Wetlands Inventory (NWI) water resource share. The algorithm is described in Section 4. Panel A shows the effect of water resource share on log values of non-residential properties by year × quarter, from equation (4). Panel B shows the effect of algorithmically-estimated deregulation under NWPR by year × quarter, for non-residential properties. Both panels use CoreLogic non-residential property transaction records extending back to 2010. Circles show point estimates and shaded areas show 95% confidence intervals. Standard errors are clustered by commuting zone. Vertical lines mark before the first quarter of 2020, when EPA published the final NWPR rule, and after the third quarter of 2021, when a judge vacated NWPR. All graphs normalize the first quarter of the year 2019 to equal zero.

Figure A9: Distributions of National Wetlands Inventory (NWI) Water Resource Share and Algorithmically Estimated Deregulation

(A) Distribution of Non-Residential Wetland Shares

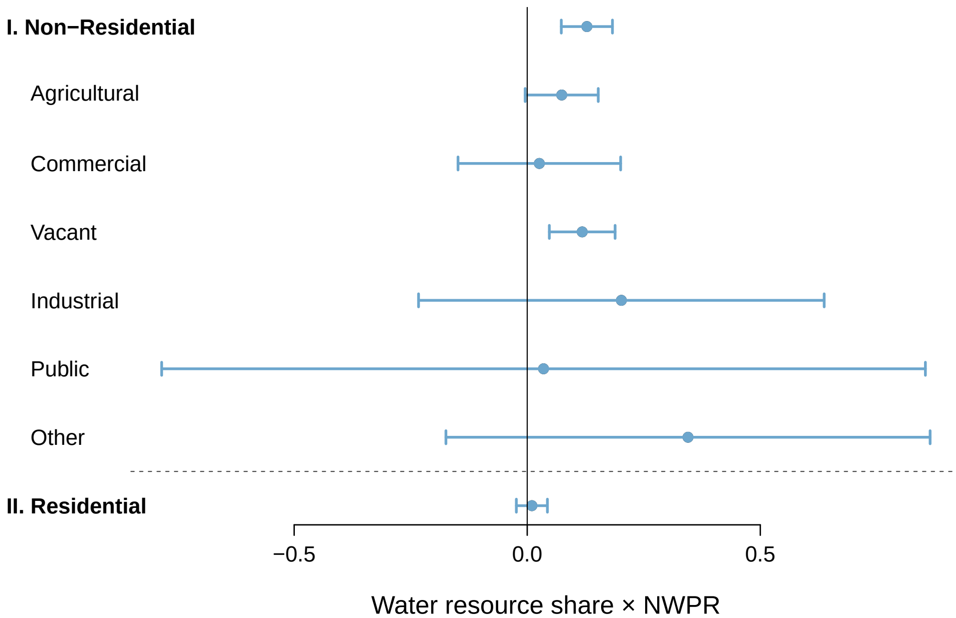
(B) Distribution of Non-Residential Algorithmic Predictions



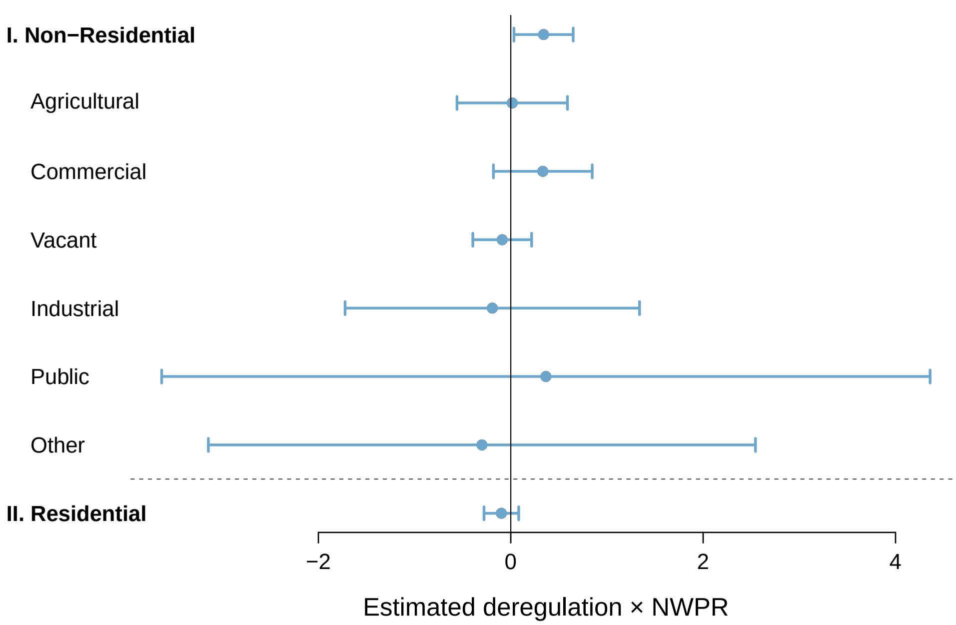
Notes: Panel A shows the distribution of NWI water resource share. Panel B shows the distribution of algorithmically estimated deregulation under the Navigable Waters Protection Rule (NWPR). Distributions are computed over the full analysis sample of non-residential properties from CoreLogic.

Figure A10: Effect of Navigable Waters Protection Rule on Log Property Values, by Land Use Subcategory

(A) Wetland Map Model

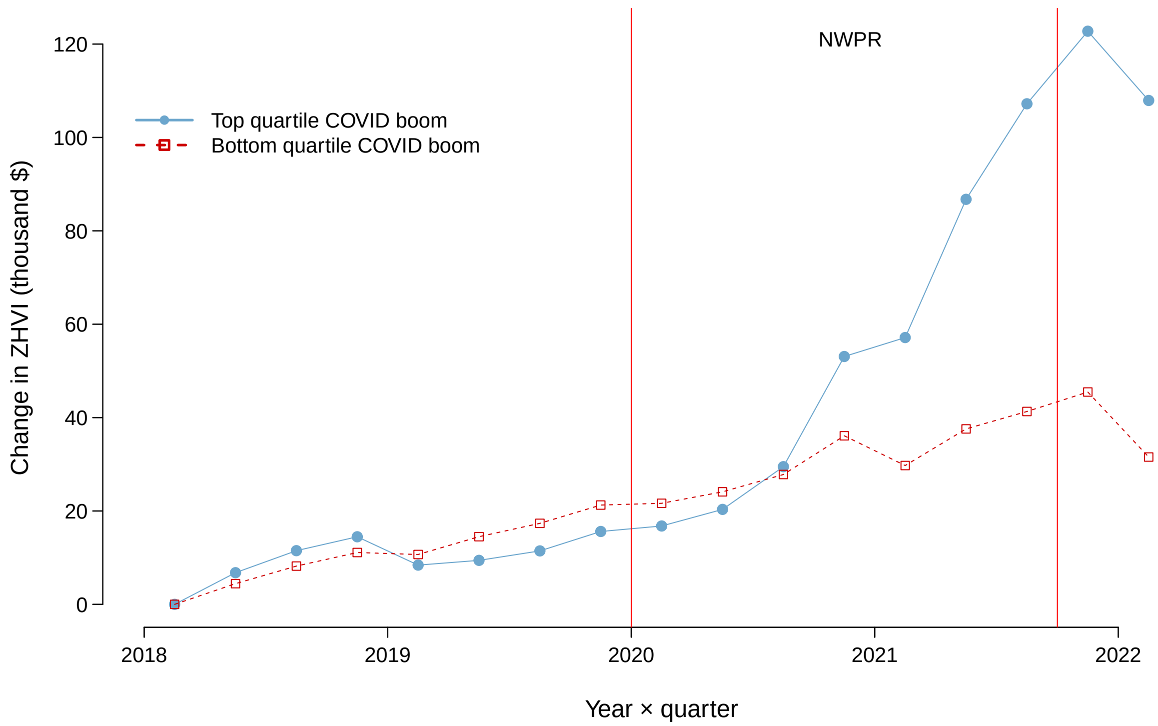


(B) Algorithmic Model



Notes: NWPR is the Navigable Waters Protection Rule. Wetland map is National Wetlands Inventory (NWI) water resource share, the share of area within 100 meters of the property centroid that is covered by any type of NWI water feature. Estimated deregulation is the difference in predicted probabilities of regulation between *Rapanos* and NWPR ($p_{iR} - p_{iN}$). Panel A uses equation (2). Panel B uses equation (17). Circles show point estimates, lines show 95% confidence intervals. Regressions use zip × month × year fixed effects and control for log property acres, log distances to the nearest town and metro area, population density decile, and work from home share. Observation counts are as follows: Non-Residential – 4,470,365; Residential – 6,918,722; Agriculture – 785,794; Commercial – 1,133,717; Vacant – 2,128,965; Industrial – 220,968; Public – 72,046; Other – 38,543.

Figure A11: Trends in Zillow Home Value Index, by Size of Local COVID Residential Housing Boom



Notes: This figure plots the change in thousands of dollars per property relative to 2018Q1 as measured by the Zillow Home Value Index (Zillow.com 2025). As with other monetary values in the paper, we convert the Zillow Home Value Index to 2024 dollars using the GDP deflator. The blue line represents properties with a top-quartile linear trend break in the Zillow Home Value Index after March 2020, and the red line represents properties that have a bottom-quartile trend break. Dollar values deflated to 2024 US$ using the GDP deflator.

Figure A12: News About Development Under the Navigable Waters Protection Rule

(A) Georgia (Mufson and Butler 2020)

The Washington Post
Democracy Dies in Darkness

Trump rule eases effort to strip-mine near Okefenokee Swamp

November 25, 2020 More than 5 years ago

216

Cypress trees line the banks of the Suwannee Canal, the main water entrance into the Okefenokee Swamp. (Hal Beral/VWPics/AP)

(B) Florida (Cassels 2021)

Florida Phoenix

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FL wetlands and waterways face development and potential harm as vacated Trump rules linger

'This was the last forest in Orlando,' says ecologist who grew up there

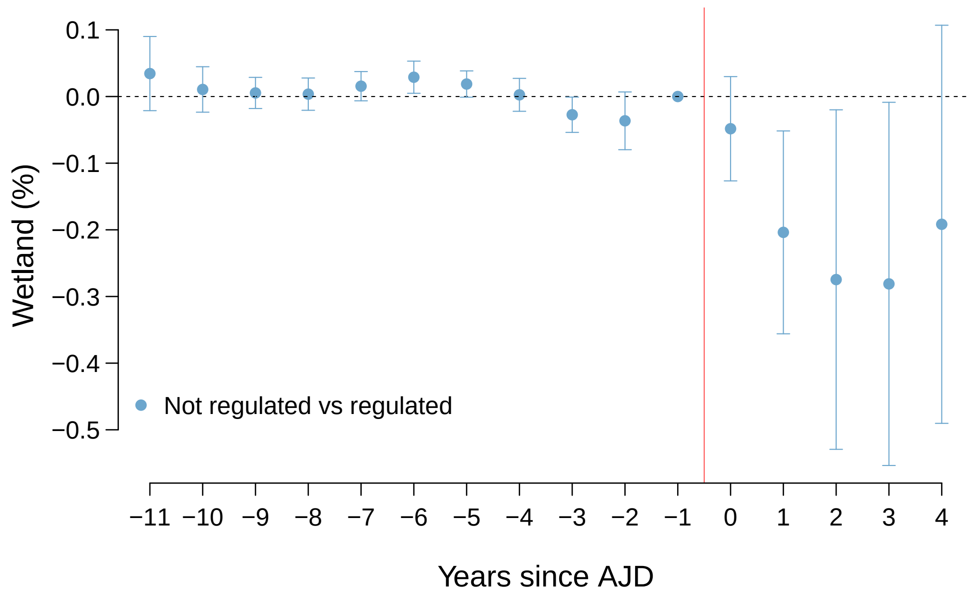
BY: LAURA CASSELS - OCTOBER 18, 2021 7:00 AM

This area of the Wekiva River headwaters, as seen in 2015, in Orlando has been cleared for an industrial park project. Critics want FL to do more to protect wetlands. Credit: Wanda Jones

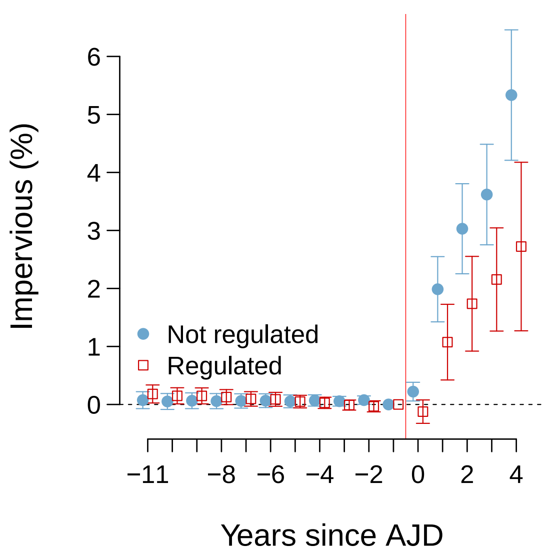
Notes: Panels show two examples of news headlines on how NWPR may affect development.

Figure A13: Development Around Approved Jurisdictional Determinations (AJD) Issued Under the Navigable Waters Protection Rule (NWPR), Event Study Extensions

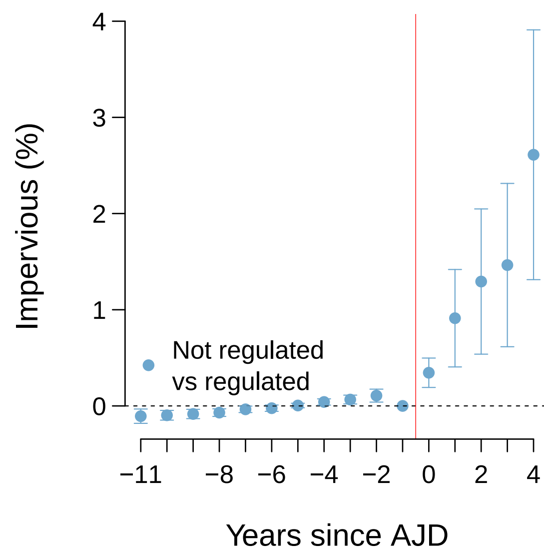
(A) Percent of Area that is Wetland, Using the Algorithm



(B) Percent of Area that is Impervious, by Regulation Status Using the Wetland Map



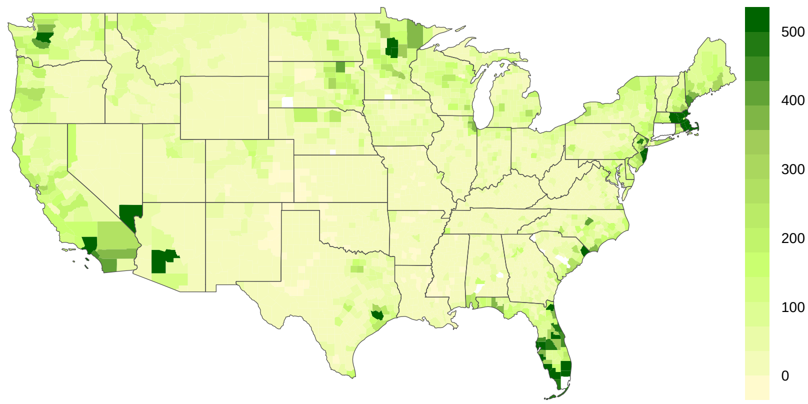
(C) Percent of Area that is Impervious, Difference Using the Wetland Map



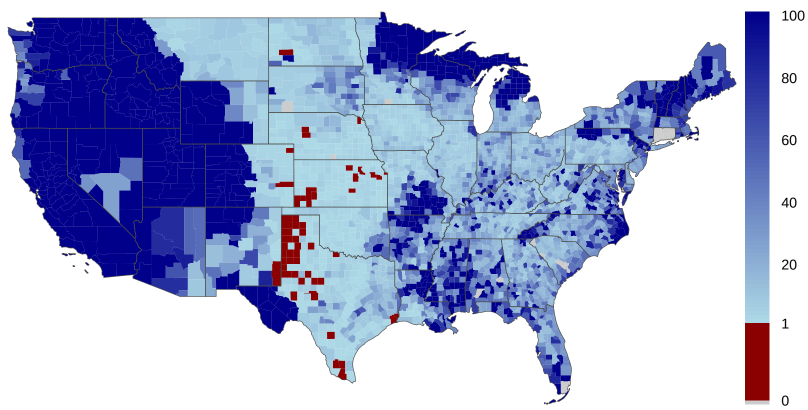
Notes: Panel A shows results from equation (6) using the algorithmically-estimated deregulation rather than National Wetlands Inventory (NWI) water resource share. The outcome is the share of land that is wetlands within 100m of each approved jurisdictional determination (AJD) site centroid. Wetland area is determined by a binary classification of each 30m pixel, measured from the 2024 edition of the National Land Cover Dataset (NLCD) (U.S. Geological Survey 2024), which covers the years 2010-2024. Panels B and C show estimates from the same equation using NWI water resource share, where the outcome is the share of developed land within 100m of each approved jurisdictional determination (AJD) site centroid, as measured by NLCD (U.S. Geological Survey 2024). In Panel B, red squares show point estimates for regulated sites, and blue circles show point estimates for non-regulated sites. In Panel C, points show the difference, i.e., the effect of an AJD for non-regulated sites relative to regulated sites. All panels show estimates in the years preceding (negative x-axis values) and following (positive x-axis values) the AJD. All regressions use the sample of AJDs issued under NWPR. Event study regressions include commuting zone × year and site fixed effects, and NWI water resource share × event time. Bars show 95% confidence intervals. Standard errors are clustered by commuting zone.

Figure A14: Navigable Waters Protection Rule (NWPR) Land Value Benefits and Flood Protection Costs, By County

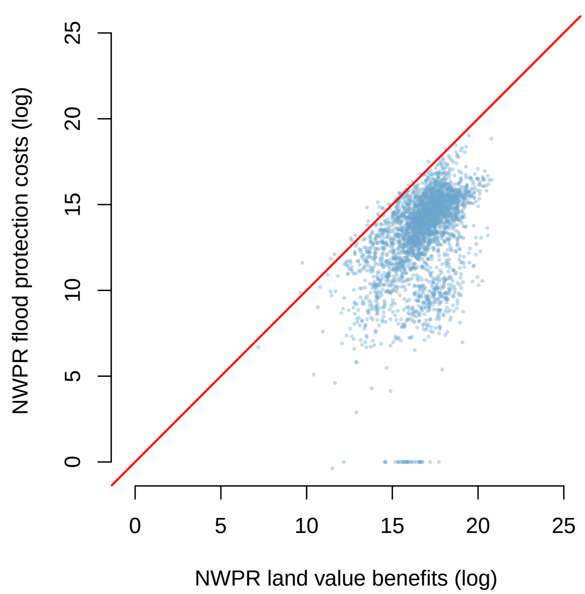
(A) NWPR Total Estimated Land Value Benefits ($ million)



(B) Ratio of Estimated NWPR Land Value Benefits to Flood Protection Costs: Map



(C) Ratio of Estimated NWPR Land Value Benefits to Flood Protection Costs: Graph



Notes: (A) Impact of NWPR on land values by county, in million USD. (B) Ratio of NWPR land value benefits to flood protection costs, by county. The ratio is top-coded at 100. (C) Scatter plot of log NWPR land value benefits to log NWPR flood protection costs. Counties below and to the right of the red 45° line have estimated land value benefits exceeding flood protection costs. Counties with zero estimated flood protection costs are assigned a log flood protection cost of zero. 33 counties have a ratio below 1, while 3,052 counties have a ratio above 1, with 606 having ratios in excess of 100. Impacts are calculated at the property-level for all 27.9 million non-residential assessor records and then aggregated to the county-level. Land value impacts apply the estimates of NWPR by water resource share reported in Figure 4. Flood protection costs are calculated using heterogeneous wetland benefits from Taylor and Druckenmiller 2022 and estimated changes in wetland area due to regulation reported in table A5 (at event time = 4). Dollar values deflated to 2024 US$ using the GDP deflator.

Table A1: Examples of Environmental Policies Around the World that Limit Land Use

Country	Policy	Description	Impact on land use	Reference
Australia	Environment Protection and Biodiversity Conservation Act 1999	Legal framework for the protection and management of nationally and internationally important flora, fauna, ecological communities, and heritage places.	Requires assessments of proposed projects on protected matters, which determines which development projects are allowed.	Department of Climate Change, Energy, the Environment and Water (2024)
Brazil	Forest Code (Código Florestal)	Mandates landowners in the Amazon rainforest and other sensitive biomes to maintain a certain percentage of their land as natural forest.	Limits deforestation and land conversion, affecting agricultural expansion and construction activities.	Amazon Environmental Research Institute (2017)
Canada	Fisheries Act	Prohibits activities that result in the harmful alteration, disruption, or destruction of fish habitat.	Restricts land development and industrial activities near water bodies to protect fish habitats.	Government of Canada (2024)
China	Environmental Protection Law (2015 Revision)	Enhances regulatory oversight on pollution and mandates stricter environmental assessments for projects.	Restricts or halts development projects that fail to meet environmental standards.	Zhang et al. (2015)
European Union	Water Framework Directive	Comprehensive framework aimed at achieving good qualitative and quantitative status of all water bodies (including rivers, lakes, groundwater, and coastal waters).	Requires member states to develop river basin management plans and restricts activities that could deteriorate water quality, effectively controlling certain types of land development and industrial activities near water bodies.	European Commission (2024)
India	Coastal Regulation Zone Notification	Regulates activities, including waste treatment plants, mining, and construction, on zone of coastal ecosystems.	Designates zones with specific restrictions on construction and land use.	Food and Agriculture Organization Legal Office (2015)
New Zealand	Resource Management Act	Manages air, soil, fresh water, coastal marine areas as well as land use and provision of infrastructure.	Activities affecting land, air, or water require authority approval, and local governments can impose restrictions on land use to protect the environment.	New Zealand Government (1991)
South Africa	National Environmental Management Act	Provides the framework for environmental governance including principles for decision-making on matters affecting the environment.	Requires federal agencies to submit an environmental impact statement prior to some development projects, which determines which projects are allowed.	Government of South Africa (1998)

Table A2: Composition of Non-Residential Properties: Transactions Versus Assessor Stock

Land use type	Number of transactions	Percent of transactions	Number of assessed properties	Percent of assessed properties
Vacant	2,128,965	47.6	11,017,791	39.4
Commercial	1,133,717	25.4	5,144,466	18.4
Agricultural	785,794	17.6	6,895,708	24.7
Industrial	220,968	4.9	1,059,608	3.8
Public	72,046	1.6	1,788,791	6.4
Recreational	67,779	1.5	327,844	1.2
Noncoded	37,680	0.8	863,163	3.1
Transport Energy	16,471	0.4	220,247	0.8
Residential Rural	6,945	0.2	624,466	2.2
Total	4,470,365	100.0	27,942,084	100.0

Notes: Transaction sample includes arms-length non-residential property sales from 2017–2023. Assessor sample includes the near-universe of non-residential properties in CoreLogic's assessor records.

Table A3: Aggregate Predicted Market Value by Land Use Type

Land Use Type	Properties (M)	Acres (M)	Assessed ($T)	Predicted ($T)	$/Acre (K)	Predicted/ assessed
Vacant	11.02	190.8	0.67	2.75	14.4	4.13
Agricultural	6.90	442.5	0.98	3.85	8.7	3.91
Commercial	5.14	18.4	2.61	5.01	272.4	1.92
Public	1.79	54.8	0.74	1.33	24.2	1.79
Industrial	1.06	7.5	0.82	1.49	197.7	1.81
Noncoded	0.86	19.8	0.08	0.27	13.7	3.34
Residential Rural	0.62	11.7	0.12	0.35	29.6	2.94
Recreational	0.33	7.4	0.11	0.20	27.1	1.86
Transport Energy	0.22	2.8	0.07	0.13	48.3	2.06
Total	27.94	755.7	6.20	15.39	20.4	2.48

Notes: Predicted values are generated using a random forest model trained on 2017–2023 non-residential transactions. Dollar values deflated to 2024 US$ using the GDP deflator.

Table A4: Effect of the Navigable Waters Protection Rule (NWPR) on Property Values, by Size of Local COVID Housing Boom

	Dependent variable: Log property value	
	(1)	(2)
A. Wetland map model		
Water resource share × NWPR	0.128***	0.131***
	(0.028)	(0.034)
Water resource share × NWPR × COVID top affected	—	-0.010
		(0.065)
B. Algorithmic model		
Estimated deregulation × NWPR	0.341**	0.623***
	(0.157)	(0.194)
Estimated deregulation × NWPR × COVID top affected	—	-0.358
		(0.288)
FE: Zip × year × month	Yes	Yes
Log predicted 2016 sale price	Yes	Yes
Log distance to town, city	Yes	Yes
Population density decile	Yes	Yes
Work from home share	Yes	Yes
Log property acres	Yes	Yes

Notes: NWPR is the Navigable Waters Protection Rule. Wetland map is National Wetlands Inventory (NWI) water resource share, the share of area within 100 meters of the property centroid that is covered by any type of NWI water feature. Panel A shows the estimates from equation (2) in the non-residential sample. Column (1) is our preferred specification. Column (2) allows the affect to vary for zip codes with large COVID housing booms by interacting Water resource share × NWPR with a binary indicator ("COVID top affected") for whether the zip code had a top-quartile trend break in housing prices starting in March 2020 (following Ramani and Bloom 2021). Panel B shows the same, but for the algorithmically estimated deregulation, the difference $p_{iR} - p_{iN}$ in predicted probabilities of regulation between *Rapanos* and NWPR, from Equation (17). All regressions have zip × year × month fixed effects and fully saturated controls. The regression in column (2) also includes the interaction of the controls with NWPR and COVID top affected. Standard errors are clustered by commuting zone. ***: p < 0.01, **: p < 0.05, *: p < 0.1

Table A5: Effect of Approved Jurisdictional Determinations (AJDs) Issued Under the Navigable Waters Protection Rule (NWPR) on Land Use

	Developed (impervious) (%)			Wetland (%)		
	(1)	(2)	(3)	(4)	(5)	(6)
Post-AJD	1.713***	1.646***	0.735*	0.365*	0.386*	0.617***
	(0.423)	(0.393)	(0.411)	(0.207)	(0.220)	(0.213)
Post-AJD × Non-regulated	1.396***	1.373***	0.312	-0.533***	-0.529***	-0.455***
	(0.354)	(0.351)	(0.296)	(0.187)	(0.186)	(0.159)
Non-regulated × Event time		0.010***	0.007***		-0.002*	-0.001
	—	(0.002)	(0.002)	—	(0.001)	(0.001)
Post-AJD × Event time			0.479***			-0.115***
	—	—	(0.131)	—	—	(0.035)
Post-AJD × Non-regulated			0.475***			-0.033
× Event time	—	—	(0.132)	—	—	(0.034)
Fitted effect: Event time = 4						
Non-Regulated	3.109	3.019	4.862	-0.167	-0.143	-0.431
Regulated	1.713	1.646	2.651	0.365	0.386	0.155
Difference	1.396	1.373	2.211	-0.533	-0.529	-0.586
P-value difference	[0.000]	[0.000]	[0.000]	[0.004]	[0.004]	[0.005]
Pre-AJD dep. var. mean	20.890	20.890	20.890	5.390	5.390	5.390
NWI × Event time interact.	Yes	Yes	Yes	Yes	Yes	Yes
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
CZ × year FE	Yes	Yes	Yes	Yes	Yes	Yes
Number of AJDs	56,003	56,003	56,003	56,003	56,003	56,003
Number of sites	155,690	155,690	155,690	155,690	155,690	155,690
Observations	2,335,350	2,335,350	2,335,350	2,335,350	2,335,350	2,335,350

Notes: This table reports estimates from equation (8). The sample consists of all AJDs issued under NWPR together with a random sample of 100,000 properties from the CoreLogic transaction data, which serve as never-treated controls. We drop any of these that already appear in the sample as AJDs. The outcome is the percentage (0-100) in a given land use within 100m radius of an approved jurisdictional determination (AJD) site for developed (impervious) land (Columns 1-3) and wetland (Columns 4-6) using the 2024 National Land Cover Dataset (NLCD) (U.S. Geological Survey 2024) at 30m resolution. The developed proxy uses the NLCD imperviousness product, which is a continuous measure of the impervious share of land within each 30m pixel rather than binary categorization of development. Post is a dummy for years following an AJD. Event time is year minus year of AJD and includes the years 2010 through 2024. Dependent variable means represent years before an AJD. Non-regulated is a dummy for whether a property was deemed non-jurisdictional under the AJD. Cols (2) and (5) allows for a differential linear trend among non-regulated properties, cols (3) and (6) further allow a trend break in the post period. Regressions include commuting zone × year fixed effects and a property level fixed effect, as well as a control for the static water resource share × event time to account for differing geophysical fundamentals. Water resource share is the share of area within 100 meters of the property centroid that is covered by any type of National Wetlands Inventory (NWI) water feature. Standard errors are clustered by commuting zone. ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

Table A6: Ecosystem Service Values from Meta-Analyses

	Brouwer et al. (1999)	de Groot et al. (2012)	Brander et al. (2013)	Bilkovic et al. (2025)	Average	Average weighted by number of studies
	(1)	(2)	(3)	(4)	(5)	(6)
A. Ecosystem Services						
Food provisioning	–	2.8%	–	–	2.8%	2.8%
Water supply	8.9%	2.6%	21.0%	–	10.9%	8.1%
Raw materials	–	1.3%	–	–	1.3%	1.3%
Genetic resources	–	0.02%	–	–	0.02%	0.02%
Medicinal resources	–	0.7%	–	–	0.7%	0.7%
Ornamental resources	–	0.2%	–	–	0.2%	0.2%
Climate regulation	–	0.1%	–	9.4%	4.7%	2.3%
Flood control	**38.1%**	**13.6%**	**43.0%**	**55.1%**	**37.4%**	**29.5%**
Regulation of water flows	–	9.2%	–	–	9.2%	9.2%
Water quality (general)	21.7%	–	–	–	21.7%	21.7%
Waste treatment	–	11.8%	–	–	11.8%	11.8%
Erosion protection	–	10.7%	–	–	10.7%	10.7%
Nutrient removal / recycling	–	2.9%	36.0%	19.9%	19.6%	13.7%
Biological control	–	1.6%	–	–	1.6%	1.6%
Nursery / habitat biodiversity	31.4%	19.3%	–	8.2%	19.7%	19.6%
Genetic diversity	–	12.4%	–	–	12.4%	12.4%
Aesthetic information	–	2.1%	–	–	2.1%	2.1%
Recreation	–	7.2%	–	7.4%	7.3%	7.3%
Inspiration	–	1.1%	–	–	1.1%	1.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Number of underlying studies	30	95	38	29	–	–
Number of underlying observations	103	305	66	43	–	–
B. Proportion of Studies by Method						
Stated preference	100.0%	11.6%	–	14.2%	–	–
Market prices	0.0%	45.5%	–	7.5%	–	–
Production function	0.0%	6.0%	–	5.8%	–	–
Cost-based methods	0.0%	20.6%	–	33.3%	–	–
Travel cost method	0.0%	5.3%	–	5.8%	–	–
Other	0.0%	11.0%	–	33.3%	–	–
Total	100.0%	100.0%	–	100.0%	–	–

Notes: Columns (1-4) of panel A show proportions of wetland value attributable to various ecosystem services from four meta-analyses (Brouwer et al. 1999; De Groot et al. 2012; Brander et al. 2013; Bilkovic et al. 2025). Column (5) reports the average value for each ecosystem service across meta-analyses. Column (6) reports a weighted average by the number of underlying studies in each meta-analysis. Panel B reports the breakdown of research methods used in underlying studies for each meta-analysis. Storm protection and disturbance moderation are coded as flood control. Stated preference methods include contingent valuation and choice experiment methods. Cost-based methods include methods using replacement costs, avoided costs, or mitigation costs. De Groot et al. (2012) report ecosystem service breakdowns for coastal and inland wetlands separately. Bilkovic et al. (2025) is the only study to explicitly consider carbon sequestration/removal as an ecosystem service (categorized as climate regulation). Several of the underlying studies measuring this service use distinct methods, such as carbon pricing and bioeconomic modeling, which fall into the Other category.