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 how recent changes to Clean Water Act regulation, measured using wetland maps and machine learning, affect land markets. Four findings emerge. First, a 2020 White House rule reduced Clean Water Act regulation by about 40 percent. Second, by deregulating wetlands, this rule increased the value of U.S. non-residential parcels by nearly 1%, with larger effects for parcels facing greater deregulation and near-zero effects for residential parcels. Third, remote sensing indicates that deregulation expanded developed surfaces like pavement, and reduced wetland area. Fourth, the deregulation increased non-residential land values by $125 billion, a magnitude that meaningfully exceeds the estimated aggregate loss in 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 com-

mission 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, and delay and uncertainty. 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, 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] Bridgeland has won many awards, including Master Planned Community of the Year, and sold areas to Chevron for research and development offices. At the same time, over four-fifths of Bridgeland properties have a major risk of flooding in the next 30 years (First Street Foundation 2025). More broadly, the Houston region is prone to 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 parcels 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 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 legally-binding approved jurisdictional determinations from the Environmental Protection Agency (EPA) and Army Corps.

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

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 parcels without mapped water resources but 20.3 percentage points for sites fully covered with mapped water resources. The algorithm indicates that the probability of regulation for the average site fell under NWPR from 36 percentage points to 21 percentage points, a decline of 41% relative to baseline.

Second, we use parcel-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 parcels, which face more restrictive Clean Water Act regulation. Values of non-residential properties deregulated under NWPR 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 parcel by $4,500, or nearly 1%, with larger effects for parcels facing more extensive deregulation.

Several tests support the integrity of the research design. First, event study graphs assess the timing of Army Corps jurisdictional determinations and property price responses around NWPR's implementation in early 2020 and subsequent judicial stay. Second, we investigate sensitivity to adding parcel-level proxies for the COVID housing boom (Ramani et al. 2024). Third, we compare NWPR's land market effects for non-residential parcels, where regulation is more restrictive, versus residential parcels. Fourth, we estimate the effect of NWPR on land values in regions with large COVID residential housing booms versus other regions. Fifth, semi-parametric binned regressions flexibly assess how the extent of deregulation affects property values.

The paper's third section investigates how Clean Water Act regulation affects remotely-sensed measures of wetland extent and impervious surfaces. These estimates both clarify a mechanism for this regulation to affect land values and help measure how regulation affects 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 fairly flat before a jurisdictional determination, for both regulated and non-regulated sites. In years after a 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. We take estimates of wetlands' flood mitigation benefits from recent quasi-experimental studies (Taylor and Druckenmiller 2022; Aronoff and Rafey 2023; Gourevitch et al. 2026). We estimate that NWPR decreased flood mitigation benefits by $13.9 billion to $22.0 billion. The range in flood mitigation benefits reflects two alternative measures of jurisdictional change under NWPR, using either the wetland map or the algorithm. In both wetland loss scenarios, NWPR's land value benefits exceed its cost in terms of lost flood protection benefits by a factor of 5.6 or more.

To interpret the social welfare consequences of these changes, we discuss evidence from other settings 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.

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 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. Contemporaneous work (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). A few 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 or 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.[2] 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 Druckenmiller (2022) estimate U.S. wetlands' flood protection benefits. Mangrove forests, a type of coastal wetland, mitigate flood damages from storms (Hochard et al. 2019; Valle et al. 2020). Aronoff and Rafey (2023) study offset markets for wetlands in Florida, and Karwowski and Skidmore (forthcoming) 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 inefficiently 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 the effects of environmental regulation

[2] Using colorful language about not fouling one's own swimming pool or backyard, several regulators have explained that discharging even treated wastewater from industrial or wastewater treatment plants 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, is typically a bad idea for industry or cities.

and development, though these data sources do not record Clean Water Act permits. 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 address the Congressional Budget Office (2025)'s call for research on the economic effects of federal permitting requirements.

We proceed as follows. Section 2 provides background. Sections 3 and 4 discuss the data and research design. Sections 5–8 study changes in regulatory stringency, property values, development outcomes, and measured costs and benefits. Section 9 concludes.

2 Background: Wetlands and Land Use Regulation Under the Clean Water Act

2.1 Wetlands

Brief historical and scientific context on wetlands helps explain many parts of our analysis. Wetlands include areas where water saturates or inundates the surface of soil with sufficient frequency and duration to support hydrophytic vegetation (i.e., water-loving plants) (U.S. Army Corps of Engineers 1987). Wetlands include swamps, marshes, bogs, fens, estuaries, playa lakes, prairie potholes, Carolina and Delmarva bays, pocosins, vernal pools, and deltas (Sullivan et al. 2020). Wetlands tend to form in flat areas where terrain and precipitation naturally route water, often though not always 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.[3] Our discussion generally follows common usage of the term "wetlands" to include only swamps, marshes and the like (i.e., palustrine wetlands); we refer to these together with lakes, ponds, and rivers 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

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

obviously characterizes wetlands, a sufficiently shallow groundwater table can form wetlands by saturating surface soils. To delineate wetlands, scientists may also sample vegetation to identify areas where a majority of plants are hydrophytic (i.e., adapted to living in soils with high moisture content). Examples of hydrophytic plants include cattails, willows, and cordgrasses. Hydric soils, which are characteristic of wetlands, form in conditions of prolonged saturation. Some characteristics of hydric soils persist for many years even if a wetland is drained.

Wetland policy has a complex history. Slightly over half of U.S. wetlands were drained between the 1600s and 1980s. Over 85 percent of wetlands in California and Midwestern states like Iowa, Missouri, Illinois, Indiana, and Ohio disappeared over this period, while states in the arid West and mid-Atlantic drained a much smaller share of wetlands. Motivated by a historical view of wetlands as a source of disease and an impediment to agriculture and transportation, federal laws throughout the 19th century encouraged residents to drain wetlands, often for agriculture and under the guise of "Reclamation." Evolving views of wetlands as a source of ecosystem services in the 1960s and 1970s led to a reversal of federal policy to protecting rather than reclaiming wetlands. President Carter's Executive Order 11990 in 1977 directed the federal government to protect wetlands, an objective which subsequent presidents articulated as "No Net Loss" of wetlands. The federal government does not have a single clear enforcement tool for this goal. 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 major tool to pursue the goal of "No Net Loss." Since the 1970s, total wetland area in the contiguous U.S. has not dramatically declined, and possibly somewhat increased (Dahl and Johnson 1991; Lang et al. 2024). The two areas of the contiguous U.S. with the highest density of wetlands today are the Gulf and Atlantic Coastal Plains between Houston and Virginia, and the Upper Midwest / Great Lakes region extending from northern Minnesota to Wisconsin (Lang et al. 2024).

To monitor No Net Loss, the U.S. Fish & Wildlife Service (FWS) produces public maps of U.S. wetlands, and reports to Congress every decade on wetland trends. FWS formally defines wetlands as "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following

three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year." (Cowardin et al. 1979)

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

Various technologies can drain wetlands to allow agricultural or other development. Canals, culverts, ditches, tile drainage, channels, pumps, and other technologies redirect water to drain wetlands. Geophysical characteristics like hydric soils, terrain slope, and subsurface geology persist even when drainage technologies divert water. Scientists can therefore in some cases identify sites that are historical wetlands even if current drainage technologies remove current soil saturation.

Wetlands provide a broad set of ecosystem services. By acting as a sponge in areas where water habitually forms, 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).[4]

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 Pollution Discharge Elimination System (NPDES), which limits pollution for industrial plants that directly discharge pollution into jurisdictional waters.

A third component of the Clean Water Act is increasingly consequential. Section 404

[4] Prehistoric wetlands also created enduring value; most fossil fuels formed from decomposition of organic material in ancient swamps.

of the Act 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) and can include wetlands that appear as dry or damp land for much of the year, or former wetlands that are dry due to drainage infrastructure like ditches and culverts. At the same time, 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 are therefore straightforward to develop. Figure A1 illustrates several examples of semi-dry wetlands, which differ markedly from the stereotypical image of wetlands.

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. The landowner typically first hires a wetland consultant to prepare a report on nearby wetlands and their potential regulatory status. Developers then typically submit the report to the Army Corps. 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 a permit from the Army Corps, usually called a Wetland Permit or Section 404 Permit. The permit describes the project and steps required to minimize impacts on regulated waters. Required steps can include restrictions on development near regulated waters, the requirement to build new wetlands in the same watershed to offset wetlands the project will develop, and others. Developers usually purchase wetland offsets from a mitigation bank, or directly mitigate impacts (i.e., build new wetlands) onsite. Since many large development properties contain water features, financing a development project can require demonstrating compliance with Clean Water Act

[5] The Army Corps is best known for building infrastructure like dams. The Regulatory Program of the Army Corps instead implements the Clean Water Act and related regulations.

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, power plants, roads and bridges, airports, golf courses, ports, oil and gas drilling, mining and others.

An example of a development project requiring mitigation may clarify. A road and bridge improvement project in Olympic National Park, Washington, affected 0.036 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).

To summarize, the wetland permitting process involves the cost of a wetland consultant, Army Corps jurisdictional determination, preparation and processing of a permit, potentially the purchase or construction of wetland and stream offsets, changes to or restrictions on allowed project design, and uncertainty, effort, and delay related to each of these steps.

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 and bulldoze whatever the developer built, then hire environmental consultants and engineers to restore water resources to their original state). If a water resource is instead deemed non-jurisdictional, the landowner can proceed free of Clean Water Act regulation, though of course the site may face state or other federal regulation. Unregulated development can re-route water through ditches, route it underground via culverts, or use other engineering drainage technologies.

2.3 Changes to Clean Water Act Rules

The Clean Water Act does not enumerate which streams, lakes, and other water resources are regulated. Courts, the EPA, and the Army Corps have therefore regularly issued rules clarifying which waters are jurisdictional.

The "regulatory ping-pong" (Cramer 2022) of a half-dozen Supreme Court and White House Clean Water Act rules in the last seven years is striking. A third of the U.S. Supreme Court's environmental rulings since 1972 address the Clean Water Act, far more than any other environmental law (Zellmer 2013).

We focus primarily on two Clean Water Act rules—*Rapanos* and NWPR. Although the

U.S. has enforced many different Clean Water Act rules over the past decade, most rules have important similarities to *Rapanos* or NWPR (Appendix A.2). 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 covering groundwater and subsurface aquifers. *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. Isolated wetlands and ephemeral streams account for a large share of water flow, pollution filtration, and flood mitigation (Taylor and Druckenmiller 2022; Skidmore et al. 2025; Brinkerhoff et al. 2024).

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. We summarize 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.

Thus, NWPR could begin affecting land markets between October 2019 and June 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 extremely 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. Appeals Court 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*, which was the first case on the first day of the Court's term in October, 2022.

Developer information and beliefs on 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.

2.4 Case Study of Wetland Development

Additional 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, thirty miles northwest of the city center. This region experiences regular flooding due to heavy rainfall, moist soils, flat terrain, and low-lying development. 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 broke ground in 2011 but initially avoided developing some areas near Cypress Creek.[7]

In October 2020, the Army Corps provided jurisdictional determinations 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

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

regulated under NWPR.[8] 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.

After these jurisdictional determinations, Bridgeland rapidly developed the area (Figure 1). Google Earth aerial imagery from 2016 shows the creek flooding parts of the surrounding area. 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. The development has won many national awards including Master Planned Community of the Year and Best Landscape of a Community.

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 wetlands development—evidenced by many high-priced homes and a Fortune 500 research campus—and the value of adjacent natural amenities, and by extension the potential cost of regulations that restrict such development.

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 data for a post-*Sackett* analysis. We choose the beginning of the period so we have roughly equal timespans before and after NWPR's rollout.

To measure Clean Water Act regulation, Army Corps approved jurisdictional determinations (AJDs). These data report the coordinate and jurisdictional determination, separately for each potential water resource within a project (U.S. Army Corps of Engineers and U.S. EPA 2025). The database has 144,281 AJDs within our sample period. The data cover all states and Army Corps districts.[9] Appendix Section B provides more information, including

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

[9] 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 normal number of AJDs up to that period and fewer (though

spatial patterns in AJDs shown in Figure A2. Greenhill et al. (2024) and Greenhill et al. (2025) also discuss additional details of the AJD data, including modest measurement error in coordinates and reported jurisdiction.

We use property transaction data from CoreLogic (2024). The analysis sample includes 2.84 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; we report results separately for each of these categories. Table A3 describes the distribution of non-residential sites across more detailed land use categories (vacant, commercial, agricultural, etc.). Following the same data quality screening steps, we also extract a random sample of 4.9 million residential transactions over the same time period. Figure A3 shows the spatial distribution of non-residential and residential transactions across the contiguous United States. We deflate all monetary values in the paper to 2024 dollars using the GDP deflator (U.S. Bureau of Economic Analysis 2025).

Ramani et al. (2024) construct zip code-level proxies for the COVID housing boom; we build on their work by constructing these proxies at finer levels. We compute the straight-line distance from each parcel'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 parcels 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.

Our second measure of jurisdiction uses predictions from a machine learning algorithm

again not zero) afterwards.

that estimates property-level probabilities of regulation under both *Rapanos* and NWPR. Section 4.1 and Appendix C.1 discuss these methods and results in more detail.

To measure land use change, we derive data on the spatial extent of developed and wetland area from the U.S. Geological Survey's National Land Cover Database (NLCD) (U.S. Geological Survey 2024). 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 the impervious product, which provides a continuous measure of development within each 30m pixel. We then calculate NLCD land use share within a 100 meter radius of the parcel centroid. Given challenges in accurately assessing wetland extent with remote sensing (Wickham et al. 2013; Guo et al. 2017), we carefully discuss multiple NLCD outcomes.

More generally, for both the National Wetlands Inventory and NLCD we take this approach of computing land use within 100m of the centroid because we do not observe property boundaries. The 100m radius (7.75 acres) covers about half the acreage of the average property in our sample (15.5 acres).

Table 1 reports summary statistics for our analysis sample of non-residential property transactions. In the mean non-residential parcel, 4.4 percent of area has water resources based on the National Wetlands Inventory,[10] and a little over half of these are (palustrine) wetlands. The mean parcel has a sale price of around $513,000 and covers 15.5 acres. Parcels with and without water resources differ along many observed dimensions—parcels with water have larger areas, lower values, and more sparse populations. These differences diminish with zip × year × month fixed effects, though do not vanish. Given these cross-sectional differences, our analysis exploits variation over time and provides several assessments of internal validity. We use two proxies for the change in jurisdiction under NWPR. The first uses the National Wetlands Inventory (U.S. Fish & Wildlife Service 2025), the most comprehensive national dataset describing the area of known water resources. In a small survey of Army Corps approved jurisdictional determinations, 75% used the National 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,

[10] Across parcels, the standard deviation of the water resource share is 0.152. Conditional on zip code × year × month fixed effects, the standard deviation is 0.106.

and it may be the most observable and salient data available to landowners and developers. Since we do not observe parcel boundaries, we draw a 100 meter radius around each parcel's coordinates to compute the share of water resources and other land use characteristics.

We focus on non-residential parcels, given the greater relevance of the Clean Water Act to them, though also discuss results for residential parcels. We also use the AJDs to provide some evidence on the importance of Clean Water Act regulation for residential versus non-residential parcels. We calculate the share of residential parcels with an AJD is 0.0001. In other words, over the time period we study, one in 10,000 residential parcels had an AJD. This proportion is 115 times smaller than the share of non-residential parcels with an AJD. The few AJDs in residentially zoned areas have extremely different characteristics from the mean transacted residential parcel. Relative to the mean residential parcel, residential parcels 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. This evidence helps motivate our focus on non-residential parcels, and interpretation of residential parcels as primarily a comparison group. Partly because residential parcels often have dwellings already constructed, they have less need for AJDs.

4 Econometrics and Algorithms

4.1 Algorithms: Jurisdiction

Building on Greenhill et al. (2024) and Greenhill et al. (2025), we train and evaluate the algorithm using AJDs. Using the algorithm's predictions, we generate a binary indicator of whether the algorithm predicts that the site is regulated, separately for each rule. 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, satellite imagery embeddings, and an indicator for whether NWPR was in force at the time of the determination.

The algorithm achieves 77% accuracy at predicting regulatory status on a spatially held-out test set. Accuracy is comparable for determinations under *Rapanos* (75%) and NWPR (78%). The algorithm outputs a continuous score between 0 and 1, which are 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 the WOTUS-ML model used in Greenhill et al. (2024) (Panel B). Appendix C.1 provides further details.

We use the algorithm to predict how the change between *Rapanos* and NWPR affected jurisdictional probabilities at each site. 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 parcels by 15pp, or 41 percent relative to baseline levels.

4.2 Econometrics: Jurisdiction

We use the following equation to estimate how NWPR affects Clean Water Act jurisdiction, measured using either the wetland map or the algorithm:

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

$$Y_{ict} = \beta(p_{iR} - p_{iN})N_{it} + \alpha_1 p_{iR} + \alpha_2 p_{iN} + \gamma N_{it} + \varepsilon_{ict} \tag{2}$$

Here Y indicates whether AJD i located in commuting zone c finalized on day t is jurisdictional. In equation (1), the variable 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 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 $\times$ month fixed effects given our interest in estimating mean differences in jurisdiction across rules, though we also estimate a version that includes year $\times$ month fixed effects.

Equation (2) uses the algorithm to assess how NWPR affected regulation. 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 (2) on a held-out test set of AJDs excluded from model training.

We have clear priors on the magnitude of the coefficients from equation (2). In equation (2), α_1 represents the relationship between algorithmically-estimated probability of regulation and true regulation under *Rapanos*. With a perfect algorithm and large sample, α_1 would equal 1. Finally, α_2 represents the effect of a site's probability of regulation under NWPR on its actual regulation under *Rapanos*; we expect this to equal zero. The main parameter of interest, β, represents the relationship between algorithmic estimates of the difference in jurisdiction between *Rapanos* and NWPR and the actual difference in jurisdiction. If the algorithm had perfect performance, β would equal -1.

4.3 Property Values

To assess how Clean Water Act regulation affects property values, we estimate a differences-in-differences model which identifies the effect of regulation from interactions between the months when NWPR is in force and cross-sectional variation in the share of each site with water resources:

$$\ln(P_{izct}) = \beta W_i N_t + \alpha W_i + X'_{izt}\gamma_1 + (N_t X_{izt})'\gamma_2 + \eta_{zt} + \varepsilon_{izct} \tag{3}$$

Here P_{izt} represents the transaction price for parcel i in zip code z sold at year $\times$ month t. W is as in equation (1). In this equation, N is an indicator that equals one during the statutory period of NWPR and zero otherwise. Unlike in equation (1), N is a pure time indicator. The controls X_{izt} include parcel size in acres and proxies for the COVID housing boom (Ramani et al. 2024)—the distances of site i from the closest metropolitan center and town center, the population density, and the share of people who work from home. The interactions $(N_t X_{izt})'$ let effects of the controls vary between *Rapanos* and NWPR. We control for acreage since it is one of few parcel attributes reported for most non-residential sites and comparable across different land use types (agricultural, commercial, industrial, etc.), where residential dwelling characteristics like bedrooms and bathrooms are not relevant. The five-digit zip code $\times$ year $\times$ month fixed effects η_{zt} adjust for overall changes in local regulation, 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. The error term ε_{izct} allows autocorrelation (clustering) by commuting zone, given commuting zones' relationship to housing markets and geophysical patterns of wetland extent. Equation (3) lets wetlands have different effects on land values under different Clean Water Act rules. We separately report results for residential and for non-residential parcels. Although our main analysis begins in 2017 and provides a somewhat even window on either side of the introduction of NWPR, since we have land transaction data back to 2010, we also report an extended event study using data over the period 2010–2023. Because few properties with AJDs transact, we estimate equation (3) using all parcels, not only parcels with AJDs (see Appendix C.4).

The coefficient β describes how the change in log property values between *Rapanos* and NWPR varies with the share of a parcel's area that has water resources. Finding $\beta > 0$ would indicate NWPR disproportionately increases values of parcels with water resources.

The identifying assumption for equation (3) to provide an unbiased estimate of the effect of NWPR on land values is that the wetland×regulation interaction $W_i N_t$ is independent of the regression error, conditional on the other explanatory variables:

$$E[W_i N_t \cdot \varepsilon_{izct} | W_i, X_{izt}, (N_t X_{izt})'] = 0 \tag{4}$$

This assumption would fail if sale prices of water resource parcels and non-water resource parcels would have had different trajectories in the absence of NWPR (failure of parallel trends). Additionally, conditional on controls, we assume that NWPR does not affect parcels without water resources. As we discuss below, we use a range of tests to assess the validity of assumption (4).

More broadly, because equation (3) identifies changes in land values within a five-digit zip code×year×month, it normalizes away changes in land values that affect entire zip codes. Sections 6.2 and 8 revisit this by examining how land values vary with proximity to wetlands and discussing how outward shifts in the supply of land may affect land values in an entire region and lead our analysis to understate the willingness to pay for deregulation.

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

$$\ln(P_{izct}) = \beta^A(p_{iR} - p_{iN})N_t + \alpha_1 p_{iR} + \alpha_2 p_{iN} + X_i'\gamma_1^A + (N_t X_i)'\gamma_2^A + \eta_{zt}^A + \varepsilon_{izct}^A \tag{5}$$

Here $p_{iR} - p_{iN}$ is as in (2), we control for the probabilities of regulation p_{iR} and p_{iN} under *Rapanos* and NWPR. As in equation (3) we add parcel-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 parcels it deregulated.

We note that equation (5) is equivalent to

$$\ln(P_{izct}) = \alpha_1 p_{iR} + \alpha_2 p_{iN} - \beta^A p_{it} + X_i'\gamma_1^A + (N_t X_i)'\gamma_2^A + \eta_{zt}^A + \varepsilon_{izct}^A \tag{6}$$

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. Equation (6) 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 use the following equation to report event study graphs of how NWPR affects land values:

$$\ln(P_{izcqt}) = \sum_{\tau} \left(\beta_\tau W_i \mathbb{1}[q_q = \tau] + (\mathbb{1}[q_q = \tau]X_i)'\gamma_\tau\right) + \eta_{zt} + \varepsilon_{izcqt} \tag{7}$$

The indicator $\mathbb{1}[q_q = \tau]$ equals 1 if year×quarter q_q equals τ and 0 otherwise. The coefficients β_τ represent the difference in the value of fully wetland relative to non-wetland parcels, in year×quarter τ relative to the reference time period. Estimating coefficients for each year×quarter q allows the effects of parcel characteristics X_i to vary flexibly with event time. To provide a visual inspection of pre-trends and assessment of how property values change in time periods around rule changes, the coefficients γ_τ let effects of the COVID boom controls X_{it} vary by year×quarter. We plot the coefficients β_τ against the year×quarters they represent. We use the first quarter of 2019 as the reference category, which clearly predates NWPR announcements.

4.4 Extensions and Sensitivity Analyses

In addition to the event study analysis, controls for proxies for the COVID housing boom, comparison of the wetland map and algorithm as proxies for NWPR deregulation, and comparison of effects for residential and non-residential parcels, we report two other sensitivity analyses. One 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 parcel, measured by either the wetland map or algorithm:

$$\ln(P_{izct}) = \sum_m \beta_m \mathbb{1}[W_i \in m] + X'_{izt}\gamma_1^B + (N_t X_{izt})'\gamma_2^B + \eta_{zt}^B + \varepsilon_{izt} \tag{8}$$

$$\begin{aligned}\ln(P_{izct}) = \sum_m \Big(\alpha_{1m}\mathbb{1}[p_{iR} \in m] + \alpha_{2m}\mathbb{1}[p_{iN} \in m] + \beta_m^N \mathbb{1}[p_{it} \in m]\Big) \\ + X'_{izt}\gamma_1^N + (N_t X_{izt})'\gamma_2^N + \eta_{zt}^N + \varepsilon_{izt}^N\end{aligned} \tag{9}$$

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 (9), the indicators $\mathbb{1}[p_i \in m]$, $\mathbb{1}[p_{iR} \in m]$, 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 directly tests for possible confounding due to the COVID housing boom by measuring whether NWPR had disproportionate effects on non-residential property values in areas that had an above-median trend break in residential property values in March 2020:

$$\begin{aligned}\ln(P_{izct}) = \kappa W_i C_z N_t + X_i'\gamma_1^C + \alpha W_i + \rho C_z + \phi W_i C_z + \beta W_i N_t + \psi C_z N_t \\ + (N_t X_i)'\gamma_2^C + \eta_{zt}^C + \varepsilon_{izct}^C\end{aligned} \tag{10}$$

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 the appreciation of wetland properties under NWPR was larger in areas that had a residential home price boom. The comparison group is wetland parcels under NWPR in non-COVID-boom areas.

4.5 Development

To analyze patterns of development around AJDs, we implement the "imputation" event study estimator proposed by Borusyak et al. (2024) (BJS), which addresses identification issues that arise from using two-way fixed effects specifications in settings with staggered treatment timing.

Let E_i denote the year parcel i gets an AJD. For parcels that never get an AJD, let $E_i = \infty$.

The BJS estimator proceeds in two stages. First, we estimate the evolution of outcomes in the absence of treatment using only observations before the event time using the following regression equation:

$$L_{ict} = \lambda_{ct} \; + \; \eta_i \; + \; u_{ict} \tag{11}$$

for observations with $t < E_i$. As in previous equations, λ_{ct} and η_i are commuting zone×year and unit fixed effects, respectively. The term L_{ict} represents the share of a given land use (developed or wetland) within a 100m radius of site i in commuting zone c in year t. Using the estimated fixed effects, we construct predicted counterfactual outcomes $\hat{L}(0)_{ict} = \hat{\lambda}_{ct} + \hat{\eta}_i$ for all parcel-year observations. We use this predicted counterfactual to residualize the outcome variable by taking the difference $\delta_{ict} = L_{ict} - \hat{L}(0)_{ict}$.

In the second stage, we estimate the following dynamic event study on the residualized outcome:

$$\delta_{ict} = \sum_{\tau} \Big(\alpha_\tau + \beta_\tau \, D_i + \gamma_\tau \, W_i \Big) \, \mathbb{1}[t = \tau] \; + \; \varepsilon_{ict} \tag{12}$$

Since we are estimating the effect of deregulation, the treatment variable $D_i \equiv 1 - Y_i$ equals one if parcel i is not regulated and zero if it is regulated. Event time indicators τ omit $\tau = -1$ as the reference period. We interpret β_τ as the differential effect of getting an AJD in relative period τ for nonregulated parcels relative to regulated parcels. Interactions of W_i with event time indicators ensure that comparisons are made between parcels with similar regulatory exposure. We compute standard errors by bootstrapping this process 100 times.

To recover the distinct effects of getting an AJD on land use by regulation status, we estimate the slightly modified second stage:

$$\delta_{ict} = \sum_{\tau} \left(\alpha_\tau + \beta_\tau^{(1)} \mathbb{1}[D_i = 1] + \beta_\tau^{(0)} \mathbb{1}[D_i = 0] + \gamma_\tau W_i \right) \mathbb{1}[t = \tau] \; + \; \varepsilon_{ict} \tag{13}$$

where $\beta_\tau^{(1)}$ is the effect of getting an AJD on land use for unregulated parcels and $\beta_\tau^{(0)}$ is the effect for regulated parcels.

We obtain average effects of AJDs on land cover by replacing the full set of event-time indicators with an indicator for the post-AJD period. This allows us to summarize the average post-AJD effect while maintaining the same residualized outcome constructed in the first stage. Our baseline specification is:

$$\delta_{ict} = \alpha \mathbb{1}[t \geq E_i] + \beta \, D_i \mathbb{1}[t \geq E_i] + \sum_{\tau} (\gamma_\tau \, W_i \, \mathbb{1}[t = \tau]) + \varepsilon_{ict} \tag{14}$$

where $\mathbb{1}[t \geq E_i]$ is an indicator equal to one in years following an AJD for parcel i. The coefficient of interest, β, captures the differential change in land use following an AJD by regulation status.

We also estimate two extensions of this specification to assess the sensitivity of our results to differential trends. First, we allow for differential pre-trends between regulated and unregulated parcels by including a linear time trend and its interaction with regulation status (τ and τD_i). Second, we allow 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 $\tau D_i \mathbb{1}[t \geq E_i]$).

4.6 Random Forest To Estimate the Market Value of Non-Transacting Properties

The analysis of aggregate land market effects of NWPR in Section 8 requires the fair market values of all parcels, not only those that transact. Residential properties transact frequently and are sufficiently homogeneous that repeat-sales indices (e.g., Zillow, Case-Shiller) reliably estimate market values even for non-transacting homes. No comparable indices exist for non-residential parcels, which transact infrequently and vary widely in size, use, and characteristics. However, county assessor records provide information on both transacting and non-transacting parcels, including each parcel's assessed value. We use this information to train a random forest model to predict the fair market value of each non-residential parcel.

Predictor variables include county, land use code, year assessed, assessed value, and property acres.

Table A4 shows the results of this random forest. The mean non-residential parcel nationally has almost double the acreage of the mean transacted parcel, at 27 versus 15.5 acres. Non-transacting parcels therefore have much lower value per acre than transacting parcels. Appendix C.2 discusses the model and its performance in detail. Nationally, we find a ratio of transaction price to assessed value of 1.998, implying that assessments average half of market value. This ratio varies substantially across states and counties, reflecting heterogeneous assessment policies and revaluation frequencies. Comparing the total estimated fair market value to total assessed value for assessed properties implies an average transaction price to assessed value ratio of 2.46; however, there is significant heterogeneity in the ratio across counties, land use types, and other observables. Figure A7 provides a visualization of the spatial heterogeneity in both observed and predicted values, and appendix C.2 provides further details.[11]

5 Effect of NWPR on Regulatory Stringency

Figure 2 shows the share of AJDs that the Army Corps determines to be jurisdictional in each quarter. In each panel, the red vertical lines demarcate the period when NWPR was operating, from the beginning of 2020 through the third quarter of 2021. As Section 2.3 notes, we emphasize that NWPR was finalized in January 2020 but only implemented in June 2020. In Panel A, blue circles represent sites in the top quartile of mapped water resources ($\geq$ 19% water resource share) and red squares represent sites with no mapped water resources (36% of all AJDs). Similarly, in Panel B, the blue circles describe sites with high probability of deregulation under NWPR, defined as having the top quartile of algorithmic predictions $p_{iR} - p_{iN}$, and the blue squares describe properties below the 36th percentile of the change in probability of regulation under NWPR.

Figure 2 reveals that NWPR decreased regulation for all parcels, and especially for parcels that the wetland map and algorithm indicate are most likely to be deregulated. In

[11] 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. 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.

both panels (A) and (B), before NWPR, regulation has fairly flat trends. After NWPR begins in early 2020, parcels with water resources and parcels the algorithm predicts to be deregulated have especially low probability of regulation. The effect occurs in the second and especially third quarter of NWPR, when the Army Corps begins using NWPR for AJDs, but not in the first quarter of 2020, when EPA and the Army Corps finalized plans for NWPR. Panel A shows that NWPR decreased the probability of regulation by about 10 percentage points (pp) for sites without mapped water resources but by 20pp for sites with a high share of water resources. Panel B shows that parcels which the algorithm identifies as most likely to be deregulated have especially large decreases in regulation. Perhaps unsurprisingly, since the algorithm is trained to predict the probability of regulation under each rule, the algorithm isolates a larger drop in regulatory probability under NWPR than the wetland maps do. While Figure 2's use of binary partitions to separate high and low deregulation groups permits simple graphs, the rest of our analysis uses the full continuous variation in wetland extent and the estimated probability of deregulation.

Table 2 provides corresponding regression estimates. Column (1) shows that the share of AJDs jurisdictional was 36.4% under *Rapanos* but fell by 11.7pp under NWPR. Column (2) uses equation (1) to find that for sites with no nearby mapped water resources, NWPR decreased the probability of regulation by 8.3pp. We conjecture that most of these sites have nearby wetlands that NWI missed, though some may have drainage infrastructure on historic wetlands or other explanations. For sites fully covered in water resources, NWPR decreased the probability of regulation by 20.3pp. 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 51.8pp. This estimate is large and positive because the National Wetlands Inventory measures surface water resources and because Army Corps engineers consult it in determining jurisdiction. This coefficient is smaller than 100pp both because *Rapanos* does not regulate all water resources and because the National Wetlands Inventory imperfectly measures the presence and extent of water resources. Column (3) estimates equation (1) on the held-out test set of AJDs excluded from model training, confirming the NWI relationship holds out of sample. Column (5) analyzes the water share data using the test set, as in equation (2). Section 4.3 discussed 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 (1.12, -0.05, and -1.14) are near this benchmark.

The coefficient near zero (0.017) on NWPR is also sensible, since it suggests that parcels where the algorithm predicts no probability of regulation under NWPR had zero additional probability of regulation under NWPR. These coefficients provide additional evidence that the algorithm is well-calibrated.

6 Effect of NWPR on Property Values

6.1 Estimated impacts

The event study graphs in Figure 3 assess how NWPR affects land values. The left panels use the wetland map and the right panels use the algorithmic prediction of regulation from Section 4.1. The horizontal axis of each graph indexes year×quarters. The vertical axis shows coefficients from the equation (7) regression of log property transaction value on interactions of the year×quarter with either the water resource share or the algorithmically-estimated deregulation.

Non-Residential Properties

Panel A of Figure 3 shows that NWPR substantially increased values of non-residential parcels with mapped water resources. Before NWPR began in early 2020, parcels with mapped water resources had broadly similar trends to parcels without water resources, though with some quarterly variability. Only one of the eleven pre-NWPR quarters is statistically significant at conventional levels and point estimates vary in sign about zero. Beginning in early 2020, when NWPR began, property values for fully water parcels increased by over 20 percent. These point estimates remain large and positive through the third quarter of 2021, while NWPR was in force. The algorithmic estimate in Panel B reveals a similar pattern but with larger magnitude, perhaps partly because the algorithm more effectively identifies which parcels NWPR deregulated.

Panels A and B of Figure 3 suggest that the effect of NWPR on land values attenuated somewhat after a court vacated NWPR in late 2021. Most point estimates from quarters after NWPR have smaller magnitude than during NWPR, and the post-NWPR values are not statistically significant. 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.[12] Although a late 2021 court ruling vacating NWPR restored regulation in the short run, land values depend on 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 (3) and (5). The main coefficient of interest describes how non-residential land values change under NWPR, for the properties that NWPR is most likely to deregulate. Columns (1) through (3) use the wetland map to measure deregulation while columns (4) through (6) use the algorithm. Positive values indicate that deregulated properties had higher transaction values under NWPR. Columns (1) and (4) control for zip code $\times$ year $\times$ month fixed effects. Columns (2) and (5) also control for the parcel size in acres. Columns (3) and (6) add parcel-level controls for the COVID-19 housing boom – work-from-home share, distance to closest population center and central business district, and population density – from Ramani et al. (2024).

Panel A of Table 3 Columns (1-3) finds that NWPR increased the value of properties that are fully water resources by 15 to 20 percent, with a standard error of about 3 percent. The estimates with and without controls have fairly similar magnitudes. The acreage and COVID controls slightly increase the point estimates' magnitude, by about one standard error. The richest specification, in column (3), indicates that NWPR increased the value of fully water non-residential parcels by 19.1 percent ($= e^{0.175} - 1$). To give additional context, we estimate that fully wetland non-residential properties sell for about 30.9 percent lower value, so NWPR decreases the penalty associated with fully wetland non-residential properties by nearly two thirds.[13]

Columns (4-6) in Panel A of Table 3 report the estimated effects of deregulation on property values using the algorithmic model. These estimates imply that NWPR increased property values by 73 to 119 percent for parcels that moved from 100 percent to 0 percent probability of regulation, with standard errors between 19 and 32 percent. Controlling for

[12] Unfortunately, our direct knowledge, internet searches, and investigation using large language models all indicate that no online prediction markets in this period describe beliefs about the expected probability of a ruling like *Sackett*.

[13] Table 3 does not show the coefficient on wetland area since it is effectively a cross-sectional estimate, and we include it primarily to obtain a differences-in-differences estimate of the coefficient on the interaction $W_i N_t$.

acreage increases the point estimate by more than one standard error, but including COVID controls in addition to acreage restores the point estimate to only slightly above the estimate with no controls. The richest specification, in column (6), indicates that moving from 100 percent to 0 percent probability of regulation increases property values by 77.8 percent ($= e^{0.576} - 1$) with a standard error of 19.4 percent. This estimate is robust to using multiple imputation to correct for potential biases in the parameter estimate and standard errors arising from using a machine-learned treatment (see Appendix Section C.5 and Table A2).[14]

Residential Properties

As Section 5 discussed, Clean Water Act deregulation is likely to affect non-residential properties most since residential properties more often have single-family housing and since development is far less common for residential properties. At the same time, residential parcels provide an important comparison. The event study graphs in Panels C and D of Figure 3 show that NWPR had no detectable effect on the value of residential parcels with water resources. The analysis using the wetland map in Panel C obtains point estimates that vary about zero. The analysis using the algorithm in Panel D obtains fairly flat point estimates that are mostly statistically indistinguishable from zero. These graphs provide little evidence that NWPR affected residential land values.

Panel B of Table 3 reports corresponding regression estimates. The regressions with the most detailed controls in columns (3) and (6) find that the effect of NWPR on the log property value of residential parcels is -0.007 (0.016) using the wetland map, or 0.025 (0.034) using the algorithm. While the confidence intervals do not rule out impacts of a few percentage points, they do exclude anything close to the non-residential values, and most of the point estimates for impacts on residential parcels are actually negative.

Panel C of Table 3 shows a triple-difference regression analyzing changes in values of non-residential versus residential properties. This specification implicitly assumes that residential properties serve as a control for possible local confounding variables. While we see good reason to question this strong assumption, we present these regressions for completeness.

The point estimates are extremely similar to those of the main non-residential estimates in Panel A. In the richest wetland map estimate of column (3), for example, the Panel A

[14] 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).

estimate finds that NWPR increased the log value of fully wetland properties by 0.175 (0.030), and the estimate using residential properties as a comparison group in Panel C obtains an estimate of 0.182 (0.034). The algorithm obtains similar patterns.

6.2 Extensions and Additional Sensitivity Analyses

This subsection discusses several alternatives to the main estimates that vary the sample and specification of our estimates on how NWPR affects land markets.

Semi-parametric bins

We first integrate more flexible measures of deregulation. Following equations (8) and (9), we let the effect of NWPR on property values vary semi-parametrically with ten bins measuring the share of a parcel covered in water resources or the algorithmically-estimated deregulation between *Rapanos* and NWPR. The reference group includes parcels with no nearby water features.

Figure 4 finds that the effect of NWPR on a non-residential parcel's transaction value generally increases with measures of exposure to regulation. In panel A, the blue circles show coefficients on indicators for whether a parcel 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 parcels with no water, parcels where 0 to 10 percent of the area is water had value increase only 1.5% ($= e^{0.015} - 1$) under NWPR, and parcels where 10 to 20 percent is water had a significantly greater increase of 7.0% ($= e^{0.067} - 1$). Effects grow close to linearly up to parcels with 50 to 60% water, whose value increases by 14.4% ($= e^{0.135} - 1$). The pattern somewhat flattens for parcels above 60% water, though Panel C shows that few parcels have water shares above 60%. Panel B shows a monotonic relationship between the probability a site was deregulated and the increase in the site's value under NWPR.

The orange diamonds in Panels A and B show corresponding estimates for residential parcels. 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. The top two bins in panel B (greater than 80% probability of regulation) do have small and insignificant positive values,

though panel D shows that we observe few of these points. Echoing the earlier differences-in-differences estimates, these semi-parametric estimates suggest that NWPR primarily affected non-residential parcels and had little detectable impact on residential parcels.

Extended housing panel

Although we lack AJDs and land use data far before NWPR, we do have land transactions data back to 2010. One might expect that the 2016 election, during which President Trump discussed weakening Clean Water Act regulation, or EPA's initial discussions of NWPR before 2020, could cause anticipation effects as developers purchased land with the hope of developing it under Clean Water Act deregulation. Figure A8 extends the event studies shown in Figure 3 back to this year. The analysis of non-residential parcels in Panel A shows that relative to parcels without wetlands, wetland parcels have flat price trends and no detectable change in the value of water resource parcels 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 parcels in time periods before NWPR. The estimated effect of NWPR in this longer panel echoes the estimates discussed earlier from the 2017-2023 data, shown in Figure A8. Panel B shows corresponding estimates using the algorithm. The period before 2017 has wider confidence intervals since it has fewer transactions and since the algorithm is trained in earlier years so may have lower performance in these earlier years, before AJD data are available. NWPR has the only systematically positive values in the entire extended panel. Notably, neither panel of Figure A8 shows detectable changes when Trump was elected in November 2016, or in the early discussions of a new possible Clean Water Act rule before 2020.

Sub-categories of non-residential land use

Non-residential parcels include several sub-categories of land use, and distinguishing among these may provide insight on how NWPR affects land markets. Appendix Figure A9 reports versions of equation (3) estimated separately by sub-category of land use. Property assessment records list these land uses typically reflecting county zoning and distinguishing agricultural, commercial, vacant, industrial, public, and other properties.

The first entry in Panel A of Figure A9 shows the point estimate for all non-residential properties, with specification corresponding to column (3) of Table 3. The next several

entries investigate sub-categories of non-residential properties, corresponding to the groups from Appendix Table A3. We obtain a positive point estimate for each sub-category of land use, though precision varies. Vacant parcels, accounting for almost half the sample as the largest sub-category, have the only statistically significant estimate. Agricultural parcels have a smaller point estimate than most other non-residential land use categories. The smaller point estimates for agriculture could reflect the Clean Water Act's exclusion of normal agricultural operations from regulation, although the confidence interval is too wide to reach meaningful conclusions. The bottom of Panel A shows the near-zero effect for residential land use. Panel B suggests that vacant parcels account for much of the treatment effects that we estimate overall for non-residential parcels, though the point estimates for other sub-categories of non-residential remain somewhat imprecise.

Size of COVID residential housing boom

Finally, we use equation (10), to obtain one other sensitivity analysis for whether the COVID boom affects our estimates. We divide the U.S. into zip codes with above- versus below-median increase in residential housing values during the pandemic. We determine the relevant zip codes by finding areas in the top and bottom quartile of trend breaks in the Zillow Home Value Index starting in March 2020, following Ramani et al. (2024).

Figure A10 shows the change in the Zillow Home Value Index separately for properties that had an above-median trend break (solid blue) and properties that had a below-median trend break (dashed red). The groups followed similar trends through mid-2020 and clearly diverged in late 2020. We note that the COVID housing boom barely began in the third quarter of 2020 and took off in the fourth quarter of 2020, two quarters after Figure 3 shows the effect of NWPR on non-residential housing values begins.

Table A5 uses equation (10) to test for differences in the estimated effect of NWPR on non-residential property between these two sets of zip codes. Column (1) repeats the main estimate from Table 3. Column (2) finds that the effect has similar magnitude and is statistically indistinguishable in zip codes that had especially large COVID residential housing booms. The point estimate of the effect of 0.016 (0.064) is under a tenth the magnitude of the main estimate. The standard error fails to reject zero, though is wide enough not to rule out moderate magnitudes. Estimates using the algorithm in Panel B have similar patterns—areas with a residential COVID boom have an insignificantly different and

negative estimated change in non-residential land values. Overall, these patterns suggest that the growth in the value of wetland non-residential parcels under NWPR is fairly independent of the COVID residential housing boom.

Land Supply and Distance to Wetlands

Thus far we have sought to estimate the extent to which removing wetland protection may increase the demand for wetland parcels, given the decreased potential development cost. The supply of total parcels (including wetland) is fixed—developers cannot create parcels out of thin air. The supply of developed land, however, could increase in response to wetland deregulation. This outward shift in the supply of developed land could decrease the equilibrium transaction value of all nearby land parcels.

Several results thus far suggest that our estimates capture only the increased demand for wetland parcels due to wetland deregulation. First, all our estimates include zip code $\times$ year $\times$ month fixed effects, which imply that we compare land values across parcels within a zip code, and which adjust for the market-wide shifts in land values due to supply or other reasons. Second, any residual changes in the equilibrium price of all parcels would affect prices of residential parcels, but we detect little effect of wetland deregulation on residential parcels.

This subsection reports additional tests for the robustness of our estimates. We first test whether shifts in the supply of developed land affect our results, then assess whether our choice of a 100-meter radius is appropriate and whether there are spatial spillovers onto neighboring parcels.

We assess potential violations of SUTVA and other spatial spillovers by examining how the effects of NWPR vary with proximity to wetlands among non-wetland parcels. If deregulation reallocated demand from non-wetland parcels toward wetland parcels, then non-wetland parcels that are closer to wetlands, where wetland parcels are closer substitutes, should experience a relative decline in prices compared to more distant non-wetland parcels. Similarly, if deregulation reduced the amenity value of wetlands, for example through wetland loss or degradation, then the environmental services previously capitalized into nearby land values would diminish, leading to larger price declines for parcels located closer to wetlands. Under either mechanism, NWPR would generate a negative price gradient with respect to distance to the nearest wetland among parcels with zero water resource share.

To assess these potential spillovers, we estimate how the price effect of NWPR varies with distance to the nearest wetland. Figure 6 presents two complementary specifications. Panel A distinguishes wetland parcels from non-wetland parcels and then bins non-wetland parcels into deciles based on distance to the nearest wetland. Consistent with our baseline results, parcels with wetlands experience a positive and statistically significant price increase during NWPR, while non-wetland parcels exhibit no systematic response. Importantly, among non-wetland parcels, proximity to wetlands does not predict larger price declines: parcels closer to wetlands are no more negatively affected than those farther away. This pattern provides no evidence of spatial spillovers operating through either substitution away from nearby non-wetland parcels or reductions in wetland amenity values.

Panel B reports an alternative specification that bins all parcels (wetland and non-wetland) by distance to the nearest wetland. Positive price effects are concentrated among parcels closest to wetlands and attenuate with distance. Although there is no sharp cut-off, the effect of NWPR on property values approaches zero between the third and fourth distance deciles (i.e., 54-126 meters from the nearest wetland), lending empirical support to the 100-meter threshold used in our main analysis. Together, these results reinforce the interpretation that NWPR increased the value of parcels with proximate wetlands by relaxing development constraints, rather than through broader spatial reallocation or negative spillovers in surrounding land markets.

7 Mechanisms: Permitting and Land Use Change

This section investigates how NWPR affected permitting and land use, with two purposes. First, analyzing these outcomes clarifies a mechanism for why the previous section finds that NWPR affects land values. Because we interpret the increase in land values as reflecting the demand for development, observing an increase in development helps complete the narrative of how and why NWPR affected land values. Second, this section provides some evidence on NWPR's environmental impacts, which Section 8 uses to compare NWPR's measured economic benefits and environmental costs.

Many anecdotes describe how NWPR affected development. The discussion of Bridgeland in Section 2.4 provides one example. Appendix Figure A11 depicts two news stories that provide others—the decisions under NWPR 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 to more aggregate statistics, the graph in Figure 5 shows the number of AJDs, by month. The solid black line shows NWPR and the dashed line shows AJDs under other rules, primarily *Rapanos*. AJDs proxy the inception of development projects.

Figure 5 shows that before NWPR, developers obtained on average 1,154 AJDs per month. After NWPR began, the average number of AJDs rose to 3,635 per month. The count remained fairly steady until NWPR was vacated in late 2021. The average number of monthly AJDs then fell to 1,424. While the statutory period of NWPR lasted from January, 2020 to August, 2021, the Army Corps only issued AJDs under NWPR from an approximately 14-month period from June, 2020 through July, 2021. If NWPR increased the number of AJDs by 2,481 per month and for 14 months, this comparison implies that NWPR increased the number of AJDs by about 2.5 years' worth, measured at pre-NWPR levels. This represents a large total increase in development. This large increase in AJDs during NWPR suggests that developers recognized the extent and value of deregulation under NWPR and responded accordingly.

Because NWPR changed regulation for a broad set of sites, we study impacts on development using an event study around AJDs. Changes in land values likely occur soon after deregulation, since land values reflect both expected future rents from owning a parcel and the option for future development. Changes in land use may occur more slowly after development, however, as landowners plan development, hire contractors, and undertake construction. Additionally, AJDs typically remain valid for five years, so a developer could wait four years after an AJD to obtain a wetland permit and then begin development. Following equation (1), we therefore compare development outcomes around the time of an AJD for regulated versus not regulated sites, controlling for a site's wetland extent or probability of regulation.

Figure 7 shows the resulting event study graph. Red diamonds show regulated sites and blue circles show non-regulated sites. Panel A uses the share of area within 100 meters of a site that has impervious surfaces as the outcome, which proxies development. Panel B uses the share that has wetlands as the outcome. We use the NLCD to measure both land use shares. Remote sensing has more measurement error in detecting wetlands than in detecting

impervious surfaces.

Figure 7 shows that development expands impervious surfaces and removes wetlands. Because the regression controls for interactions of the probability of regulation with event time, this analysis reflects the differential development of non-regulated versus regulated parcels with observably similar characteristics. Panel A shows that in years before an AJD, sites have virtually no differential trend in the share of land that is impervious. After an AJD, development expands more rapidly for non-regulated sites than for regulated sites. After four years, the share of land that is impervious increases by 2.6 percentage points more in non-regulated sites relative to regulated sites. Given the persistently linear slope of these differences, though 4+ years after an AJD, the longer-term difference between the effects of an AJD project on the share of land development for deregulated sites relative to regulated ones may exceed 2.6 percentage points.

Panel B of Figure 7 examines wetland depletion around the time of AJD projects. In years before an AJD, sites have no differential trend in wetland extent. After an AJD, non-regulated sites have a greater decline in wetland share relative to regulated sites. After four years, wetland shares in non-regulated sites decline by 0.573 percentage points more than in regulated sites.

Figure A12 shows estimates from the same regression using the algorithmically-estimated deregulation rather than water resource share. Figure A13 shows the effects of an AJD on land use outcomes distinctly for nonregulated and regulated sites, as estimated by equation (13).

Table A6 reports corresponding regressions. Columns (1)–(3) examine impacts on the share of land that is impervious. Columns (4)–(6) examine impacts on wetland extent. Columns (1) and (4) report a standard mean-shift estimate which allows outcomes to discretely change post- versus pre-AJD. Columns (2) and (5) allow non-regulated sites to have a differential trend in outcomes even before an AJD project begins. Columns (3) and (6) allow this trend to 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 five years, for non-regulated versus regulated sites.

Table A6 finds moderate effects of AJD projects on impervious surfaces, especially for deregulated sites, and smaller effects on wetlands. The main estimate in column (1) indicates that after 5 years, an AJD 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 or allowing for a trend break do not substantially change the magnitude of the estimated effects. The corresponding main estimate for wetland share after 4 years in column (4) is -0.16% for non-regulated sites and 0.37% for regulated sites, implying that deregulation decreases the wetland share around sites by 0.53 percentage points relative to a baseline mean of 5.39%. Estimates in columns (2) and (5), which allow for a differential trend in regulated sites, are somewhat smaller than the main estimates, but the effect of regulation is still different from zero at 99% confidence. Columns (3) and (6), which further allow for a trend break in regulated sites, estimate much larger effects for both regulated and unregulated sites.

8 Measured Costs and Benefits

This section discusses the aggregate effects of NWPR on land values and flood mitigation, then discusses welfare implications.

8.1 Aggregate Effects of NWPR on Land Values

We use regressions from earlier in the paper to calculate how deregulation affected the market value of non-residential properties. We use the semi-parametric binned rather than the linear estimates here because the non-linear effects capture the uneven distribution and effects of water resource shares across properties. These regressions imply that NWPR increased the value of the mean log transacted non-residential property value by 0.0081 to 0.0084, or slightly less than one percent. Column (1) of Table 4, Panel D, multiplies these estimates by the mean value of transacted properties. This calculation indicates that NWPR increased the mean value of non-residential properties that transact by $4,400 to $4,500.

Column (2) uses the estimated value of non-residential properties that do not transact, obtained from the random forest described in Section 4.6. These results suggest that non-transacting and transacting non-residential parcels have similar values, and so NWPR increased the value of the mean non-residential transacting property and the mean non-residential property overall by similar amounts.

We use the following equations to calculate how NWPR affects aggregate property values

and not just mean property values

$$\Delta P_1 = \frac{\sum_m (\beta_m T_m)}{\sum_m T_m} P \tag{15}$$

$$\Delta P_2 = \frac{\sum_j (\delta_j \Delta R_j \mathcal{T}_j)}{\sum_j \mathcal{T}_j} P \tag{16}$$

In equation (15), β_m represents the semi-parametric binned impact of how NWPR affects log property values in wetland bin m, from equation (8). The term T_m represents the total transacted value of non-residential properties in each wetland share bin m. The term P represents the total value of all U.S. non-residential properties, including properties that do not transact in our analysis sample. Equation (16) is similar but uses the algorithm rather than wetland bins, so δ_j represents the estimated impact of NWPR on the log value of properties in deregulation bin j from equation (9). Similarly, ΔR_j represents the estimated deregulation from *Rapanos* to NWPR in deregulation bin j. Finally, $\mathcal{T}_j$ represents the total value of transacted properties in this bin. Table A7 lists values of $T_m, \mathcal{T}_j$, and ΔR_j for each bin.

We calculate that the total fair market value of the near-universe of U.S. non-residential properties is $P = \$15.05$ trillion.

Equations (15) and (16) imply large impacts of NWPR on land values. Using either the wetland map or algorithm, we calculate that NWPR increased the value of the average non-residential property by 0.8%. Multiplying by the total value of non-residential properties implies that NWPR increased the value of all non-residential properties by $\Delta P_1 = \$126$ billion or $\Delta P_2 = \$123$ billion.[15]

We interpret NWPR as a shock to the quality of developed land, so that our estimates reflect the demand for unregulated versus regulated wetlands. As we discuss in Section 8.4, these estimates can be interpreted as a lower bound on the welfare effects of NWPR, accounting for sorting and general equilibrium effects (Banzhaf 2021).

[15] This figure is not comparable to the Greenhill et al. (2024) estimate of the value of land that NWPR deregulated. The Greenhill et al. (2024) calculation combines residential and non-residential land, counts whether a parcel had the probability of jurisdiction change from above to below 50% (by not how extensively each parcel 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.

Mitigation Banking Benchmarks of Regulatory Costs

Why does removing Clean Water Act regulation from wetland parcels increase their value? This subsection explores one important component of regulatory compliance costs. Under the Clean Water Act, many projects that develop wetlands must pay others to build wetlands that offset the developed areas. The market prices of these offsets, often called compensatory wetland mitigation, provide one benchmark for the change in land values that we estimate.

We assume an average mitigation cost of $150,000 per acre, based on scattered evidence that Appendix B.4 discusses. The mean non-residential parcel in our sample covers 15.5 acres, 0.83 of them wetlands. Column (2) of Table 2 estimates that NWPR deregulated 20.3% of wetlands or about 0.17 acres per parcel (=0.83*0.203). Column (3) of Table A7 indicates that the effect of NWPR on the value of the average property was 0.0081 to 0.0084. If deregulation affected all wetlands and no other areas, purchasing wetland offsets would cost $25,500 to $26,500 (0.0081/0.17, 0.0084/0.17) per acre of wetlands. We interpret Column (1) of Table 2 to say that NWPR decreased regulation by 11.7% and land value changes only reflect deregulated wetlands, this would imply that each regulated acre of wetlands is worth $220,000 to $226,000. An alternative avenue would consider how many wetland acres the average project actually develops, which Panel C of Table A8 indicates is 0.037 to 0.059 acres. This would imply value per developed wetland acre of $75,000 to $122,000 (4,400/0.059, 4,500/0.037). For context, Panel A of Table 1 implies that non-residential property values average $33,000 per acre (513,000/15.5). At $150,000 per acre, full deregulation would save about $28,500 per property in avoided mitigation costs. This magnitude would fully account for our observed property value effects if developers were required to purchase offsets for approximately 6 percent of wetlands. If only 1.5 percent of wetlands required offsets, mitigation banking costs would explain roughly one-quarter of the estimated price response. The remaining willingness to pay likely reflects other regulatory burdens such as permitting delays, project redesigns, and consultant or compliance costs (Sunding and Zilberman 2002).

While this calculation is approximate, it suggests that mitigation banking costs plausibly account for a meaningful share of landowners' valuation of deregulation. They also provide one benchmark suggesting that the land value impacts we estimate potentially have comparable order of magnitude as market prices for wetland compliance.

Comparing these magnitudes with estimated regulatory costs of other major environ-

mental laws reveals large magnitudes. The annual productivity cost of compliance with the Clean Air Act is estimated at around $20 billion (Greenstone et al. 2012). The Census Bureau's Pollution Abatement Costs and Expenditures Survey[16] estimates that industrial sources spend $10.3 billion annually on operating water pollution abatement equipment and $2.0 billion on investment in water pollution abatement capital. Keiser and Shapiro 2019 estimate U.S. spending of about $55.7 billion annually on drinking water treatment.[17]

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

This subsection infers the effect of NWPR on wetland area by combining our estimates of NWPR's effect on regulatory stringency from Table 2 and the effect of regulatory status on land cover from Figure 7. We then apply the estimates of how property damages from flooding respond to changes in wetland area from Taylor and Druckenmiller (2022) to value the associated change in flood protection services.

Hundreds of studies estimate value of different ecosystem services from wetlands using a mix of stated preference, travel cost, and related methods. Many of these studies look at a single water resource in a single region, leading to substantial geographical heterogeneity. Studies also vary in publication outlet; while many studies appear in peer-reviewed journals, others are government or agency reports or commissioned technical analyses. A few meta-analyses quantify the estimated monetized benefits of wetlands through various channels of different ecosystem services. Appendix B.5 and Table A9 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 percent of the estimated benefits of wetlands; nutrient removal, biodiversity, and recreation account for the remaining 45 percent. Including older meta analyses and averaging across studies would indicate that 25 to 37 percent of the value of wetlands reflects flood mitigation benefits; the ecosystem

[16] See https://www.epa.gov/sites/default/files/2017-04/pace_2005_ma200-05_1.xls, accessed Oct 10, 2025.

[17] We deflate values in this paragraph to 2024 U.S. dollars using the GDP deflator.

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.

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 between non-regulated and regulated sites following AJDs under NWPR (Panel B of Figure 7). Four years after an AJD, wetland cover grew by 0.258 percentage points on regulated sites and declined by 0.315 percentage points on non-regulated sites, implying that deregulation reduces wetland area by 0.573 percentage points Two features of the underlying data suggest that this estimate is 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 therefore interpret this estimate as a lower bound on the true effect of regulation on wetland extent.

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). This implies that NWPR reduced the value of wetland flood protection services by $13.9 to $22.0 billion. The range in these estimates reflects whether the change in regulatory stringency is estimated using the wetland map or the algorithm.

Remote detection of development is less susceptible to the detection errors that affect wetland mapping, as impervious surfaces have distinct spectral signatures and are measured as continuous fractions rather than binary classifications. We therefore compute alternative estimates of value of lost flood mitigation services based on changes in impervious land cover, assuming development replaces wetlands one-to-one. Table A8 shows results.

8.3 Comparing Flood Mitigation Benefits and Land Values

This subsection compares the estimated change in land values to the change in flood mitigation damages, then discusses implications for social welfare. Panel B of Table 4, column (4), indicates that NWPR increased national land values by $123 billion to $126 billion. These statistics include all non-residential parcels nationally, including both parcels that do and do not transact. The range reflects the difference between the algorithmic model and the wetland map model, which differ in this aggregate statistic by about 2.4% percent.

Panel D of Table 4 reports our estimate of the aggregate increase in flood damages due to NWPR.

Comparing these aggregate estimates of land value benefits against flood damages due to NWPR implies large ratios. One could interpret this ratio as comparing an important category of measured benefits against an important category of measured costs. Panel E of Table 4, column (4), indicates that this ratio ranges from 5.6 to 9.1, depending on the difference between the wetland map or the algorithm.

Table A8 shows analogous benefit-cost ratios under the alternative assumption that all newly impervious surfaces represent developed wetlands. The implied benefit-cost ratio under this conservative assumption is 1.2 to 2.0.

One could also ask how this policy change 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 Clean Water Act, 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 (Hahn et al., forthcoming). The CBO could use a version of this logic to model effects of Clean Water Act regulation on investment and government revenue.

8.4 Social Welfare

These statistics provide a partial welfare analysis of this law.[18] In the classic and simplest hedonic model (Rosen 1974), the effect of a marginal policy change in local amenities on land values measures the willingness to pay for this change. This framework has the appeal that it would imply that the change in land values represents the full benefits of this law.

A few important characteristics of this setting, however, complicate that interpretation. NWPR represents a discrete rather than marginal policy change. Additionally, we study

[18] We focus on a comparison of measured costs and benefits without reporting the marginal value of public funds (Hahn et al., forthcoming) because we analyze a change in regulation rather than a direct change in tax or subsidy rates.

how land values change over time, rather than studying a cross-section of units as Rosen's original paper described. In this setting, one can interpret the change in land values as providing a bound on the true willingness to pay for this policy change, rather than point identifying it (Banzhaf 2021).

Additionally, the controls in our research design imply that it analyzes changes in land values within a local area, and therefore that the analysis abstracts from changes in wages. In a more general setting, spatial policies may affect both wages and land values, and analysis of both land and labor markets is required to measure the full willingness to pay for the policy change (Roback 1982). In general, not measuring changes in wages due to a policy reform that people value will tend to understate its benefits.

While the total U.S. area is fixed, NWPR may affect the supply of developed land. This is related to the point that general equilibrium shifts in the price schedule of land quality can lead differences-in-differences hedonics to understate the welfare consequences of policy shocks (Banzhaf 2021). If this supply effect were important, then areas with elastic supply of developed land would likely experience larger increases in developed land supply due to NWPR, which would attenuate estimates of how wetland deregulation affects land values in these areas. We test this directly by interacting NWPR $\times$ water resource shares with eight equally-sized bins of metropolitan-level housing supply elasticity from Saiz (2010), as in Krause and Chakma (2025).[19] This suggests that supply-side shifts do not meaningfully bias our estimates.

Our estimates of aggregate property value changes can be interpreted as a lower bound on the land value–based welfare effects of NWPR for all households, accounting for sorting and general equilibrium effects (Banzhaf 2021). Specifically, our regression estimates capture movement along the ex-post hedonic price function (i.e., the price schedule prevailing after NWPR implementation) by comparing homes that were affected by NWPR deregulation to those that were not. As shown in Banzhaf (2021), when aggregated across households, such estimates correspond to Hicksian Equivalent Surplus: the amount of income that would need to be granted to U.S. households under the pre-NWPR interpretation of WOTUS to make them as well off, in terms of land values, as they are under NWPR.

[19] A Wald χ^2 test has p-value of 0.63, which fails to reject the hypothesis that the effect of NWPR on land values of wetland parcels is similar in areas with high and low housing supply elasticities. If our estimates reflected growing supply of developed parcels, the estimates might be more moderate at the higher supply elasticity bins, and we do not observe direct evidence of this.

Importantly, these estimates do not capture the full welfare effects of NWPR. They reflect only the component of welfare that is capitalized into land values and therefore exclude welfare changes arising from changes in environmental service flows that are imperfectly capitalized. Furthermore, the resulting welfare measure represents a lower bound because post-NWPR market prices are set by the marginal buyer, who gains less surplus than the average buyer. While the magnitude of the gap between this lower bound and total welfare is unknown, Banzhaf 2021 presents simulations indicating that the lower-bound estimates range from approximately 75% of equivalent surplus for large amenity changes affecting a substantial share of homes to 92% for smaller but non-marginal changes, suggesting that the bound is economically meaningful.

We also note that flood mitigation benefits represent only one component of wetlands' ecological benefits. Wetlands provide many additional ecosystem services, including water and air filtration, wildlife habitat, recreation, and carbon storage, which are not captured here. As we discuss below, better quantifying these ecosystem benefits would allow research and policy to more carefully incorporate their values.

More broadly, our estimates of aggregate land value impacts require caveats. Our estimate of the change in land values covers non-residential parcels. This estimate uses the same data filters as the main regressions, from Section 3 (removing properties with missing location, missing or unrealistic assessment values and acreages, etc.).[20] Additionally, our interpretation of land value-based changes in welfare as the economic cost of regulation assumes that property values do not capitalize the environmental benefits of wetlands, which would offset some forgone development costs. This assumption is broadly consistent with empirical evidence that water quality and wetland area changes do not substantially capitalize into property values (Keiser and Shapiro 2019; Taylor and Druckenmiller 2022) and surveys that reveal low willingness to pay for wetlands (U.S. EPA and U.S. Army Corps of Engineers 2021). The failure of these benefits to capitalize into home values may be explained by limited information on wetland benefits and the fact that most wetland benefits (i.e., flood mitigation, water quality, potential carbon storage) are enjoyed downstream or as public goods—with the possible exception of more localized values from a recreational and

[20] A large share are excluded for having reported value of <$100/acre, which may reflect non-arms length transactions or data errors. While the exclusions in aggregate account for 30% of all 39 million non-residential parcels in the CoreLogic data, they account for less than 1% of non-residential total land values.

wildlife perspective.

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 parcels, which are more subject to Clean Water Act regulation. Parcels 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 $123 to $126 billion, relative to the prior Clean Water Act rule.

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. Understanding impacts of other regulations would be valuable. *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 leave other ecosystem services from wetlands unmeasured, including water quality, biodiversity, and others. Comprehensively measuring these services would help better understand and design policies affecting wetlands. Our estimates also reveal substantial spatial heterogeneity in the costs and benefits of regulation, suggesting that a spatially differentiated approach—protecting high-value wetlands while streamlining permitting elsewhere—could outperform uniform regulation.

Finally, we do not distinguish what component 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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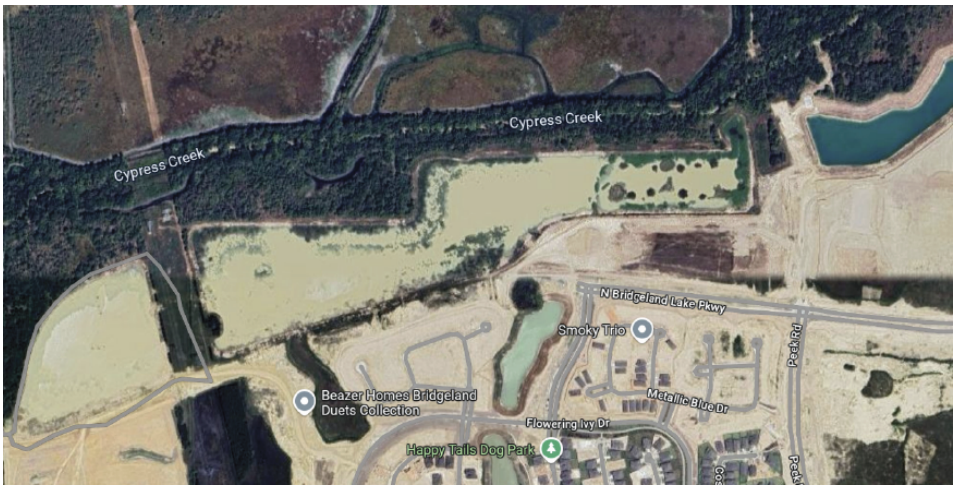
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Figure 1: Development Example From the Bridgeland Master Planned Community, Texas

(A) Aerial Image of Flooding, 2016



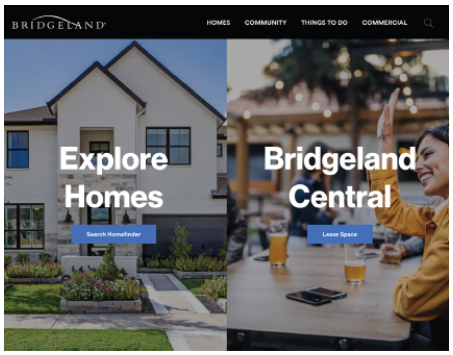
(B) Aerial Image of Development, 2024



(C) Google Street View



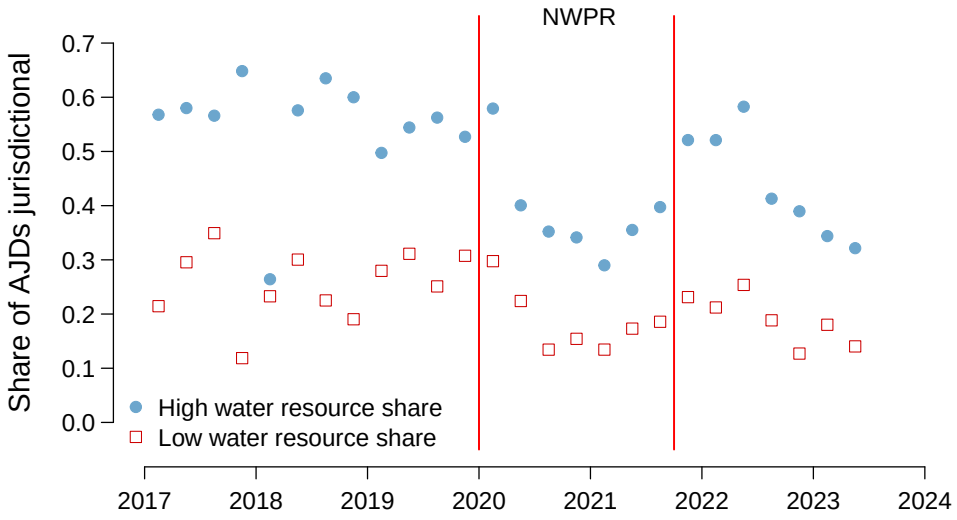
(D) Developer Website



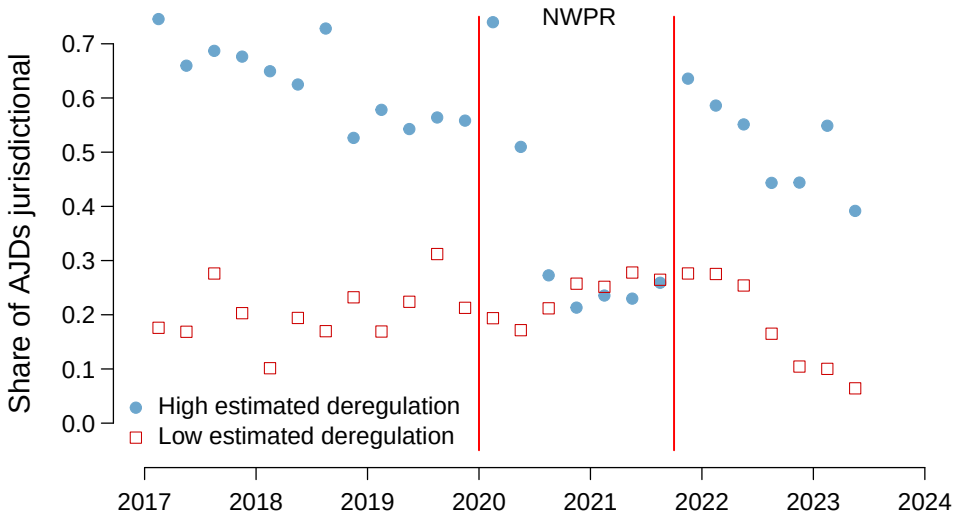
Notes: Panels show imagery of the Bridgeland housing development near Cypress Creek about 25 miles northwest of central Houston, TX, which received jurisdictional AJDs under the Navigable Waters Protection Rule (NWPR) in October 2020. Panel A shows aerial imagery from Google Earth of flooding in 2016. Yellow pins represent all AJDs in this area. All occurred during NWPR and were non-jurisdictional. Panel B shows recent aerial imagery from Google Earth. 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 7, 2025.

Figure 2: Share of Approved Jurisdictional Determinations that are Regulated Under the Clean Water Act, 2017-2023

(A) Using Wetland Map



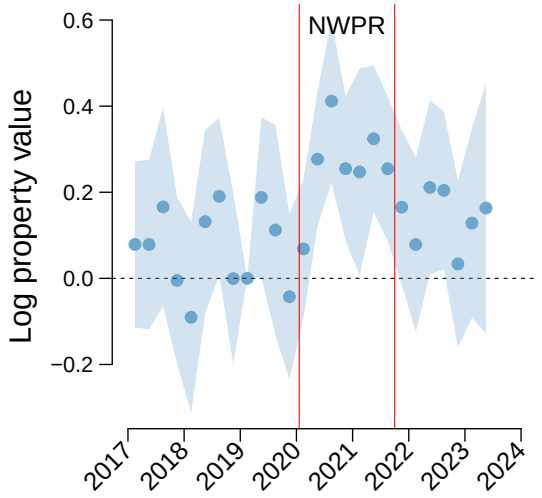
(B) Using Algorithm



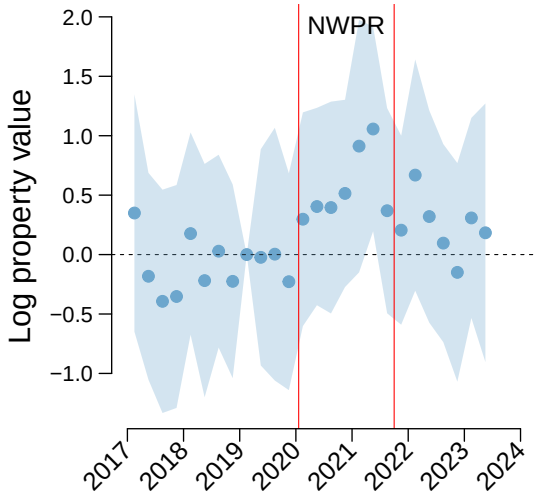
Notes: Graphs analyze approved jurisdictional determinations (AJDs). Both panels show the share of AJDs jurisdictional in each year × quarter. In Panel A, blue circles describe properties above the 75th percentile of water resource share (representing sites with water resource share exceeding 19%) and 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, Wetland Map is National Wetlands Inventory (NWI) water resource share. 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 AJDs 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

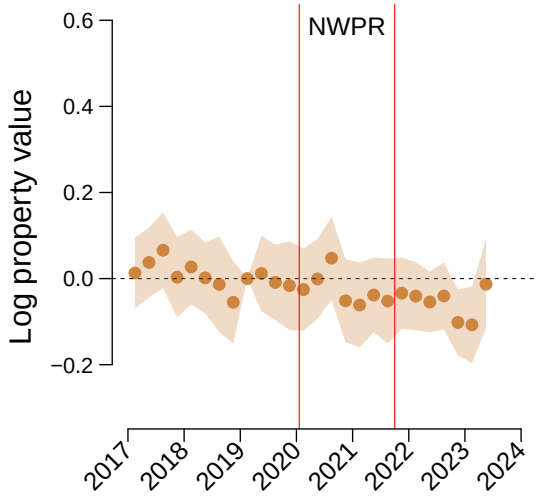
(A) Using Wetland Map, Non-residential



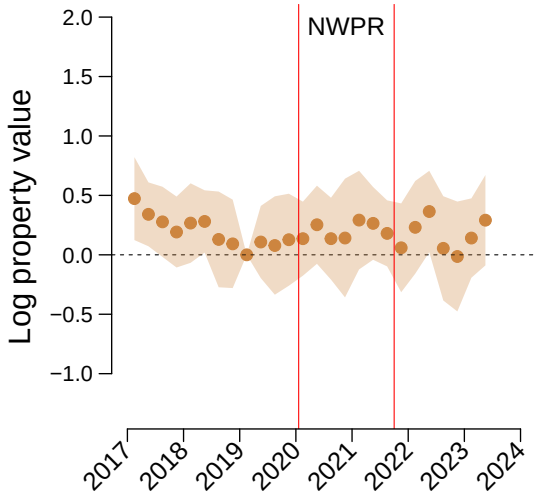
(B) Using Algorithm, Non-residential



(C) Using Wetland Map, Residential



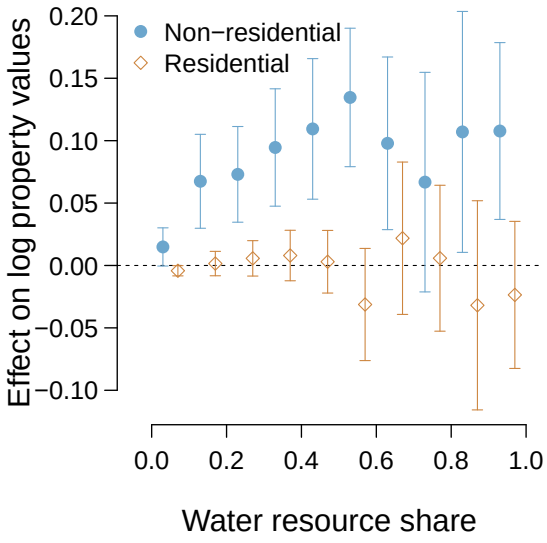
(D) Using Algorithm, Residential



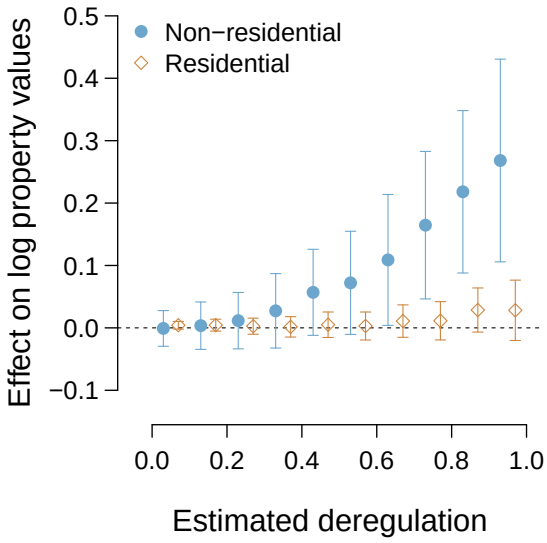
Notes: Wetland Map is National Wetlands Inventory (NWI) water resource share. Panel A shows the effect of water resource share on log values of non-residential properties by year × quarter from equation (7). Panel B shows the effect algorithmically estimated deregulation under NWPR by year × quarter, for non-residential properties. Panels C and D show corresponding values for residential parcels. 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

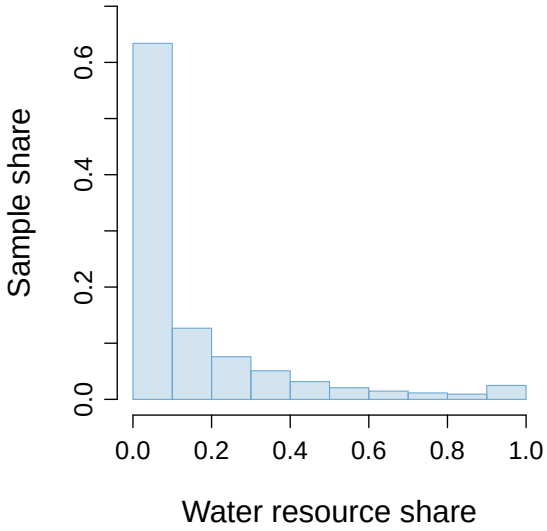
(A) Using Wetland Map



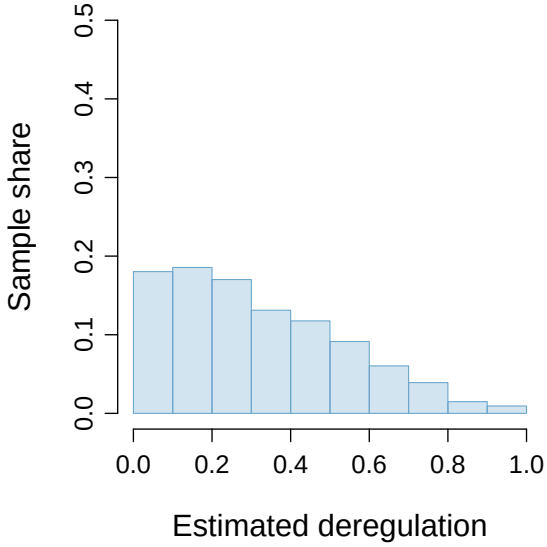
(B) Using Algorithm



(C) Distribution of Non-Residential Wetland Shares

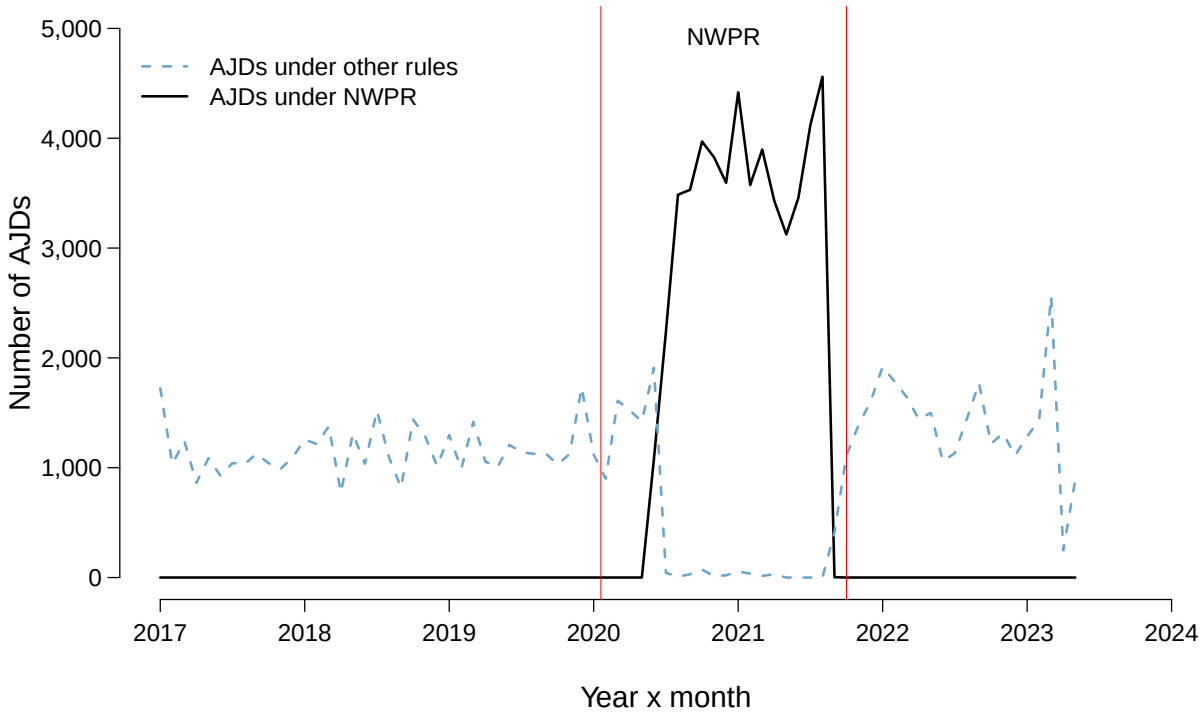


(D) Distribution of Non-Residential Algorithmic Predictions



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 property values, where NWI wetland share proxies regulation. We separate shares into bins with width of 0.1 from 0 to 1. The reference category is parcels 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. Panels C and D show the distribution of water resource shares and probabilities of regulation, respectively, among non-residential property transactions in the analysis sample.

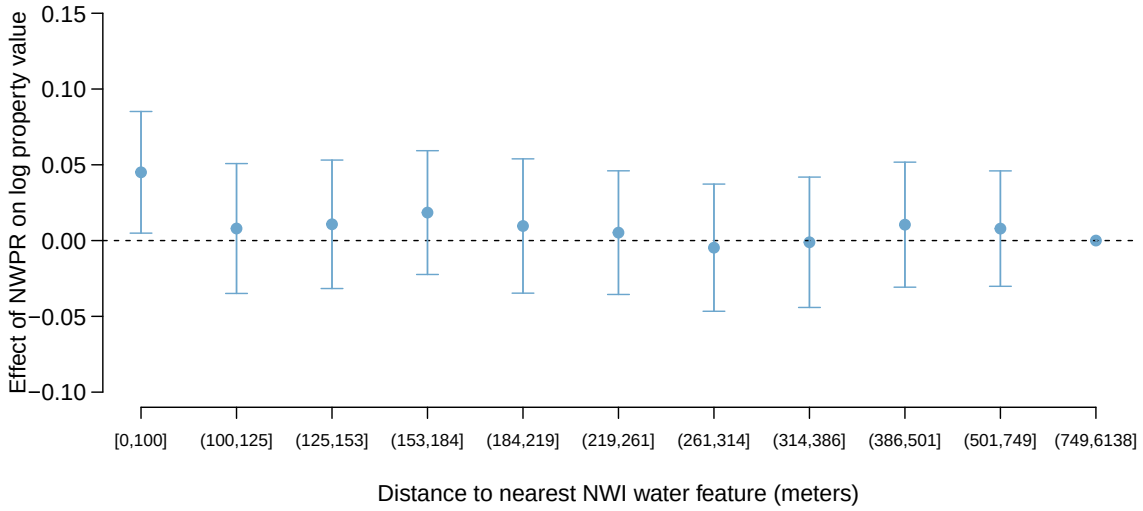
Figure 5: Clean Water Act Approved Jurisdictional Determinations (AJDs), by Rule



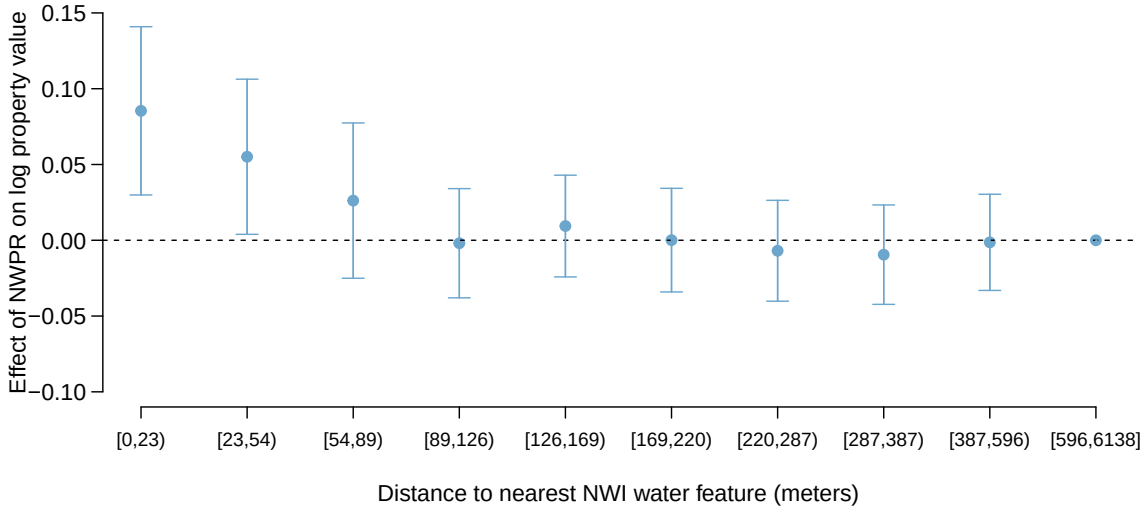
Notes: NWPR is the Navigable Waters Protection Rule. Figure shows the number of Clean Water Act approved jurisdictional determinations (AJDs) each month, separately by rule. The black line shows AJDs under NWPR, and the blue dashed line shows AJDs under *Rapanos* or the Clean Water Rule (CWR). Vertical 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 6: Effects of Navigable Waters Protection Rule (NWPR) on Property Values, by Distance to Nearest Wetland

(A) Imposing break at 100 meters



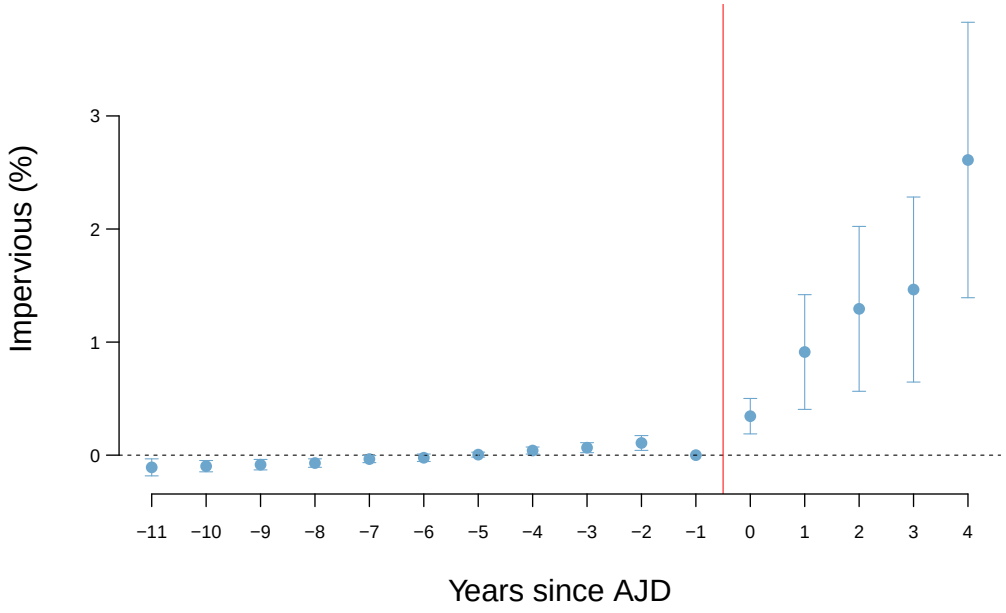
(B) Bins for deciles of distance



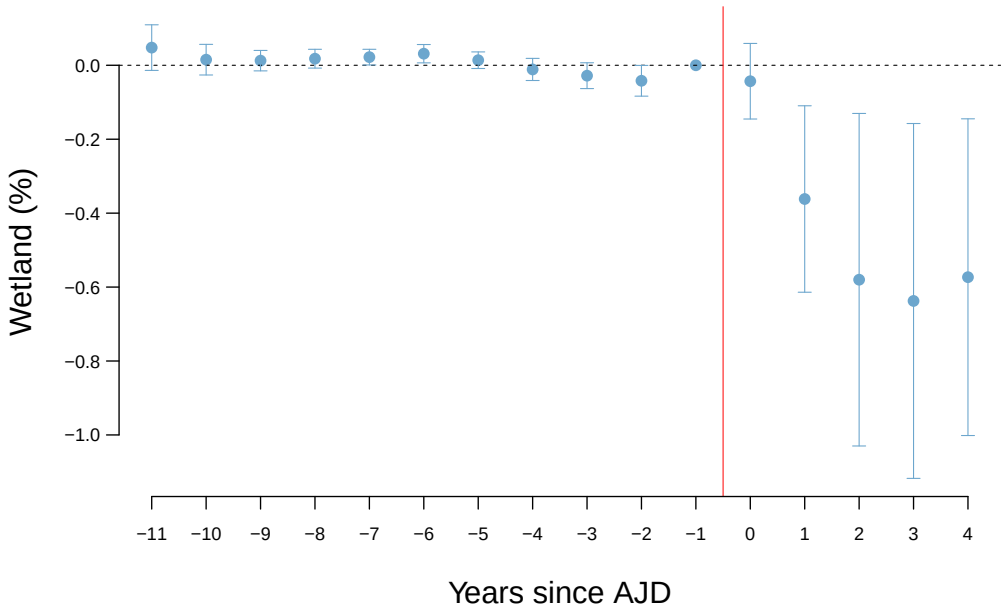
Notes: Both panels show the effect of NWPR on log property value by the distance of the parcel to nearest water feature, as measured by the National Wetlands Inventory (NWI). Panel A separates wetland parcels (those with an NWI feature within 100 meters) and non-wetland parcels (those greater than 100 meters from the nearest NWI feature), as in the main analysis. Distances for non-wetland parcels are binned into deciles. The reference bin is the fifth distance decile among non-wetland parcels. Panel B does not distinguish between wetland and non-wetland parcels as in the main analysis, but rather calculates the distance to the nearest NWI water feature for all properties in the sample. The x-axis shows deciles of distance to nearest NWI feature. The reference category is the fifth decile among all parcels. Circles show point estimates and shaded areas show 95% confidence intervals. Standard errors are clustered by commuting zone.

Figure 7: Development Around Approved Jurisdictional Determinations (AJD), Event Study Graphs

(A) Percent of Area Within 100m Radius that is Impervious



(B) Percent of Area Within 100m Radius that is Wetland



Notes: Figure shows results from equation (12) where the outcome is either the share of developed land (Panel A) or the share of wetlands (Panel B) within 100m of each approved jurisdictional determination (AJD) site centroid, as measured by the 2024 National Land Cover Dataset (NLCD) (U.S. Geological Survey 2024). Points show the effect of an AJD for non-regulated sites relative to regulated sites in the years preceding (negative x-axis values) and following (positive x-axis values) the AJD. We proxy development using NLCD imperviousness, a continuous measure of the impervious share of land within each 30m pixel, and a binary classification for wetlands. 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, with standard errors clustered by commuting zone.

Table 1: Mean Characteristics of Non-residential Property Transactions

Property area	15.53
	(91.15)
ln(Price)	11.74
	(1.68)
Price	512,516
	(1,105,587)
Water resource share (percent)	4.43
	(13.59)
Wetland share (percent)	3.06
	(12.51)
ln(Distance to town)	1.15
	(1.10)
ln(Distance to metro)	3.45
	(1.15)
ln(Population density)	4.67
	(2.33)
Work from home share (percent)	34.63
	(10.06)
From Algorithm	
Probability regulated under *Rapanos*	0.36
	(0.22)
Probability regulated under NWPR	0.21
	(0.18)
Estimated deregulation: *Rapanos* - NWPR	0.15
	(0.15)
Observations	2,834,923

Notes: Data are from CoreLogic and include US non-residential property transactions in the years 2017 to 2023. Total transactions: 2,913,860. Unique properties: 2,460,711. Water resource share is the percentage of land within 100m of the property centroid covered by National Wetland Inventory (NWI) water features. Wetland share is defined similarly for National Land Cover Database (NLCD) wetlands (U.S. Geological Survey 2024).

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

	Dependent Variable: Regulated					
	(1)	(2)	(3)	(4)	(5)	(6)
NWPR AJD	-0.117***	-0.083***	-0.091***	-0.294**	0.017	0.024
	(0.022)	(0.022)	(0.028)	(0.096)	(0.016)	(0.053)
Water resource share	—	0.518***	0.438***	0.443***	—	—
		(0.047)	(0.071)	(0.062)		
Water resource share	—	-0.203***	-0.084	-0.089	—	—
× NWPR AJD		(0.061)	(0.098)	(0.087)		
Probability of regulation	—	—	—	—	1.121***	1.094***
under *Rapanos*					(0.098)	(0.091)
Probability of regulation	—	—	—	—	-0.048	-0.032
under NWPR					(0.114)	(0.103)
Estimated deregulation	—	—	—	—	-1.136***	-1.123***
× NWPR AJD					(0.121)	(0.115)
Constant	0.364***	0.298***	0.300***		-0.036**	
	(0.028)	(0.028)	(0.029)	—	(0.014)	—
Year × month FEs	No	No	No	Yes	No	Yes
Observations	144,081	144,081	25,292	25,292	25,292	25,292

Notes: Column (1) shows the change in jurisdiction induced by the Navigable Waters Protection Rule (NWPR). Column (2) shows estimates from equation (1). The dependent variable is an indicator for whether the approved jurisdictional determination (AJD) site was jurisdictional. Water resource share equals share of area within 100 meters of the property centroid that is covered by any type of National Wetland Inventory (NWI) water feature. NWPR AJD is an indicator for whether the AJD was adjudicated under NWPR. This regression is estimated in the full sample of AJDs. Column (3) also shows estimates from equation (1), but the regression is estimated on the held-out test set of AJDs that were not used to train the machine learning algorithm. Column (5) shows estimates from equation (2), where Estimated deregulation represents the change in predicted probabilities of regulation between *Rapanos* and NWPR. Columns (4) and (6) use the same specification as columns (3) and (5) except with year × month fixed effects. Columns (3-6) are estimated in the held-out test set of AJDs. 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	0.142***	0.179***	0.175***	—	—	—
	(0.032)	(0.030)	(0.030)			
Estimated deregulation × NWPR	—	—	—	0.550***	0.782***	0.576***
				(0.191)	(0.287)	(0.178)
Observations	2,834,923	2,834,923	2,834,923	2,834,923	2,834,923	2,834,923
B. Residential Properties						
Water resource share × NWPR	-0.015	-0.010	-0.007	—	—	—
	(0.018)	(0.017)	(0.016)			
Estimated deregulation × NWPR	—	—	—	-0.013	-0.008	0.025
				(0.033)	(0.032)	(0.034)
Observations	4,885,186	4,885,186	4,885,186	4,885,186	4,885,186	4,885,186
C. Non-Residential vs. Residential						
Water resource share × NWPR	0.157***	0.189***	0.182***	—	—	—
× Non-residential	(0.037)	(0.035)	(0.034)			
Estimated deregulation × NWPR	—	—	—	0.555***	0.656***	0.540***
× Non-residential				(0.180)	(0.174)	(0.166)
Observations	7,720,109	7,720,109	7,720,109	7,720,109	7,720,109	7,720,109
FE: Zip × year × month	Yes	Yes	Yes	Yes	Yes	Yes
Log property acres	—	Yes	Yes	—	Yes	Yes
Log distance to town, metro	—	—	Yes	—	—	Yes
Log population density	—	—	Yes	—	—	Yes
Work from home share	—	—	Yes	—	—	Yes

Notes: Estimates in columns (1)-(3) reflect estimates of equation (3). Columns (4)-(6) reflect estimates of equation (5). Panel A uses a sample of non-residential properties. Panel B uses a sample of residential properties. Panel C estimates a triple difference on the full sample, treating the residential properties as a comparison group. We interact all controls with an indicator for whether the Navigable Waters Protection Rule (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 Wetland Inventory (NWI) water feature. Etimated deregulation represents the change in predicted probabilities of regulation between *Rapanos* and NWPR. 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		Total	
	(1)	(2)	(3)	(4)
A. Property Characteristics				
Number of Properties	—	—	2,834,923	27,718,874
Property Value ($M)	0.513	0.543	1,452,943	15,048,916
Property Acres	15.535	27.005	44,039,851	748,559,833
Wetland Acres	0.830	1.508	2,351,941	1,508,015
B. Effect of NWPR on Land Values				
Using wetland map (logs)	0.0084	—	—	—
Using algorithm (logs)	0.0081	—	—	—
Using wetland map ($M)	0.0043	0.0045	12,161	125,959
Using algorithm ($M)	0.0042	0.0044	11,841	122,648
C. Effect of NWPR on Wetland Extent				
Using wetland map (acres)	-0.008	-0.014	-23,215	-394,607
Using algorithm (acres)	-0.013	-0.022	-36,658	-623,092
D. Effect of NWPR on Wetland Flood Protection				
Flood mitigation value ($/acre of wetlands)				
Annual	1,057	—	—	—
Present value	35,261	—	—	—
Effect on flood damages ($M, present value)				
Using wetland map	—	—	-818	-13,914
Using algorithm	—	—	-1,292	-21,971
E. Ratio of NWPR Land Value Benefits to Flood Protection Costs				
Using wetland map	—	—	14.9	9.1
Using algorithm	—	—	9.2	5.6
Transacted Properties	Yes	—	Yes	—
All Properties	—	Yes	—	Yes

Notes: Columns (1) and (3) show non-residential properties that transacted in our analysis sample. Columns (2) and (4) show all non-residential properties from CoreLogic assessor data, in which the assessed value is scaled by the ratio of price to assessed value (2.46) predicted by a random forest model (Appendix C.2). Wetland acres represent the percent of land within 100m of the property centroid covered by National Wetland Inventory (NWI) water features, multiplied by property acreage. Panel B scales the effect of the Navigable Waters Protection Rule (NWPR) on land values (see Table A7) by the average transaction price in our analysis sample. Panel C shows the effects of NWPR on wetland area 4 years after an AJD (see Figure 7). Wetland Map is National Wetland Inventory (NWI) water resource share. 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 (see Table 2) to get estimates for the average parcel. Panel E divides estimates in Panel D by the corresponding estimates in Panel B 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.

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 includes information on property sales like sales price and date.

Our CoreLogic extract includes approximately 2.8 million non-residential and 4.9 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 NWPR's judicial stay. 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).[21] Table A3 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. About 14,000 of our sample of 2.8 million (0.5%), residential properties typically represent larger rural parcels with minimal housing structures, making them more similar to non-residential land in their exposure to CWA regulation. 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 parcel 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 parcel identifier (`clip`), since we use this identifier to link property details to transaction records.

[21] 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.

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 parcel identifier (`clip`), transaction ID (`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.

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 27.7 million nonresidential properties. Among these, 44% have at least one recorded transaction ever. The mean property size in the assessor sample is 27 acres, and the total covered acreage is 749 million acres.[22] The mean U.S. property value is \$221,000.[23]

We use a sample to calculate summary statistics like wetland share and probability regulated for the average parcel overall. We randomly select 1 million properties from this set of 27.7 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 = 7.2%) or wetlands (mean = 4.2%). Applying the wetland share to the average U.S. property (27 acres) results in an estimated 1.15 acres of wetlands per property, and 31.9 million acres of wetlands total.

The composition of non-residential property transactions differs from the full stock

[22] 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.

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

of non-residential properties (Table A3). Commercial properties are relatively more likely to transact (25% of transacted parcels versus 19% of U.S. parcels), 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 parcels. Vacant land is particularly likely to transact (47% of transactions versus 39% of U.S. parcels).

B.2 Approved Jurisdictional Determinations (AJDs)

We use records of approved jurisdictional determinations (AJDs) 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 parcels 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. Green points are jurisdictional and Brown points are not. In our sample, 31% 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 parcel-level controls: log property acres, log distance to nearest town center, log distance to nearest metro area, log population density, and work from home share.

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 log population density, 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. Madsen et al. (2010) report a price of about $75,000 per acre in the year 2008, and 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 2023; 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.

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 percent 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 percent of total reported coastal wetland value, but this share falls to roughly 12 percent 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 percent of total coastal wetland ecosystem service value (and about 12 percent 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 percent 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 percent of total coastal wetland ecosystem service value across storm risk reduction, fish habitat, nutrient removal, carbon storage, and fishing benefits.

Table A9 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 percent; weighting by number of studies yields roughly 30 percent, and weighting by number of observations yields approximately 25 percent.

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 percent of total wetland value, property value gains from wetland deregulation exceed associated ecosystem service losses in most scenarios considered in this paper.

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. The algorithm closely follows 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 the MOSAIKS API (Carleton et al. 2023),[24] 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 77% accuracy at predicting regulatory status on held-out test set. Accuracy is comparable for determinations made under *Rapanos* (75%) and NWPR (78%).

The algorithm outputs a continuous score between 0 and 1, which are 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

[24] Imagery embeddings are constructed from 4 meter Planet imagery at 0.1 degree ($\sim$ 10km) resolution. We use 1,000 MOSAIKS features, with 500 each constructed using patch size 4 and patch size 6.

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 = 0.35) than under NWPR (mean = 0.25). 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 all features achieves comparable accuracy and can be deployed at fraction of the computational 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:

$$Y_{id} = \alpha p_{iR} + \sum_{\tau} \left(\beta_{\tau} \left(p_{iR} - p_{iN} \right) \mathbb{1}[q_q = \tau] + \gamma_{\tau} \mathbb{1}[q_q = \tau] \right) + \delta_d + \epsilon_{id} \tag{17}$$

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 (17) 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 while WOTUS-ML has slightly higher accuracy overall (79% vs. 78% accuracy) at predicted regulatory status, 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 parcels, 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 (15.5 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 2.8 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, parcel 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 568,033 transactions and predicts the total sales value to within 2.7% of the observed aggregate ($258 billion predicted vs. $251 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 A6). For instance, when we compute price-per-acre predictions implied by our preferred model, it attains an R-squared of 0.87, 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 A7) 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 $15.05 trillion, or 2.46 times the assessed value ($6.12 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 A7) and land use category (Table A4). 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 $3.76 trillion, which aligns closely 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. parcels, 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: Alternative Algorithmic Specifications

We use the following alternate version of the event study second stage equation (12) to estimate NWPR's land use impacts:

$$\delta_{ict} = \sum_{\tau} \Big(\alpha_\tau + \beta_\tau \, D_i + \gamma_\tau \, (p_{iR} - p_{iN}) \Big) \, \mathbb{1}[t = \tau] \; + \; \varepsilon_{ict} \tag{18}$$

$\delta_{ict} \equiv L_{ict} - \hat{L}(0)_{ict}$, 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 (11). 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 A12.

C.4 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 parcel values for only parcels with an AJD. Our investigation of this alternative analysis found that only about 200 parcels had a transaction before and after an AJD. The main text focuses on all parcels rather than only parcels 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.5 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 parcels 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

$$Y_i = \alpha + \beta \widehat{p}_i + \gamma Z + \varepsilon \tag{19}$$

where Y_i is the observed regulatory status under either *Rapanos* or NWPR for parcel 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 parcel 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 5 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.

Table A2 reports estimates from the multiple-imputation correction procedure. The corrected estimate of the effect of NWPR deregulation on log property values is 0.714, compared to 0.576 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.

Figure A1: Examples of Semi-Dry Wetlands

(A) Isolated Wetland



(B) Google Data Center



(C) Moapa Solar Project Satellite Image

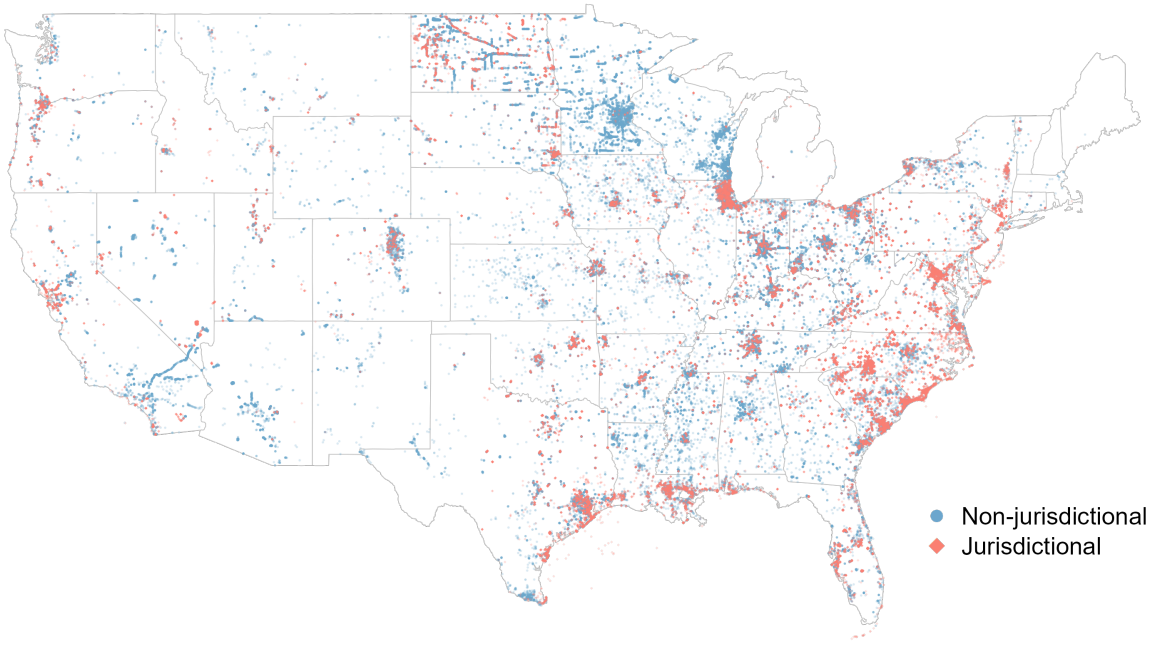


(D) Moapa Solar Project Development



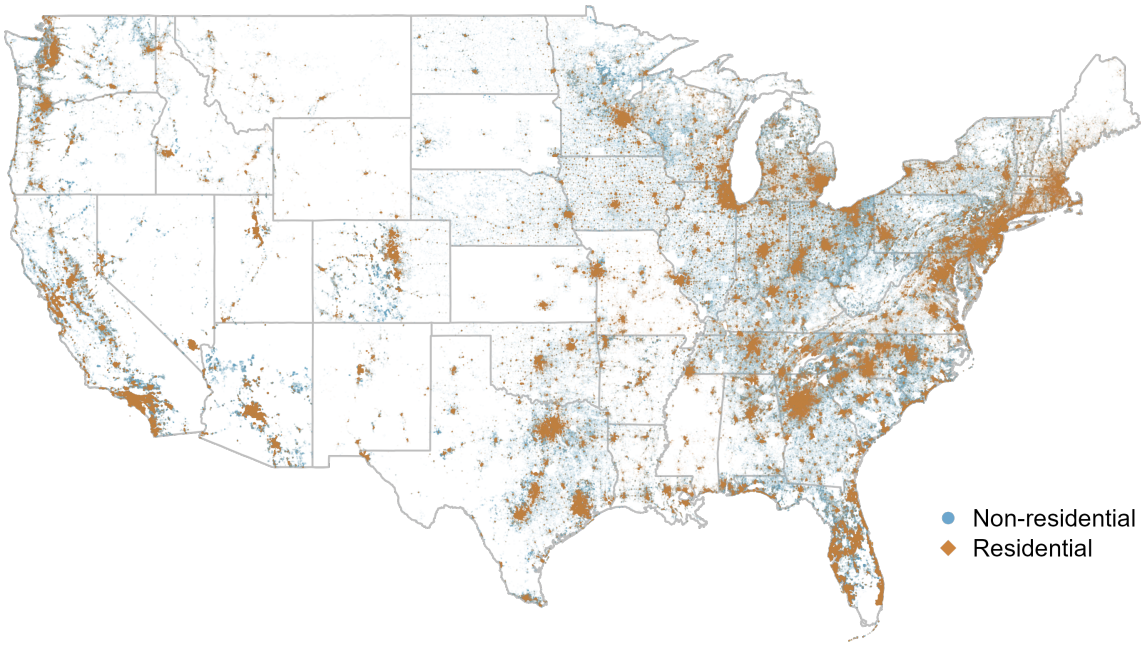
Notes: Panel A shows a non-stereotypically dry isolated wetland. Source: http://www.wetlandsprofessional.com/isolated-wetlands.html. Panel B shows a Google data center built on an isolated wetland. Source: Aerial imagery of Google data center construction at MidAmerica Industrial Park near Pryor, Oklahoma (approximately 36.31°N, 95.32°W). Panel C shows a satellite image of the land surrounding the Moapa Solar Project, built on the Moapa River Indian Reservation. Source: Google Maps satellite imagery of the Moapa Southern Paiute Solar Project vicinity near Interstate 15, Clark County, Nevada. Panel D is a snapshot of Moapa Solar Project development. Source: Google Earth satellite imagery of the Moapa Southern Paiute Solar Project construction area, Clark County, Nevada (approximately 36.53°N, 114.77°W).

Figure A2: Locations and Outcomes of 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 = 98,315). Red dots show jurisdictional sites (N = 45,966) Jurisdictional sites are plotted on top of non-jurisdictional sites with a high degree of transparency.

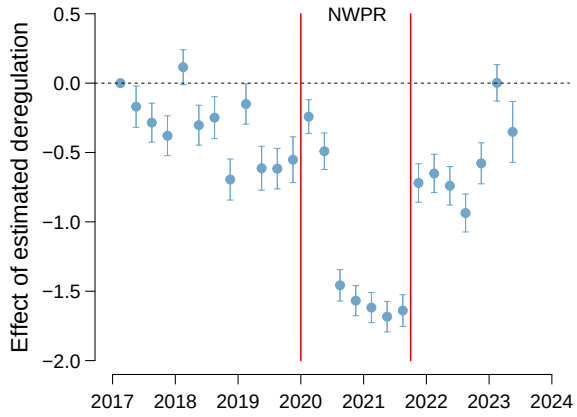
Figure A3: Transaction Locations from CoreLogic, Non-residential and Residential Parcels



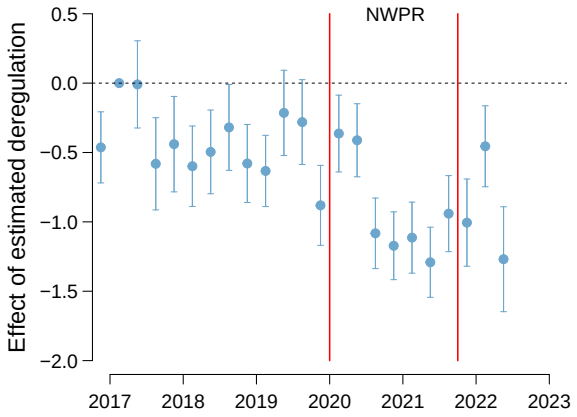
Notes: Map shows the Contiguous United States overlaid with the locations of CoreLogic transactions from our analysis sample. Blue dots are non-residential properties (N = 2,834,923). Tan diamonds are residential properties (N = 4,885,186). Residential properties are plotted on top of non-residential properties with a high degree of transparency.

Figure A4: Testing Algorithms for Predicting Changes in the Probability of Regulation

(A) Tabular Model

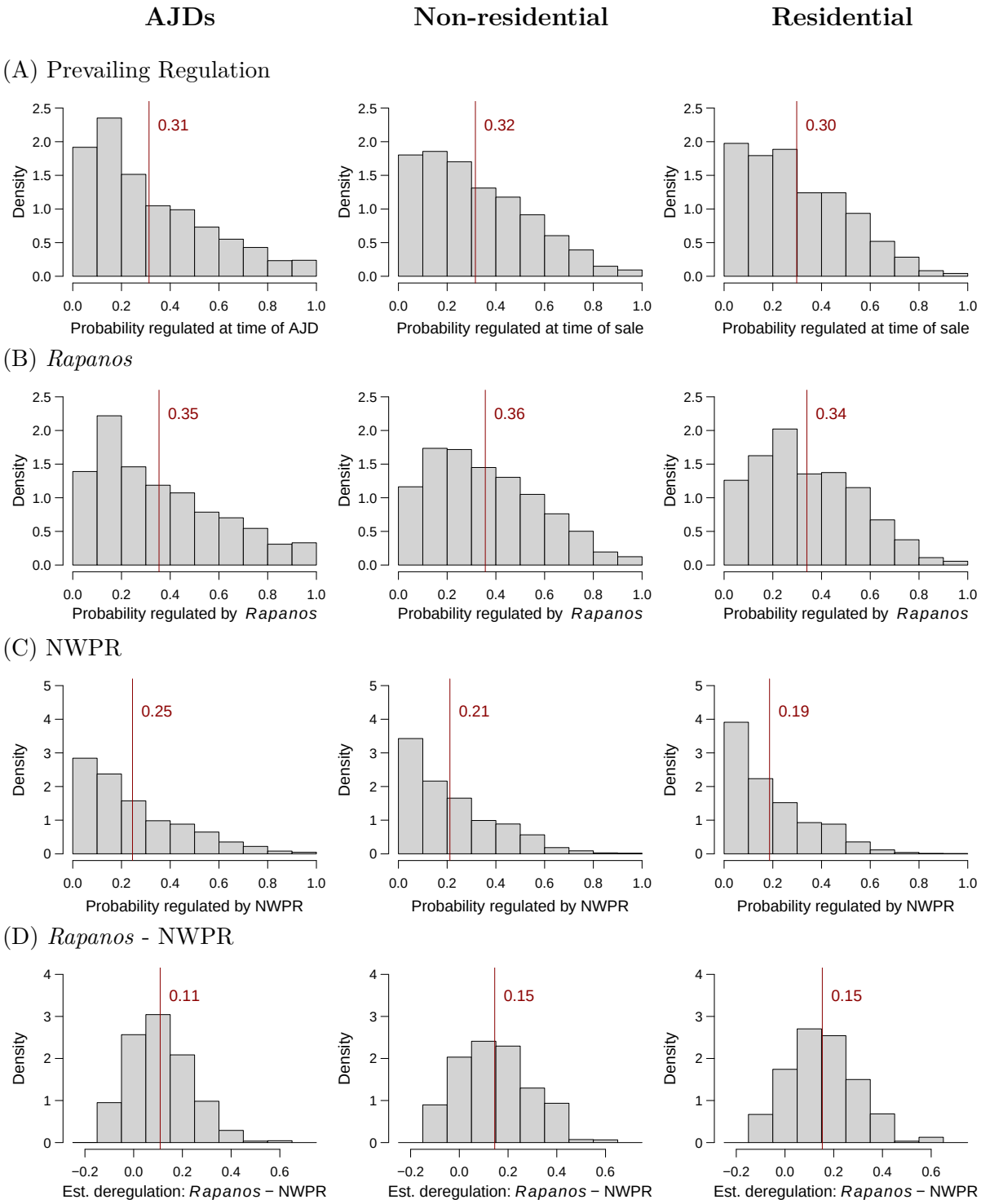


(B) Image-Based Model



Notes: NWPR is the Navigable Waters Protection Rule. Event studies of the effect of estimated deregulation $= p_{iR} - p_{iN}$ on jurisdiction from equation (17). The event studies are estimated among approved jurisdictional determinations (AJDs). The outcome is set equal to 1 if the site is determined to be regulated and 0 otherwise. We estimate a coefficient (blue dots) 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 tabular, ridge regression model used in this study and Panel B uses the predicted probabilities from the image-based CNN used in Greenhill et al. (2024). Further details on the models are provided in Appendix C.1.

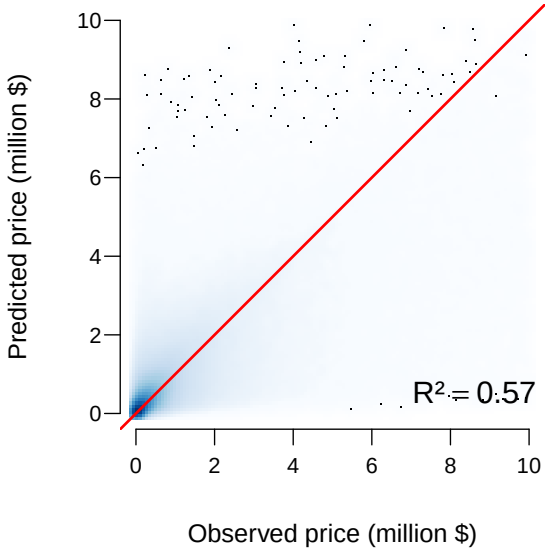
Figure A5: Predicted Probabilities of Regulation, by Sample



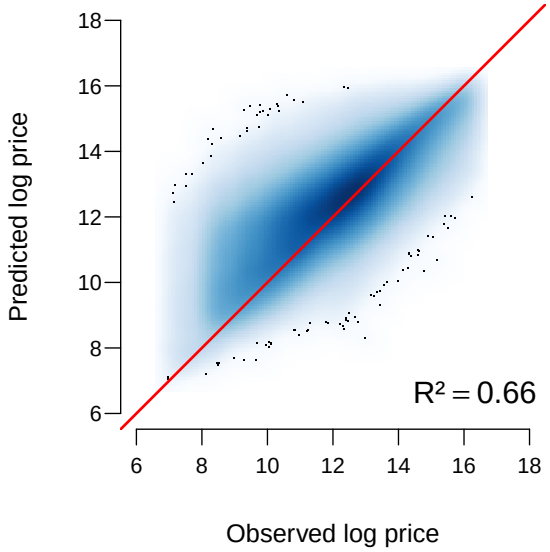
Notes: NWPR is the Navigable Waters Protection Rule. Predicted probabilities of regulation from the machine learning algorithm. Panel A shows the probabilities under the rule in force at the time of the approved jurisdictional determination (AJD) or property sale. Panel B shows the probabilities under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

Figure A6: Model Performance for Predicting Fair Market Value

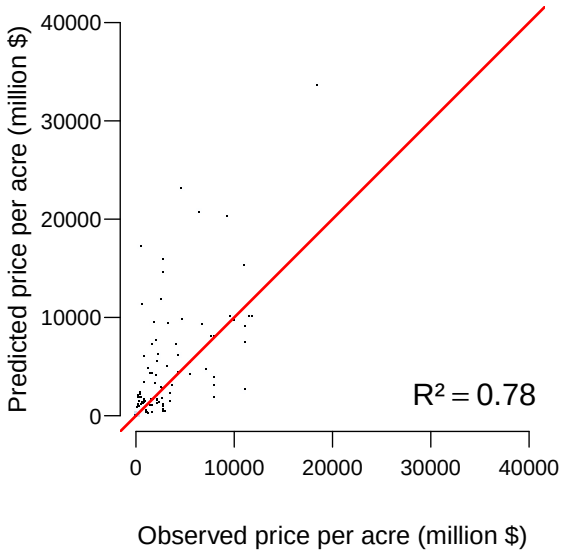
(A) Property-level price



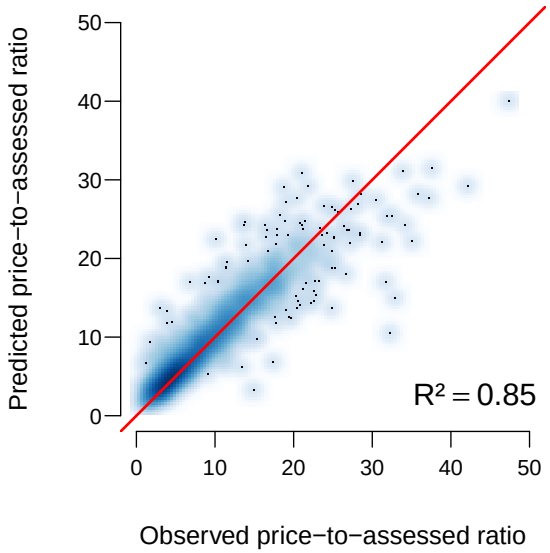
(B) Property-level log price



(C) Property-level price per acre



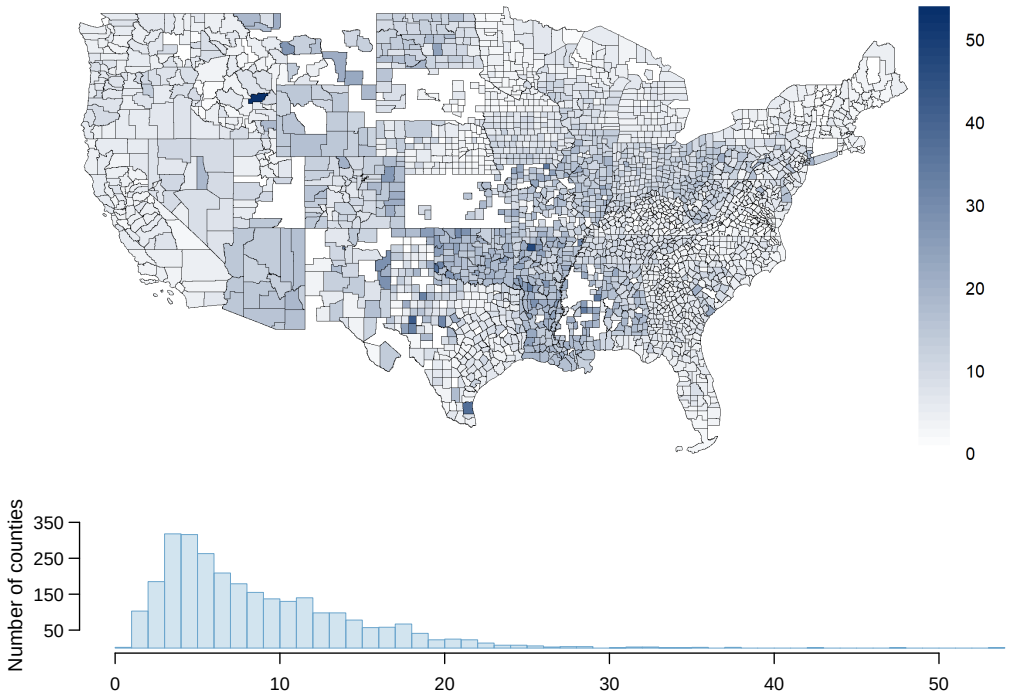
(D) County-level price-to-assessed value ratio



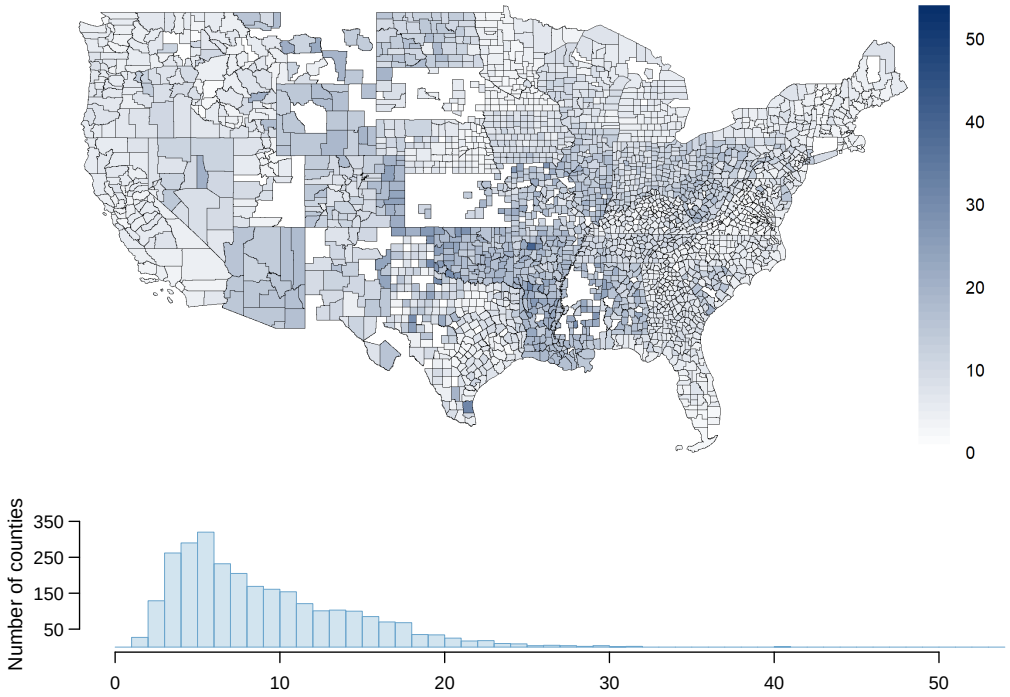
Notes: Plots show observed values (x-axis) against predicted values (y-axis) from the random forest model that predicts property sales price as a function of assessor records (Appendix C.2). All Panels show a model trained to predict property sales prices in levels directly. Panel A shows the correspondence 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 A7: County-level Sales Price to Assessed Value Ratios

(A) Observed price-to-assessed value ratio



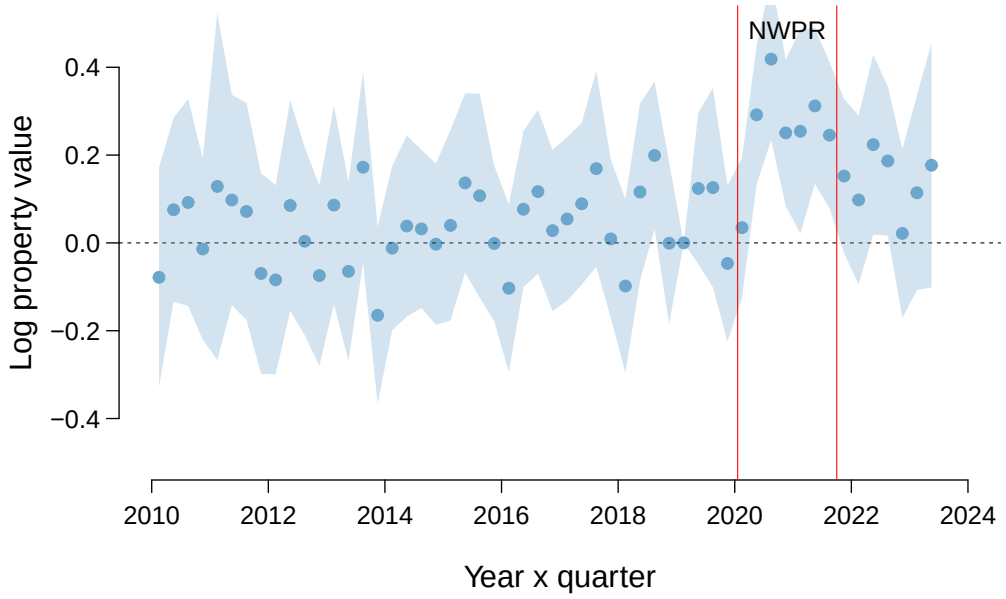
(B) Predicted price-to-assessed value ratio



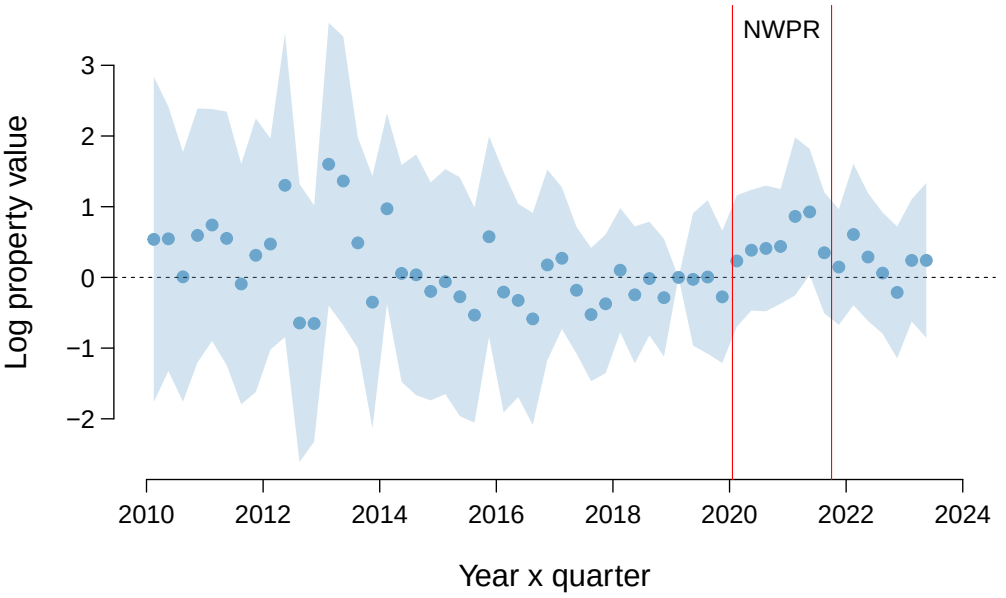
Notes: Maps and histograms show the county-level ratio of sales price to assessed values, as computed in our main sample of 2.8 million non-residential properties that transacted between 2017 and 2023. Panel A shows the observed ratios. Panel B shows the ratios predicted using a random forest (Appendix C.2).

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

(A) Wetland Map Model



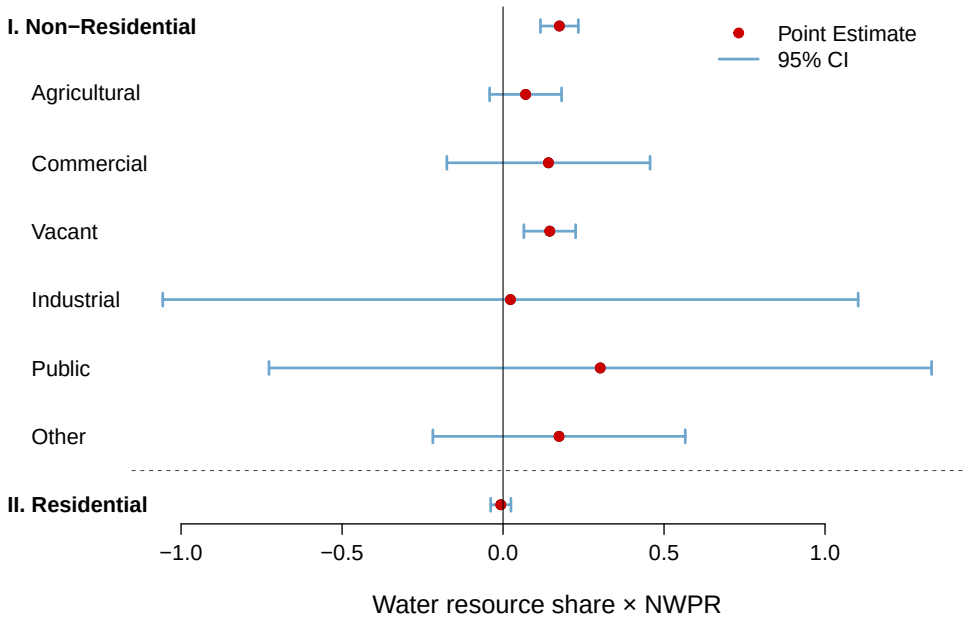
(B) Algorithmic Model



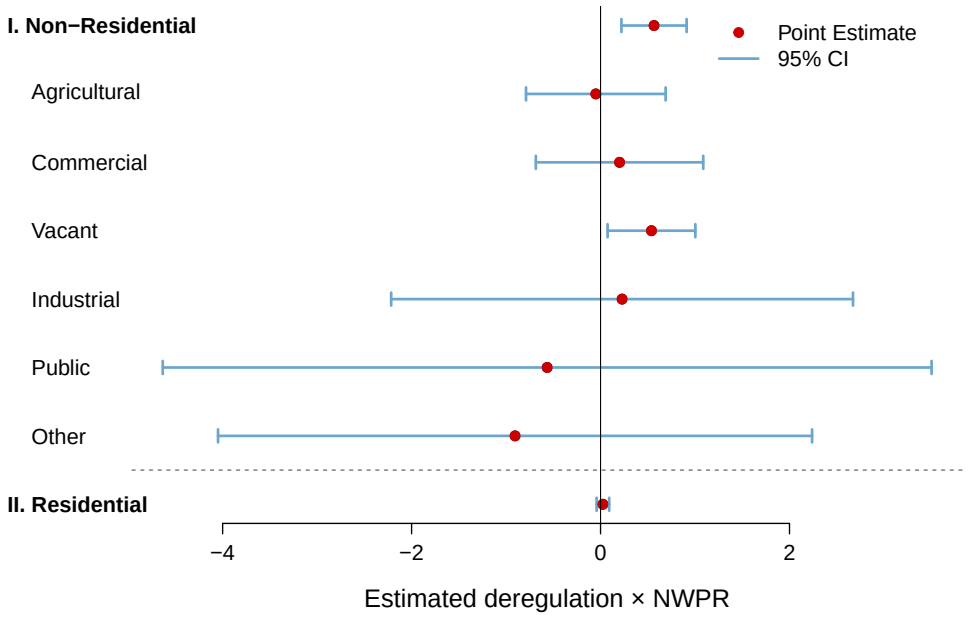
Notes: NWPR is the Navigable Waters Protection Rule. This figure shows estimates from equation (7) and analogous equation using the algorithm, but using CoreLogic non-residential property transaction records extending back to 2010. Wetland Map is National Wetland Inventory (NWI) water resource share. Panel A shows point estimates for coefficients on Water resource share × NWPR by year × quarter. Panel B shows point estimates for coefficients on the algorithmically estimated deregulation × NWPR by year × quarter, where estimated deregulation is the difference $p_{iR} - p_{iN}$ in predicted probabilities of regulation between *Rapanos* and NWPR. Shaded area shows 95% confidence intervals where standard errors are clustered by commuting zone. Vertical red lines indicate the period when NWPR was in force.

Figure A9: Effect of Clean Water Act Rules on Log Property Values, by Land Use

(A) Wetland Map Model

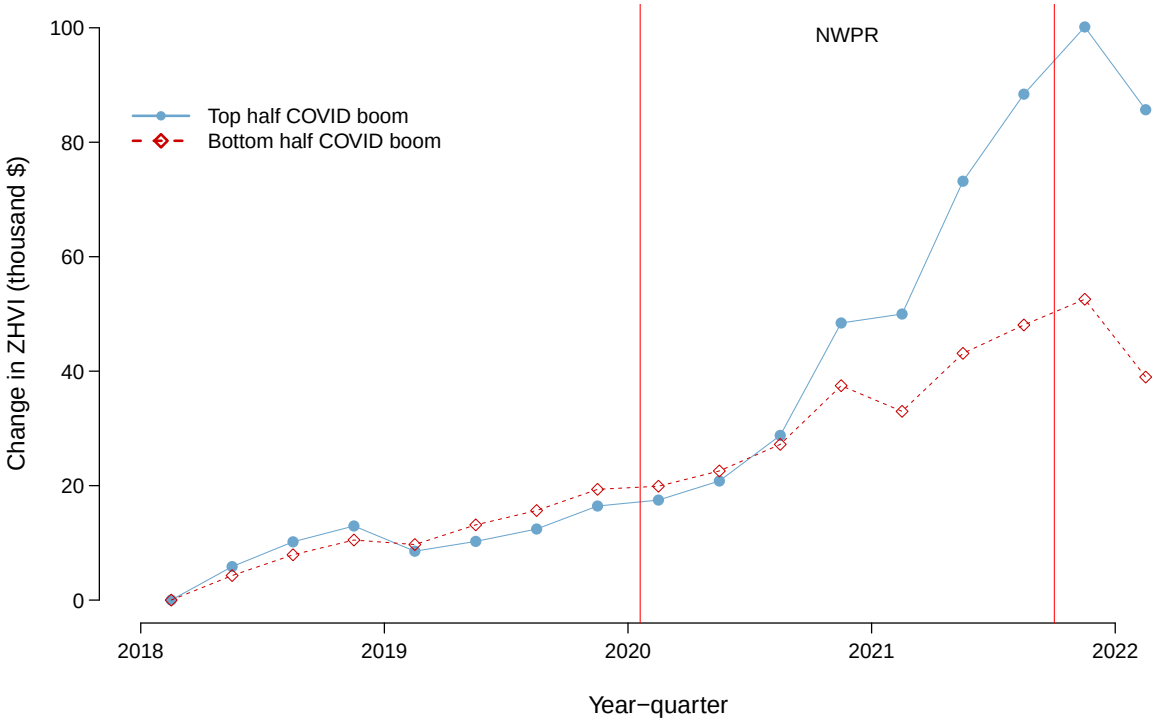


(B) Algorithmic Model



Notes: NWPR is the Navigable Waters Protection Rule. Wetland Map is National Wetland 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 $p_{iR} - p_{iN}$ in predicted probabilities of regulation between *Rapanos* and NWPR. Estimates in Panel A are from equation (3). Estimates in Panel B are from equation (5). Red dots show point estimates, and blue 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, log population density, and work from home share. Subsample observation counts are as follows: Non-Residential – 2,834,923; Residential – 4,885,186; Agriculture – 533,906; Commercial – 707,191; Vacant – 1,332,593; Industrial – 117,358; Public – 48,426; Other – 25,729.

Figure A10: Trends in Zillow Home Value Index, by Size of Local COVID 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 (ZHVI) (Zillow.com 2025) over the four-year period centered at March 2020, the beginning of the Navigable Waters Protection Rule (NWPR). We convert ZHVI values to 2024 dollars using a gdp deflator. The blue line represents properties that have an above-median linear trend break in the ZHVI after March 2020, and the red line represents properties that have a below-median trend break.

Figure A11: News Stories of Development Allowed Under the 2020 Navigable Waters Protection Rule

(A) Georgia



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



Florida Phoenix

EDUCATION HEALTH POLITICS & LAW ENVIRONMENT CULTURE & SOCIETY WORKING & THE ECONOMY

CULTURE & SOCIETY ENVIRONMENT POLITICS & LAW WORKING & THE ECONOMY

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

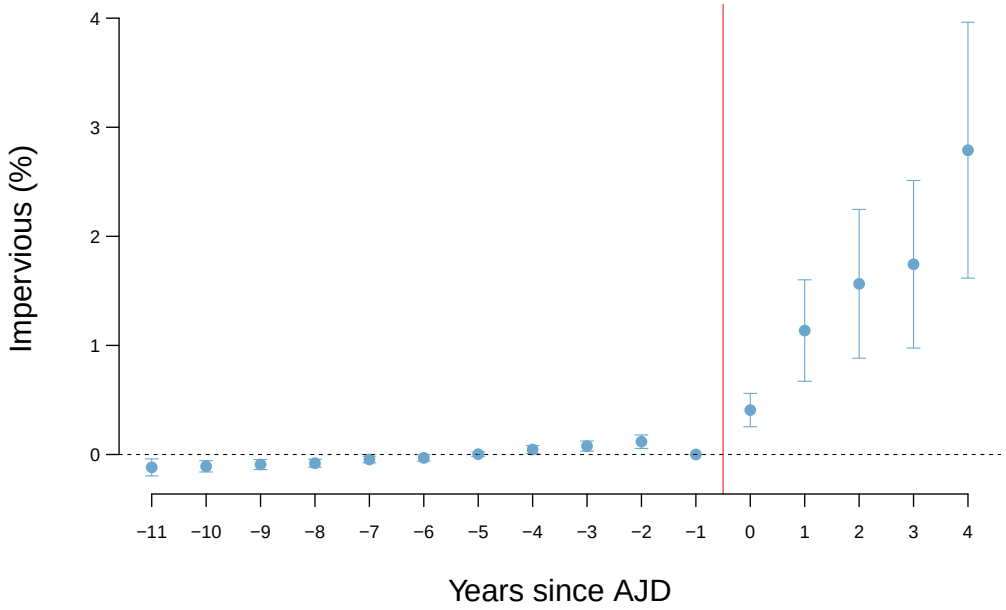
BY: LAURA CASSELS - OCTOBER 18, 2021 7:00 AM

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

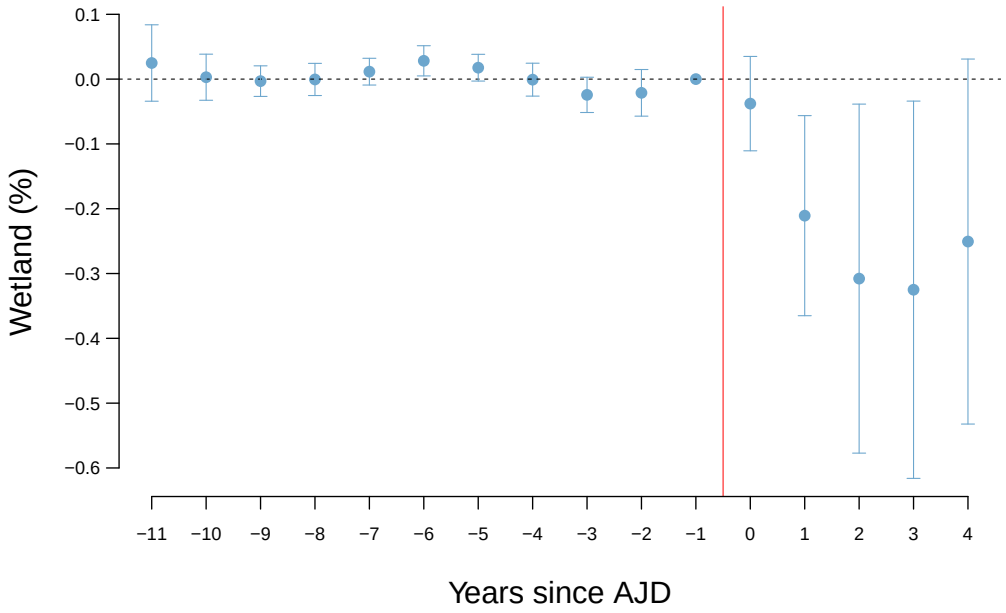
Notes: Panels A (Mufson and Butler 2020) and B (Cassels 2021) show examples of news headlines on how NWPR may affect development.

Figure A12: Development Around Approved Jurisdictional Determinations (AJD), Event Study Graphs Using the Algorithm

(A) Percent of Area Within 100m Radius that is Impervious



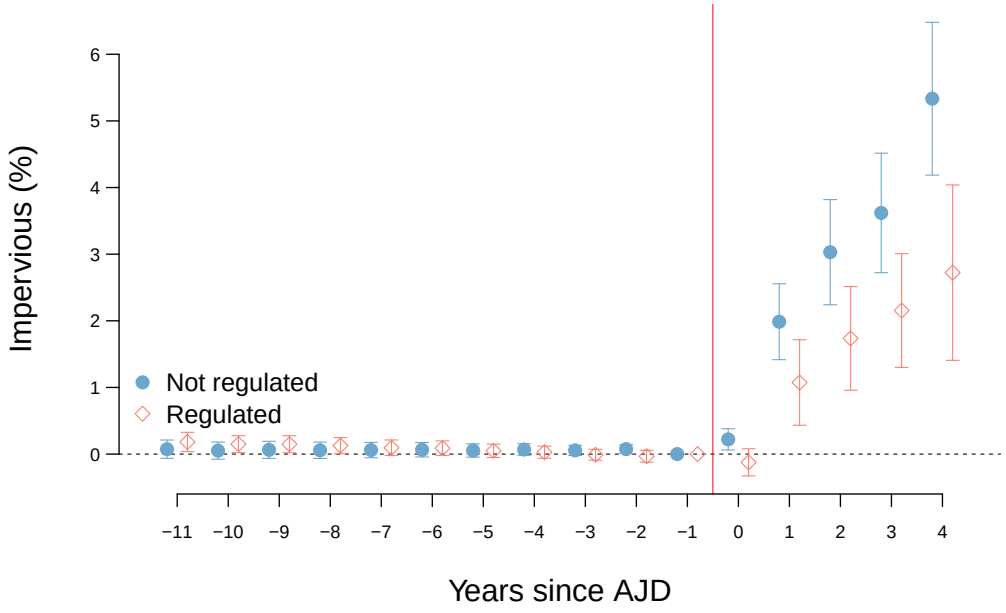
(B) Percent of Area Within 100m Radius that is Wetland



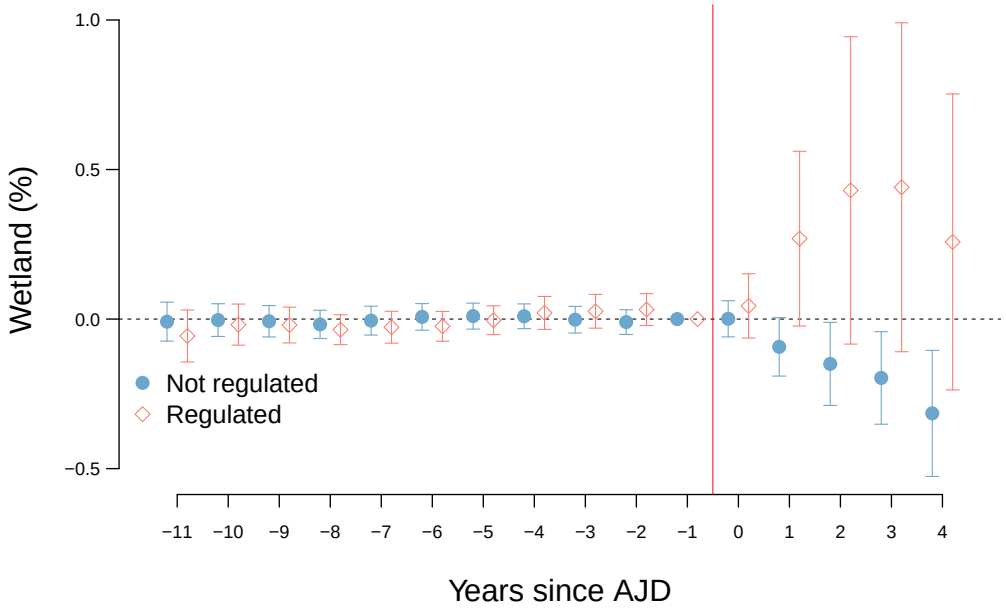
Notes: Figure is analogous to Figure 7 but uses the algorithmically-estimated deregulation rather than National Wetland Inventory (NWI) water resource share. Figure shows results from equation (12) where the outcome is either the share of developed land (Panel A) or the share of wetlands (Panel B) within 100m of each approved jurisdictional determination (AJD) site centroid, as measured by the 2024 National Land Cover Dataset (NLCD) (U.S. Geological Survey 2024). Points show the effect of an AJD for non-regulated sites relative to regulated sites in the years preceding (negative x-axis values) and following (positive x-axis values) the AJD. We proxy development using NLCD imperviousness, a continuous measure of the impervious share of land within each 30m pixel, and a binary classification for wetlands. Event study regressions include commuting zone × year and site fixed effects, and National Wetland Inventory (NWI) water resource share × event time. Bars show 95% confidence intervals, with standard errors clustered by commuting zone.

Figure A13: Development Around Approved Jurisdictional Determinations (AJD) by Regulation Status, Event Study Graphs

(A) Percent of Area Within 100m Radius that is Impervious



(B) Percent of Area Within 100m Radius that is Wetland



Notes: This figure plots the same effects as in Figure 7, separately for regulated and unregulated sites. Points show the share of developed land in Panel A and wetlands in Panel B, as measured by the 2024 National Land Cover Dataset (NLCD) (U.S. Geological Survey 2024), in the years preceding (negative x-axis values) and following (positive x-axis values) an approved jurisdictional determination (AJD). We proxy development using NLCD imperviousness, a continuous measure of the impervious share of land within each 30m pixel, and a binary classification for wetlands. Event study regressions include commuting zone × year and site fixed effects, and National Wetland Inventory (NWI) share × event time, following equation (13). We compute land use within a 100m radius of each site centroid. Red diamonds show point estimates for regulated sites; blue circles show point estimates for not regulated sites. Bars show 95% confidence intervals, with standard errors clustered by commuting zone.

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.	FAO 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: Effect of Clean Water Act Rules on Log Property Values, Multiple Imputation Correction

	Dependent Variable: Log property value	
	(1)	(2)
Estimated deregulation × NWPR	0.576***	0.714**
	(0.178)	(0.348)
Zip × year × month FEs	Yes	Yes
Log property acres	Yes	Yes
Log distance to town, metro	Yes	Yes
Log population density	Yes	Yes
Work from home share	Yes	Yes
Observations	2,834,923	2,834,923

Notes: Column (1) reports the effect of NWPR deregulation on log property values estimated using the algorithmic model, repeated from Table 3, Column (6). Column (2) shows the same effect, but estimated using multiple imputation to correct for potential biases in the parameter estimates and standard errors introduced by using a machine learned treatment. We follow the correction procedure proposed in Proctor et al. 2023, as described in Section C.5.

Table A3: Composition of Non-Residential Properties: Transactions vs. Assessor Stock

Land Use Type	N transactions	% of transactions	N assessed properties	Assessor %
Vacant	1,332,593	47.0	10,868,882	39.2
Commercial	707,191	24.9	5,117,505	18.5
Agricultural	533,906	18.8	6,889,418	24.9
Industrial	117,358	4.1	1,051,809	3.8
Public	48,426	1.7	1,783,979	6.4
Recreational	44,376	1.6	326,508	1.2
Noncoded	27,475	1.0	850,785	3.1
Residential Rural	14,196	0.5	611,873	2.2
Transport Energy	9,402	0.3	218,115	0.8
Total	**2,834,923**	**100.0**	**27,718,874**	**100.0**

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

Table A4: Aggregate Predicted Market Value by Land Use Type

Land Use Type	Parcels (M)	Acres (M)	Assessed ($T)	Predicted ($T)	$/Acre (K)	Pred/Assess
Vacant	10.87	184.7	0.64	2.70	14.6	4.23
Agricultural	6.89	442.3	0.98	3.76	8.5	3.83
Commercial	5.12	18.2	2.58	4.91	269.5	1.90
Public	1.78	54.7	0.74	1.32	24.2	1.80
Industrial	1.05	7.4	0.81	1.43	191.7	1.76
Noncoded	0.85	19.5	0.08	0.26	13.5	3.31
Residential_rural	0.61	11.6	0.12	0.33	28.8	2.87
Recreational	0.33	7.4	0.11	0.20	26.7	1.83
Transport_energy	0.22	2.7	0.06	0.13	48.2	2.04
Total	**27.72**	**748.6**	**6.12**	**15.05**	**20.1**	**2.46**

Notes: Predicted values from random forest model trained on 2017–2023 non-residential transactions.

Table A5: 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	0.175***	0.173***
	(0.030)	(0.043)
Water resource share × NWPR	—	0.016
× COVID top affected		(0.064)
B. Algorithmic Model		
Estimated deregulation × NWPR	0.576***	0.607***
	(0.178)	(0.225)
Estimated deregulation × NWPR	—	-0.025
× COVID top affected		(0.316)
FE: Zip × year × month	Yes	Yes
Log property acres	Yes	Yes
Log distance to town, city	Yes	Yes
Log population density	Yes	Yes
Work from home share	Yes	Yes

Notes: NWPR is the Navigable Waters Protection Rule. Wetland Map is National Wetland 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 (3) 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 an above-median 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 (5). 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 A6: Effect of Approved Jurisdictional Determinations (AJDs) on Land Use Under the Navigable Waters Protection Rule (NWPR)

	Developed (impervious) (%)			Wetland (%)		
	(1)	(2)	(3)	(4)	(5)	(6)
Post-AJD	1.714***	1.620***	0.536	0.368*	0.370*	0.309*
	(0.422)	(0.394)	(0.430)	(0.207)	(0.206)	(0.160)
Post-AJD × Non-regulated	1.393***	1.371***	0.381	-0.533***	-0.527***	-0.328**
	(0.353)	(0.350)	(0.303)	(0.187)	(0.186)	(0.140)
Non-regulated × Event time		0.010***	0.006***		-0.002**	-0.002*
	—	(0.002)	(0.002)	—	(0.001)	(0.001)
Post-AJD × Event time			0.547***			0.024
	—	—	(0.157)	—	—	(0.045)
Post-AJD × Non-regulated			0.444***			-0.090**
× Event time	—	—	(0.138)	—	—	(0.041)
Fitted effect: Event time = 4						
Non-Regulated	3.108	2.991	4.882	-0.164	-0.158	-0.280
Regulated	1.714	1.620	2.725	0.368	0.370	0.407
Difference	1.393	1.371	2.158	-0.533	-0.527	-0.687
P-value difference	[0.000]	[0.000]	[0.001]	[0.004]	[0.005]	[0.001]
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	56,017	56,017	56,017	56,017	56,017	56,017
Observations	2,335,635	2,335,635	2,335,635	2,335,635	2,335,635	2,335,635

Notes: This table reports estimates from a linear regression where 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 Wetland Inventory (NWI) water feature. Standard errors are clustered by commuting zone. ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

Table A7: Aggregating the Economic Impact of the Navigable Waters Protection Rule (NWPR) on Land Values

	Estimated deregulation	Effect of deregulation	Effect of NWPR	Value (B)	Share value
	(1)	(2)	(3)	(4)	(5)
A. Wetland Map Model					
Water resource share					
0%	—	—	0.000	1121	0.771
(0%, 10%]	—	—	0.015	226	0.156
(10%, 20%]	—	—	0.067	40	0.028
(20%, 30%]	—	—	0.073	23	0.016
(30%, 40%]	—	—	0.095	14	0.010
(40%, 50%]	—	—	0.109	8	0.006
(50%, 60%]	—	—	0.135	5	0.004
(60%, 70%]	—	—	0.098	4	0.002
(70%, 80%]	—	—	0.067	3	0.002
(80%, 90%]	—	—	0.107	2	0.002
(90%, 100%]	—	—	0.108	6	0.004
Mean property	—	—	0.008	—	—
B. Algorithmic Model					
Probability of regulation					
0%	0.147	0.000	0.000	55	0.038
(0%, 10%]	0.082	-0.001	-0.000	187	0.129
(10%, 20%]	0.073	0.004	0.000	259	0.178
(20%, 30%]	0.097	0.012	0.001	276	0.190
(30%, 40%]	0.190	0.027	0.005	192	0.132
(40%, 50%]	0.222	0.057	0.013	163	0.112
(50%, 60%]	0.206	0.072	0.015	138	0.095
(60%, 70%]	0.202	0.109	0.022	90	0.062
(70%, 80%]	0.255	0.165	0.042	61	0.042
(80%, 90%]	0.256	0.218	0.056	21	0.015
(90%, 100%]	0.219	0.268	0.059	11	0.007
Mean property	—	0.038	0.008	—	—

Notes: NWPR is the Navigable Waters Protection Rule. Water resource share equals share of area within 100 meters of the property centroid that is covered by any type of National Wetland Inventory (NWI) water feature. This table shows the parameter estimates and transaction shares used to calculate the impact of NWPR on the mean parcel value. Panel A shows values for the wetland map model and Panel B shows values for the algorithmic model. Column (1) shows the algorithmically estimated deregulation. Column (2) shows the estimated effect of deregulation on log property sale price (β_j from equation (9) multiplied by -1). These two columns are only estimated in the algorithmic model. Column (3) shows the estimated effect of NWPR on log property sale price. In Panel A, these estimates represent the effect of NWPR on prices for each bin of water resource share. In Panel B, these values are calculated by multiplying estimated deregulation from Column (1) with the effect of deregulation on log sales price from Column (2). Properties with 0 water resource share and 0 probability of regulation are used as the reference categories, so the coefficient estimates are mechanically equal to 0. Column (4) shows the total value of properties transacted in each category. Column (5) shows the share of transacted value in each category. These shared are used as weights when calculating the effect of NWPR deregulation the sale price for the mean property.

Table A8: Land Value Benefits Versus Flood Protection Costs of Clean Water Act Deregulation Assuming All Development Occurs on Wetlands

	Mean		Total	
	(1)	(2)	(3)	(4)
A. Effect of NWPR on Development				
Using wetland map (acres)	0.037	0.065	105,747	1,797,428
Using algorithm (acres)	0.059	0.102	166,977	2,838,171
B. 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	—	—	-3,728	-63,380
Using algorithm	—	—	-5,887	-100,078
C. Ratio of NWPR Land Value Benefits to Flood Protection Costs				
Using wetland map	—	—	3.3	2.0
Using algorithm	—	—	2.0	1.2
Transacted Properties	Yes	—	Yes	—
All Properties	—	Yes	—	Yes

Notes: Columns (1) and (3) show non-residential properties that transacted in our analysis sample. Columns (2) and (4) show all non-residential properties from CoreLogic assessor data, in which the assessed value is scaled by the ratio of price to assessed value (2.46) predicted by a random forest model (Appendix C.2). Wetland acres represent the percent of land within 100m of the property centroid covered by National Wetland Inventory (NWI) water features, multiplied by property acreage. Panel B scales the effect of the Navigable Waters Protection Rule (NWPR) on land values (see Table A7) by the average transaction price in our analysis sample. Panel C shows the effects of NWPR on wetland area 4 years after an AJD (see Figure 7). Wetland Map is National Wetland Inventory (NWI) water resource share. 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 (see Table 2) to get estimates for the average parcel. Panel E divides estimates in Panel D by the corresponding estimates in Panel B and multiplies by -1.

Table A9: Ecosystem Service Values from Meta-Analyses

	Brouwer et al. (1999)	de Groot et al. (2012)	Brander et al. (2013)	Bilkovic et al. (2025)	Average
A. Ecosystem Services					
Food provisioning	–	2.8%	–	–	2.8%
Water supply	8.9%	2.6%	21.0%	–	10.9%
Raw materials	–	1.3%	–	–	1.3%
Genetic resources	–	0.02%	–	–	0.02%
Medicinal resources	–	0.7%	–	–	0.7%
Ornamental resources	–	0.2%	–	–	0.2%
Climate regulation	–	0.1%	–	9.4%	4.7%
Flood control	**38.1%**	**13.6%**	**43.0%**	**55.1%**	**37.4%**
Regulation of water flows	–	9.2%	–	–	9.2%
Water quality (general)	21.7%	–	–	–	21.7%
Waste treatment	–	11.8%	–	–	11.8%
Erosion protection	–	10.7%	–	–	10.7%
Nutrient removal / recycling	–	2.9%	36.0%	19.9%	19.6%
Biological control	–	1.6%	–	–	1.6%
Nursury / habitat biodiversity	31.4%	19.3%	–	8.2%	19.7%
Genetic diversity	–	12.4%	–	–	12.4%
Aesthetic information	–	2.1%	–	–	2.1%
Recreation	–	7.2%	–	7.4%	7.3%
Inspiration	–	1.1%	–	–	1.1%
Total	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: This table shows 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). Panel A reports these proportions, and 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. We combine these by taking a weighted average of values over both categories by the number of studies and report a single proportion for each ecosystem service. 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.