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 values and land use. 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, deregulation expanded permitting and impervious surfaces like pavement while reducing wetland area. Fourth, the aggregate increase in land values of $111 to $114 billion exceeds the estimated loss in wetlands' flood mitigation services by a factor of three or more, though other ecosystem services remain unmeasured.

JEL: H23, Q25, Q50, R30, R52

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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; quantify impacts on land markets, development, and the environment; and 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. Other countries such as Brazil, China, the European Union, and India 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, skewing housing values, and distorting spatial patterns of economic growth. Hsieh and Moretti (2019) estimate that land use restrictions have reduced aggregate U.S. growth by up to a third over four decades. Spatial misallocation is particularly important as land use regulation can be concentrated in especially productive regions. *Abundance* (Klein and Thompson 2025) laments 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). The U.S. House and Senate both have bills under debate, with some bipartisan support, to streamline environmental permitting (Hill 2025; Picon 2025).

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, while the Clean Water Act focuses on U.S. development expansions today, the historical importance

of wetland development is reflected in high-value areas of iconic global cities that expanded onto former wetlands, including Boston's South End (former tidal marshes), London's East End (former tidal marshes), Eastern Mexico City (former lake), much of Jakarta (former swampy alluvial plain), much of New Orleans (former cypress swamps), and many others.

Some stakeholders contend that Clean Water Act's regulation of land use can increase uncertainty, delays, and costs. To comply, developers typically commission a wetland consulting report, request the U.S. Army Corps of Engineers (Army Corps) to determine jurisdiction, and then obtain and comply with a federal wetland permit. Permits can require changing the design of the project, leaving areas undeveloped, paying to build new nearby wetlands, or spending on other compensatory mitigation investments, plus delay and uncertainty. In congressional testimony on data center development, Microsoft's president summarized (Halverson 2025):

> The No. 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.

Uncertainty also reflects the "regulatory ping-pong" (Cramer 2022) of a half-dozen Supreme Court and White House Clean Water Act rules in the last decade. 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 on one of the largest recent policy changes, the 2020 Navigable Waters Protection Rule (NWPR) and its subsequent judicial stay suspending the rule. NWPR deregulated ephemeral streams that flow a small portion of each year and thus are not "relatively permanent," and isolated wetlands, which lack a continuous surface water connection to navigable waters.

A case study helps clarify the tradeoff these regulations skirt between allowing development of valuable land and preserving important ecosystem services. Bridgeland, Texas, is an 11,500 acre master planned community on the outskirts of Houston. Just after NWPR passed, 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. This region is prone to heavy periodic rainfall and significant flooding common to the Houston area (Harris County Flood Control District 2025). Bridgeland has since developed parts of this area including multi-million dollar homes, trails, and water features. Bridgeland has won awards including Master Planned Community of the Year

and sold areas to a Fortune 500 company (Chevron) to provide offices for its research and development staff.[1]

To move from a case study to understand the national impacts of regulation, 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 wetland and water resources and a machine learning algorithm that we train. These two approaches have complementary strengths—the wetland map allows for simple interpretation in geophysical terms and reflects information readily available to stakeholders, while the algorithm allows interpretation in terms of the probability of regulation. For validation and algorithm training, we use data on legally-binding approved jurisdictional determinations from the Environmental Protection Agency (EPA) and Army Corps.

We find that NWPR dramatically decreased Clean Water Act jurisdiction, and the subsequent judicial stay somewhat restored it. The probability of regulation fell under NWPR by 8 percentage points for parcels without mapped water resources but 29 percentage points for sites fully covered with mapped water resources. The algorithm indicates that the mean probability of regulation fell under NWPR from 36 percentage points to 21 percentage points, a decline of 41 percent relative to baseline. The wetland map and the algorithm suggest comparable patterns of regulation.

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 are far more affected by Clean Water Act regulation. For example, the probability that a non-residential parcel has an Army Corps jurisdictional determination is 115 times greater than the corresponding probability for residential parcels.

We find that Clean Water Act regulation substantially affects values of non-residential parcels. Event study graphs using either the wetland map or algorithm show that values of properties deregulated under NWPR are relatively flat before NWPR, jump in value under NWPR, and move back towards baseline values after NWPR. We discuss how expectations of subsequent deregulation may affect these patterns. Regressions indicate that NWPR increased the value of the average non-residential parcel by \$4,400 to \$4,500, or nearly 1%, with larger effects for parcels facing more extensive deregulation.

Several tests assess internal validity, which support the integrity of the research design.

[1] See Bridgeland's promotional video: https://vimeo.com/1086789891?fl=pl&fe=sh

First, we report event study graphs that assess the timing of Army Corps jurisdictional determinations and property price responses around NWPR's implementation in early 2020 and subsequent judicial stay. Second, given overlap in the time between NWPR and the COVID-19 pandemic, we investigate the sensitivity of results to adding parcel-level proxies for the COVID housing boom (Ramani et al. 2024): the share of individuals who can work from home based on industry of employment, the distances to the closest town center and metro area, and population density. Third, we compare NWPR's land market effects for residential parcels versus effects for non-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, separately for non-residential and residential parcels. Sixth, we estimate heterogeneous price impacts by housing supply elasticity to assess the importance of shifts in the supply of developable land. Finally, we test how NWPR affected prices of parcels that experienced little to no change in regulation.

The paper's third section investigates how Clean Water Act regulation affects development. These estimates both clarify a mechanism for this regulation to affect land values and help measure how regulation affects one component of ecosystem services. We study changes in remotely-sensed measures of wetland extent and impervious surfaces in years surrounding an Army Corps jurisdictional determination, which proxies for development projects. We also compare patterns of outcomes between projects that are regulated versus observably similar projects that are not.

We find that 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. These effects occur for both regulated and non-regulated sites, though are larger for non-regulated sites.

The paper's fourth section compares estimates of the economic cost of Clean Water Act regulation estimated from property values against one important environmental benefit—flood mitigation. We focus on recent national estimates of wetlands' flood mitigation benefits (Taylor and Druckenmiller 2022), though we discuss an analysis from Florida (Aronoff and Rafey 2023) and a meta-analysis of stated preferences (U.S. EPA and U.S. Army Corps of Engineers 2022). We estimate that NWPR increased all U.S. non-residential land values,

including parcels that did not transact in our analysis period, by a total of $111 billion (algorithmic analysis) to $114 billion (wetland map analysis). We estimate that NWPR decreased flood mitigation benefits by $5.8 billion to $53.5 billion. The range in flood mitigation benefits primarily reflects different assumptions and data sources on the extent of wetlands lost to development after NWPR. Across scenarios, NWPR's land value benefits exceed its cost in terms of lost flood protection benefits by a factor of 2.1 or more. This analysis may underestimate the total value of lost ecosystem services by excluding certain classes of flood damages and other categories of wetland benefits like water filtration and habitat protection, as well as general equilibrium shifts in the hedonic price function.

By providing a comprehensive analysis of the costs and benefits of a major change in Clean Water Act jurisdiction, this paper directly addresses the Congressional Budget Office's call for new research on the economic effects of federal permitting requirements (Congressional Budget Office 2025).

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. 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). This study summarizes reported costs of internal staff time and outside experts, but ignores 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 entirely. The EPA and Army Corps (2021) estimate the cost of permit fees and mitigation costs for Clean Water Act regulation, though not other components of costs. Contemporaneous work (Liu 2025) studies how litigation interacts with land use regulation to lengthen 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). Greenhill et al. 2024 and Greenhill et al. 2025 analyze how NWPR affects jurisdiction.

We also believe this paper provides the first comprehensive economic analysis of the

Clean Water Act regulation of land use. 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 several decades ago (Behrer et al. 2021; Earnhart and Segerson 2012). These are separate from the regulations we study. Most factories and municipal wastewater treatment plants 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).

More broadly, this paper 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) use spatial and temporal variation in U.S. wetlands to estimate wetlands' flood protection benefits. Evidence suggests that mangroves, a type of coastal wetland, prevent flood damages from storms (Hochard et al. 2019; Valle et al. 2020). Schiffman (2024) highlights the increasing use of wetlands as nature-based infrastructure for urban flood mitigation. 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. 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 land use regulation. Several recent studies use proprietary construction permit datasets such as BuildZoom and Shovels to analyze the effects of environmental regulation and development (e.g., Frank et al. 2025; Van Der Kroft et al. 2025), though these sources do not record Clean Water Act permitting information. A broader agenda, related

[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, is typically a bad idea for industry or cities.

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 proceed as follows. Section 2 provides background. Sections 3 and 4 discuss the data and research design. Subsequent sections present the four sets of results: Section 5 analyzes changes in regulatory stringency, Section 6 investigates effects on property values, Section 7 analyzes development outcomes, and Section 8 compares measured costs and benefits. Section 9 concludes.

2 Background: Land Use Regulation Under the Clean Water Act

2.1 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 (Keiser and Shapiro 2019; Flynn and Marcus 2025; Jerch, forthcoming). 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 of the Act restricts the discharge of "dredge and fill material" into jurisdictional waters. In practice, this clause restricts all construction and development activity (e.g., use of heavy machinery) that affects jurisdictional waters, 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 currently dry due to nearby drainage infrastructure like canals, ditches, and culverts.

Wetlands are often imagined as areas with moderately deep standing water for much of the year. In practice, however, many areas that fall under Clean Water Act jurisdiction are dry for substantial portions of the year and are therefore relatively easy to develop. Figure A1 illustrates several examples of semi-dry wetlands, which differ markedly from the stereotypical image of wetlands.

We discuss two types of water resources—wetlands and all (surface) water resources. Wetlands include swamps, bogs, marshes, and related areas.[3] Our broad categorization of water resources includes wetlands along with lakes, ponds, streams, and estuaries.

The EPA and Army Corps implement Section 404 regulations as follows.[4] 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 are 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 requirements (Strassner et al. 2016). Uncertainty, effort, and delay in each of these steps can increase their economic cost. 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,

[3] The widely-used Cowardin et al. (1979) classification of water resources describes these as "palustrine" wetlands—inland, non-tidal water resources with water-loving (hydrophytic) plants. We do not generally use the hydrological and Cowardin et al. (1979) interpretation of "wetlands," which includes lakes, ponds, streams, and estuaries (hydrologically known as lacustrine, riverine, and estuarine wetlands) along with palustrine wetlands.

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

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). In contrast, if a water resource is deemed non jurisdictional, the landowner can proceed free of Clean Water Act regulation. Such development can include re-routing water through ditches, routing it underground via culverts, or using other engineering drainage technologies—though it is worth noting that a site may be subject to state-level or other federal land use regulations.

2.2 Changes to Clean Water Act Rules

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

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 either *Rapanos* or NWPR (Appendix A.3). 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, including groundwater and subsurface aquifers. *Rapanos* was the main rule enforced before 2020 and after the 2021 judicial stay on NWPR.[5] The 2020 Navigable Waters Protection Rule (NWPR) implemented Justice Scalia's plurality opinion from *Rapanos*. It deregulated

[5] 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.

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," and thus 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 (Brinkerhoff et al. 2024; Skidmore et al. 2025; Taylor and Druckenmiller 2022).

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 window of possible beginning periods for NWPR, we use the first quarter of 2019 as the reference category in event study graphs, since it clearly predates NWPR announcements.

NWPR had a complex conclusion. On August 30, 2021, a U.S. District Court vacated NWPR, so jurisdiction reverted to *Rapanos*. The same month, a U.S. Appeals Court ruled in *Sackett*. In January 2022, the Supreme Court agreed to hear *Sackett*, which had oral arguments on October 3, 2022 (the first case on the first day of the Court's term).

Developer information and beliefs on and after 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.

2.3 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, in a region experiencing regular flooding due to heavy rainfall, moist soils, flat terrain, and low-lying development. This development is intended eventually to have 20,000 homes and is one of the country's top-selling 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 development near Cypress Creek.

In October 2020, the Army Corps provided jurisdictional determinations under NWPR for 90 water features in an area of Bridgeland property that surrounds Cypress Creek, collectively covering 80 acres of wetlands and basins plus 20 linear miles of ditches and streams (U.S. Army Corps of Engineers 2020). The Army Corps concluded that none of the sites were regulated under NWPR.[6] Many of the water resources under consideration were near Cypress Creek but lacked a continuous surface water connection—sites that would have likely been regulated under *Rapanos* but not under NWPR.

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

[6] 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 Bridgeland property.

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. First Street Foundation (2025) estimates that 81.9% of properties in Bridgeland have a major risk of flooding in the next 30 years. At the same time, the many high-priced homes, research campus for a Fortune-500 company, and the value of the adjacent natural amenities demonstrate the demand for such development on wetlands and the potential costs of regulation that restricts such development.

3 Data

We analyze data spanning the period January 1, 2017 to May 25, 2023. All our data covers this time period, which spans the main policy changes we study. 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, we use data from approved jurisdictional determinations (AJDs) issued by the Army Corps. The tabular 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.[7] Greenhill et al. (2024); Greenhill et al. (2025) discuss additional details, including modest measurement error in coordinates and reported jurisdiction.

We use property transaction data from CoreLogic (CoreLogic 2024). Our 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 sep-

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

arately for each of these categories. See Table A6 details on the breakdown. Following the same data quality screening steps, we also extract a random sample of 4.9 million residential transactions over the same time period. We deflate all dollar values in the paper to 2024 using the GDP deflator (U.S. Bureau of Economic Analysis, n.d.).

We join the data from CoreLogic with data from multiple sources to construct parcel-level proxies for the COVID housing boom: measures of each parcel's distance to the nearest town center and metro area, population density, and share of people working from home. We compute the straight-line distance from each parcel's centroid to the nearest Census "place" (city/town) center using NHGIS point shapefiles (U.S. Census Bureau 2015). Distances to the nearest major metropolitan area are obtained by matching parcels to the closest of the 400 largest U.S. cities using the SimpleMaps U.S. Cities Database (SimpleMaps.com 2023), which is compiled from several U.S. Census Bureau and U.S. Geological Survey datasets. Population density is defined as 2020 block population (U.S. Census Bureau 2020) divided by land area in square kilometers. 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.

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,[8] 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 $\times$ year $\times$ 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. Our 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).

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

While the National Wetlands Inventory has known errors of inclusion and exclusion (U.S. Fish & Wildlife Service 2025; Kudray and Gale 2000; NC Wetlands 2025; National Research Council 2001), it provides a transparent and simple proxy for where NWPR may change regulation, and it may be the most observable and salient data available to landowners and developers. Since we do not observe parcel boundaries, we draw a 100 meter radius around each parcel's latitude/longitude to compute the share of water resources and other land use characteristics. Our second measure of jurisdiction uses predictions from a machine learning algorithm that estimates property-level probabilities of regulation under both *Rapanos* and NWPR. Building on Greenhill et al. (2024), 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 local characteristics: the share of a 100-meter radius around the site centroid covered by each water resource class (e.g. 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. 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 A3 shows the probabilities 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. Non-residential parcels are 2pp more likely than residential parcels to be regulated under either rule.

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, as opposed to a binary land use categorization. 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 actual property boundaries in our dataset, only the centroids. So to obtain a representative value for each property—and not just the value at an arbitrary point—we compute spatial statistics within a 100m radius (7.75 acres) which is about half the acreage of the average property in our sample (15.5 acres).

4 Econometrics

4.1 Jurisdiction

We use the following equation to estimate how NWPR affects Clean Water Act jurisdiction:

$$Y_{ict} = \alpha W_i + \gamma \mathbb{1}[R_t = \text{NWPR}] + \beta W_i \mathbb{1}[R_t = \text{NWPR}] + \varepsilon_{ict} \tag{1}$$

Here Y indicates whether AJD i located in commuting zone c made on day t is jurisdictional. 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 $\mathbb{1}[R_t = NWPR]$ equals one if NWPR was in force at time t and zero otherwise. The coefficient β tests whether NWPR disproportionately deregulates sites with water resources.

An analogous equation uses the algorithm to assess how NWPR affected regulation:

$$\begin{aligned} Y_{ict} = {} & \alpha_1 p(Rapanos)_i + \alpha_2 p(\text{NWPR})_i + \gamma \mathbb{1}[R_t = \text{NWPR}] \\ & + \beta \Delta\text{Regulation}_i \mathbb{1}[R_t = \text{NWPR}] + \varepsilon_{ict} \end{aligned} \tag{2}$$

Here Y and R are as in (1). The algorithm estimates the probabilities $p(Rapanos)_i$ and $p(\text{NWPR})_i$ that *Rapanos* and NWPR regulate site i. The variable $\Delta\text{Regulation}_i \equiv p(\text{NWPR})_i -$

$p(Rapanos)_i$ equals the change in the probability of regulation between NWPR and *Rapanos*. We estimate equation (2) on a held-out test set of AJDs excluded from model training.

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. 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. 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.

4.2 Property Values

Difference in Difference estimates

To assess how Clean Water Act regulation affects property values, we estimate a difference-in-differences model in which the policy effect is identified from interactions between the onset of NWPR and cross-sectional variation in parcel-level water resource share:

$$\ln(P_{izct}) = \alpha W_i + \beta W_i \mathbb{1}[R_t = \text{NWPR}] + X_i'\gamma_1 + (\mathbb{1}[R_t = \text{NWPR}]X_i)'\gamma_2 + \eta_{zt} + \varepsilon_{izct} \quad (3)$$

Here P_{izt} represents the transaction price for parcel i in zip code z sold at year $\times$ month t from our analysis sample of property transactions from CoreLogic. The terms W and R are as in equation (1). The controls X_{izt} include parcel size 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 five-digit zip code $\times$ year $\times$ month fixed effects η_{zt} adjust for overall changes in local regulation, housing market conditions, national effects of NWPR common to all properties, and other unobserved local shocks. The error ε_{izct} allows autocorrelation (clustering) by commuting zone, given commuting zones' relationship to housing markets and geophysical patterns of wetland extent. Notably, our estimating equation follows the procedure outlined in Banzhaf 2021 for hedonic difference-in-differences estimators by allowing for different coefficients on the parameters describing the ex-ante and ex-post hedonic price functions.

The coefficient β describes how the change in log property values between NWPR and *Rapanos* differs 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 analysis includes all properties given the small number of properties that have both AJDs and transactions (Appendix C.4).

Equation (3) makes two main identifying assumptions. First, it assumes that the sales prices of water resource parcels and non-water resource parcels would have followed similar trajectories in the absence of treatment (parallel trends). We use event study graphs to examine trends in parcels with more versus fewer water resources in periods before policy implementation. Second, equation (3) assumes that conditional on controls, NWPR does not affect parcels without water resources (the stable unit treatment value assumption). We provide some evidence on this assumption by directly estimating effects of NWPR on parcels without water resources.

We estimate analogous results by using the algorithmic estimate of regulatory probabilities rather than the wetland map to proxy for jurisdiction:

$$\begin{aligned}\ln(P_{izct}) = \alpha_1 p(Rapanos)_i + \alpha_2 p(\text{NWPR})_i + \beta^A \Delta\text{Regulation}_i \mathbb{1}[R_t = \text{NWPR}] \\ + X_i'\gamma_1^A + (\mathbb{1}[R_t = \text{NWPR}]X_i)'\gamma_2^A + \eta_{zt}^A + \varepsilon_{izct}^A\end{aligned} \tag{4}$$

Here $\Delta\text{Regulation}_i \mathbb{1}[R_t = NWPR]$ is defined as in (2). Also as in (2), we control for the probabilities of regulation under *Rapanos* and NWPR during the period when *Rapanos* was in force. We add parcel-level observable characteristics (X_{izt}) and zip × year × month fixed effects (η_{zt}^A), echoing equation (3). The coefficient β^A represents the effect of changing Clean Water Act regulation on property values. Finding $\beta^A < 0$ would correspondingly imply that regulation reduces property values. Since $\Delta\text{Regulation} < 0$ for most properties, finding $\beta^A < 0$ would imply that NWPR increased property values for the parcels it deregulated.

We note that equation (4) is equivalent to

$$\begin{aligned}\ln(P_{izct}) = \alpha_1 p_i(Rapanos) + \alpha_2 p_i(\text{NWPR}) + \beta^A \text{Regulation}_i \\ + X_i'\gamma_1^A + (\mathbb{1}[R_t = \text{NWPR}]X_i)'\gamma_2^A + \eta_{zt}^A + \varepsilon_{izct}^A\end{aligned} \tag{5}$$

where $\text{Regulation}_i = p_i(Rapanos)\mathbb{1}[R_t = Rapanos] + p_i(\text{NWPR})\mathbb{1}[R_t = NWPR]$ represents the probability of regulation at the time of the property transaction. Equation (5) allows the simple interpretation of β^A as the effect of regulation on property values.

We use the following equation to report event study graphs:

$$\ln(P_{izcqt}) = \sum_{\tau} \Big(\beta_\tau W_i \mathbb{1}[q_q = \tau] + (\mathbb{1}[q_q = \tau] X_i)' \gamma_\tau \Big) + \eta_{zt} + \varepsilon_{izcqt} \tag{6}$$

The indicator $\mathbb{1}[q_q = \tau]$ equals 1 if year×quarter q_q equals τ and 0 otherwise. Estimating coefficients for each year×quarter q allows the effects of parcel characteristics X_i to vary flexibly with event time. We plot the coefficients β_τ against the year×quarters they represent. This graph permits a visual inspection of pre-trends and assessment of how property values change in time periods around rule changes.

4.3 Extensions and Sensitivity Analysis

We report a semi-parametric specification that allows for non-linear effects of water resource share on property values:

$$\ln(P_{izct}) = \sum_{m} \beta_m \mathbb{1}[W_i \in m] + X'_{izt} \gamma_1^B + (\mathbb{1}[R_t = \text{NWPR}] X_{izt})' \gamma_2^B + \eta_{zt}^B + \varepsilon_{izt} \tag{7}$$

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 the mth bin. We use ten bins ranging from 0 to 1 in equal increments of 0.1. We use a similar equation with the algorithm to estimate non-linear effects of the probability of regulation on property values:

$$\begin{aligned} \ln(P_{izct}) = \sum_{m} \Big(\alpha_{1m} \mathbb{1}[p_i(\textit{Rapanos}) \in m] + \alpha_{2m} \mathbb{1}[p_i(\text{NWPR}) \in m] + \beta_m^N \mathbb{1}[\text{Regulation}_i \in m] \Big) \\ + X'_{izt} \gamma_1^N + (\mathbb{1}[R_t = \text{NWPR}] X_{izt})' \gamma_2^N + \eta_{zt}^N + \varepsilon_{izt}^N \end{aligned} \tag{8}$$

Here the indicators $\mathbb{1}[\text{Regulation}_i \in m]$, $\mathbb{1}[p_i(\textit{Rapanos}) \in m]$, and $\mathbb{1}[p_i(NWPR) \in m]$ equal one if property i's probabilities of regulation at time t, under *Rapanos* and under NWPR are in the mth bin.

We report this semi-parametric graph both for its own interest and because the intensity of the water resource share or probability of deregulation vary continuously across parcels. The semi-parametric graph sheds some light on the marginal land market effects of

deregulation at different levels of wetland concentration.

One threat to internal validity is the COVID-19 pandemic, which overlapped with NWPR and affected housing markets. The pandemic disproportionately increased demand for properties on the urban periphery (Ramani et al. 2024), where wetlands may be relatively more common. The zip × year × month fixed effects flexibly control for trends in land markets, including from the COVID-19 pandemic, and the Ramani-Bloom controls directly control for proxies for this shock.

As another direct test, we identify zip codes that had an above-median trend break in residential property values in March 2020. When the pandemic began, we test whether NWPR had disproportionate effects on non-residential property values in these areas:

$$\begin{aligned}\ln(P_{izct}) = \alpha W_i + \rho C_z + \phi W_i C_z + \beta W_i \mathbb{1}[R_t = \text{NWPR}] + \psi C_z \mathbb{1}[R_t = \text{NWPR}] + \\ \kappa W_i C_z \mathbb{1}[R_t = \text{NWPR}] + X_i' \gamma_1^C + (\mathbb{1}[R_t = \text{NWPR}] X_i)' \gamma_2^C + \eta_{zt}^C + \varepsilon_{izct}^C\end{aligned} \tag{9}$$

Finally, we report one test for the importance of shifts in land supply. We interpret NWPR as a shock to land quality, so that our estimates reflect the demand for unregulated versus regulated wetlands. At the same time, this shock 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.

To test for price effects of shifts in the supply of developed land due to NWPR, we interact the treatment variable with eight bins spanning the MSA-level housing supply elasticity e_i from Saiz (2010), as in Krause and Chakma (2025):

$$\begin{aligned}\ln(P_{izct}) = \sum_{q=1}^{8} \Big(\theta_{1q} W_i \mathbb{1}[e_i = q] + \theta_{2q} W_i \mathbb{1}[R_t = \text{NWPR}] \mathbb{1}[e_i = q] \Big) + \\ X_i' \gamma_1 + (\mathbb{1}[R_t = \text{NWPR}] X_i)' \gamma_2 + \eta_{zt} + \varepsilon_{izct}\end{aligned} \tag{10}$$

4.4 Development

We use the following equation to estimate patterns of development around AJDs:

$$L_{ict} = \sum_{\tau} \Big(\beta_\tau \, Y_i \, \mathbb{1}[t = \tau] + \gamma_\tau \, W_i \, \mathbb{1}[t = \tau] \Big) + \lambda_{ct} \; + \; \eta_i \; + \; \varepsilon_{ict} \tag{11}$$

Here jurisdiction Y and water extent W_i are as in equation (1). The term L_{it} represents the share of a given land use (developed or wetland) within a 100m radius of site i in year t. The event year indicators $\tau \in \{-4, -3, -2, 0, 1, 2, 3, 4\}$ omit $\tau = -1$ as the reference period. The initial and final categories $\tau = -4$ and $\tau = 4$ include all event times before or after the focal period [-4,4]. Although jurisdictional and non-jurisdictional parcels differ in their geophysical attributes, the interaction of event time indicators with the time-invariant measure of wetland share W_i provides a way to obtain estimates for similar parcels, conditional on geophysical characteristics. The equation includes parcel fixed effects η_i and commuting zone×year fixed effects λ_{ct}. The error term ε_{ict} allows clustering by commuting zone. As earlier, we also highlight analogous results using the algorithm in place of the wetland map for W.

5 Effect of NWPR on Regulatory Stringency

Figure 2 shows the share of AJDs that the Army Corps determines to be jurisdictional, by 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. In Panel A, red circles represent sites with no mapped water resources, which account for 36% of all AJDs, and blue squares represent sites in the top quartile of mapped water resources ($\geq$ 19% water resource share). Panel B separates sites with high and low probability of deregulation under NWPR, according to the algorithm.

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 both panels, before NWPR began, regulation has fairly flat trends. After NWPR begins, parcels with water resources and parcels the algorithm predicts to be deregulated have especially large probability of deregulation. Panel A shows that NWPR decreased regulation by about 10pp for sites without 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 decrease in regulation. Perhaps unsurprisingly, the algorithm isolates a larger drop in regulatory probability under NWPR and the wetland maps do. While this figure'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 the measures of deregulation.

Table 2 provides corresponding regression estimates. Column (1) shows that the overall share of AJDs jurisdictional was 36.4% under *Rapanos* but fell by 11.7pp under NWPR. Column (2) uses equation (1) to show that for sites with no nearby water resources, NWPR decreased the probability of regulation by 8pp. For sites fully covered in water resources, however, NWPR decreased the probability of regulation by 29pp. 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. Unsurprisingly, this estimate is large and positive because the National Wetlands Inventory measures surface water resources and because Army Corps engineers consult this resource in determining jurisdiction. This coefficient is smaller than 100pp both because *Rapanos* does not regulate all water resources and because the wetland map imperfectly measures 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 (4) uses the algorithm on this same test set, as in equation (2). Section 4.2 described 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 (4) estimates of (1.12, -0.05, and 1.14) are near this benchmark. These coefficients provide additional evidence that the model is well-calibrated.

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.

6 Regulation and Property Values

6.1 Estimated impacts

Figure 3 shows event study analyses of how NWPR affects land values, estimated using equation (6). Panels A and C use the wetland map; Panels B and D use the algorithm. In each graph, the horizontal axis shows year×quarters. The vertical axis shows coefficients from a regression of log transaction value on interactions of the quarter with either the water resource share or the algorithm-estimated probability of deregulation, as in equation (3).

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 annual variability. Only one of the eleven pre-NWPR quarters is statistically significant at conventional levels and point estimates vary sign about zero, with no obvious trend. Beginning in the second quarter of 2020, when the Army Corps began implementing NWPR, 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 even larger magnitude. Panel B indicates that parcels where NWPR decreased the estimated probability of regulation by 100% had a log price increase of around 0.5. The algorithmic research design in Panel B obtains coefficients with larger magnitude than the water area research design in Panel A perhaps in part because the algorithm does a better job than water area maps alone at identifying which parcels NWPR deregulated.

The point estimates in Panels A and B of Figure 3 indicate that the values of properties with water resources or that the algorithm indicates became deregulated declined somewhat when NWPR was vacated in late 2021. Most point estimates from quarters after NWPR was vacated have smaller magnitude than during NWPR, and the values generally do not differ from zero at 95% confidence. These point estimates suggest that land markets no longer fully

incorporated the value of deregulation under NWPR, though they do not completely reverse the pattern of land market outcomes under NWPR. As Section 2.2 discusses, stakeholder beliefs in this period are ambiguous, given the conservative Supreme Court majority and procession of *Sackett* through courts.[9] Although a late 2021 court ruling vacating NWPR ensured short-run deregulation of Army Corps AJDs, as shown in Figure 2, land values depend on beliefs about long-run regulation, which may not adjust as rapidly and fully.

Panel A of Table 3 shows the corresponding regression estimates. The coefficient we report describes how non-residential land values change in the months when NWPR was in effect for properties most likely to be deregulated. Columns (1) through (3) use the wetland map to measure deregulation, while columns (4) through (6) use the algorithm. Positive values indicate that these properties had higher sale prices under NWPR. Columns (1) and (4) control for zip code × year × month fixed effects. Columns (2) and (5) control for the parcel size in acres. Columns (3) and (6) add parcel-level controls for the COVID-19 housing boom from Ramani et al. (2024).

Panel A of Table 3 finds that NWPR increased the value of properties that are fully water resources by around 19 percent. The estimates with and without controls have somewhat similar magnitudes. The richest specification, in column (3), indicates that NWPR increased the value of fully water non-residential parcels by 19.1 percent ($= e^{0.175}$).

Residential Properties

As Section 5 explained, we expect Clean Water Act deregulation to have the largest effects on non-residential properties, since residential properties more often have buildings and AJDs are far less common for residential properties. At the same time, reporting comparable estimates for residential parcels provides an important comparison. The event studies in Panels C and D of Figure 3 show no meaningful change in the value of residential parcels with water resources while NWPR was in force. For the wetland map analysis in Panel C, the point estimates are close to zero in magnitude and the signs vary about zero. For the algorithm in Panel D, point estimates are fairly flat and 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 richest specification

[9] We believe that no online prediction or betting markets in this period describe market beliefs about a rule like *Sackett*.

obtains that NWPR changes log land values by -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 the point estimates are actually negative.

Comparing Non-Residential and Residential Properties

Panel C of Table 3 shows a triple-difference regression comparing changes in values of non-residential versus residential properties. This specification implicitly makes the strong assumption that non-residential properties serve as a control for possible local confounding variables.

The point estimates in Panel C of Table 3 are extremely similar to those of the main estimates in Panel A. In the richest wetland map estimate of column (3), for example, the differences-in-differences estimate of Panel A implies that NWPR increased the log value of fully wetland properties by 0.175 (0.030), and a differences-in-differences-in-differences estimate of Panel C obtains an estimate of 0.182 (0.034). The algorithm obtains a similar comparison.

Non-residential parcels include several sub-categories of land use. Distinguishing among these may provide further insight on how NWPR affects land markets. Figure A14 reports versions of equation (3) estimated separately by land use as categorized by property assessment records, and reflecting (typically) county zoning, distinguishing agricultural, commercial, vacant, industrial, public, and other properties.

Table A2 shows qualitatively similar patterns of results for most sub-categories of non-residential land use, though precision varies by category in tandem with sample size. Estimates are clearest for vacant parcels, where making development less costly has sensibly large benefits. Partly this is likely because vacant parcels have the largest sample size (N=1.3 million) and constitute nearly half the non-residential sample. Public properties also have large point estimates, though they are less precise given the smaller sample (N=50,000). Several other non-residential sub-categories have large but imprecise point estimates. The estimated impact of NWPR on agricultural lands is smaller, possibly because many activities on agricultural lands and any wetlands converted to cropland before 1985 ("prior converted cropland") are exempt from Section 404 regulation.[10]

[10] Many lands regulated under the Clean Water Act and in areas that NLCD classifies as agriculture are

6.2 Extensions and Additional Sensitivity Analyses

Size of COVID residential housing boom

As an additional way to assess whether the COVID housing boom affects our estimates of how NWPR affected land markets, we divide the U.S. into two sets of zip codes: one which had above-median increase in residential housing values during the pandemic, and one which had below-median change in residential housing values. We determine the relevant zip codes by finding areas in the top and bottom quartile of price trend breaks starting in March 2020, following Ramani and Bloom (2021).

Figure A10 shows the change in the Zillow Home Value Index (ZHVI) separately for properties that had an above-median trend break (blue) and properties that had a below-median trend break (red). The groups followed identical trends before March 2020 and diverged in late 2020. By early 2022, home values in the above-median trend group rose \$120,000, while home values in the below-median trend group rose only \$60,000. We note that the COVID housing boom barely began in the third quarter of 2020 and substantially took off in the fourth quarter of 2020, two quarters after the effect of NWPR on non-residential housing values begins (Figure 3).

Table A3 tests for differences in the estimated effect of NWPR on non-residential property. Column (1) repeats the main estimate that NWPR increased log non-residential property values by 0.175 in fully wetland non-residential properties. 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 0.016 (0.064) is about a tenth the magnitude of the main estimate. The standard error fails to reject zero, though is wide enough not to rule out economically meaningful positive or negative magnitudes. Estimates using the algorithm in Panel B have similar patterns—areas with a residential COVID boom have an insignificantly different change in non-residential land values, and the point estimate of the interaction is small, though again somewhat imprecise.

actually small infrastructure or other areas adjacent to cropland, and therefore not exempt from Clean Water Act regulation (Greenhill et al. 2025).

Semi-parametric bins

We also estimate semi-parametric dose-response functions using equation (7) that relate the effect of NWPR on property values to the share of a parcel covered in water resources. We divide parcels into ten groups based on water resource share—parcels with water share in [0.00, 0.10], [0.10, 0.20], etc. The reference group includes parcels with no nearby water features. We then regress property values on the interaction of NWPR with these indicators, separately for residential and for non-residential parcels. We estimate analogous functions using bins for the algorithmic probability of deregulation instead of water resource share, as in equation (8).

Figure 6 finds that the effect of NWPR on a non-residential parcel's transaction value is largely monotonic increasing in wetland share. In panel A, the 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 a predicted probability of deregulation between 0 and 10%, 10 and 20%, etc. The vertical lines show 95% confidence intervals. The blue lines and shaded confidence intervals among non-residential parcels show a clear positive relationship between the share of a parcel that is water and the property value among non-residential parcels. Relative to parcels with no water, parcels where 0 to 10 percent of the area is water had a value increase of only 1.5% under NWPR; parcels where 30 to 40 percent is water had an increase of 9.5%; and parcels with 60 to 70 percent water had an increase of 9.8%. The pattern is monotone up to 60% water, at which point it somewhat flattens out. Panel C shows that few parcels have above 60% water share. Panel D indicates that predicted probabilities of deregulation are more evenly distributed than water resource shares, and dose–response estimates based on the algorithmic model exhibit a notably monotonic pattern.

The triangles in Panels A and B show estimates for residential parcels. These estimates for all wetland bins and predicted probability of regulation bins are somewhat near zero, the confidence regions cover zero, and the slope is fairly flat. This semi-parametric estimate echoes the difference in difference estimate earlier, which indicates that NWPR primarily affected non-residential land markets and had little spillover to residential parcels. Both are monotone, though the wetlands respond in the first half of the distribution while the algorithm responds in the second half. The support of the models is different, as shown in Panels B and C, so perhaps the difference in patterns between the two models is unsurprising.

Appendix Table A4 shows one additional test for spillovers of NWPR onto other properties. [PLACEHOLDER: Update text to match current triple-difference specification in Table A5. Old point estimate 0.0057 (0.0177) is from a previous specification.]

Local equilibrium land prices

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 or residential parcels.

This subsection reports a couple other tests for whether spillovers or shifts in the supply of developed land affect our estimates. We test for differential price impacts in locations with higher versus lower housing supply elasticities, as in Krause and Chakma (2025). We define eight equally-sized bins using metropolitan-level housing supply elasticity estimates from Saiz (2010), which we interact with the NWPR $\times$ water shares.

Figure A6 shows results. A Wald chi-squared 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.

A complementary way to assess potential violations of SUTVA and other spatial spillovers is to examine 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 A7 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.

Another consideration is that NWPR could reallocate demand from non-water resource parcels to nearby water resource parcels. This would violate the Stable Unit Treatment Value Assumption (SUTVA) because we are effectively using non-water resource parcels as the control group in our difference-in-difference estimator. (An analogous comment applies for the algorithm.) To test for this possibility, we implement a triple difference specification of the binned dose-response function that allows us to estimate the impact of NWPR on

non-residential parcels with zero water resource shares. Table A4 shows that the point estimates for the effect of NWPR on property values is positive for all non-residential parcels, including those with zero water resource share. The point estimate for zero water resource properties is very slightly above but not significantly different from zero. If NWPR were simply reallocating demand from non-water resource parcels to water resource parcels, we would expect this coefficient to be negative. Thus, we interpret our findings as Clean Water Act deregulation creating new value on water resource parcels by unlocking their development potential.

An additional feature of the housing market that complicates interpretation is that we cannot observe property buyers' expectations about regulation. Because land is a durable asset, the price a buyer is willing to pay for a parcel depends not only on its current regulatory status, but also the buyer's expectations over its future regulatory status. Our estimates rely on a sharp change in regulatory status at the time NWPR was implemented. However, property buyers' expectations could have been changing in the years or months leading up to NWPR's enactment as information became available about prospective Clean Water Act rule changes. For example, buyers may have updated their expectations about the probability of deregulation when Trump was elected in November 2016, when he issued an Executive Order in February 2017 directing the EPA to revisit the definition of WOTUS, or when a draft of NWPR was first released for public comment in February 2019. If these events increased buyers' subjective probabilities of deregulation prior to the time the NWPR rule was finalized in January 2020, our approach that assumes a sharp discontinuity at this date would underestimate the impact of regulation on property values.

Although we lack AJDs and land use data back to 2010, we do have land values back to this time. 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 Panels A and B back to the year 2010. Panel A shows that under the wetland map model, there is no detectable change in the value of water resource parcels until the rule is finalized in early 2020. Additionally, the flat estimates over this decade-long pre-period suggest that idiosyncratic forces do not routinely drive changes in values of wetland parcels in times besides NWPR. Panel B shows estimates over the same period under the algorithmic

model. Confidence intervals are larger in the period before 2017 due to a smaller sample of algorithm predictions before the main analysis period of 2017-2023. but NWPR is the only systematically positive period in the entire sample.

7 Mechanisms: Permitting and Land Use Change

This section investigates how NWPR affected permitting and land use, with two purposes. First, it observes a mechanism for why NWPR affects land values. Second, it estimates environmental impacts of NWPR, which Section 8 utilizes to calculate the value of the law's environmental consequences.

This section investigates how NWPR affected development. The time series graph in Figure 4 shows the number of AJDs, by month. The light blue dashed line shows *Rapanos* and the solid black line shows NWPR. AJDs proxy the inception of development projects, which is especially relevant to our setting.

While anecdotal evidence suggests that NWPR influenced development outcomes (Figure A2), we pursue a more systematic analysis to assess these effects. Figure 4 shows that before NWPR, developers obtained around 1,000 AJDs per month. After NWPR began, the number of AJDs rose to 4,000 per month. The count remained fairly steady until NWPR was vacated in late 2021. The number of monthly AJDs then fell to around 1,500. If NWPR increased the number of AJDs by 2,750 per month and lasted 21 months, this time series comparison implies that NWPR increased the number of AJDs by about 4.5 years' worth at pre-NWPR levels. This is 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 wide range sites, we study impacts on development using an event study around AJDs. Changes in land values likely occur soon or immediately after deregulation, since land values reflect expected future rents from owning a parcel, and also reflect the option for future development. Development effects of deregulation may be more gradual, however, as landowners plan projects, hire contractors, and develop properties. An AJD, for example, is valid for five years, so a developer could wait four years after an AJD to obtain a wetland permit and begin on development.

To study how NWPR changed wetland extent, we therefore compare development out-

comes around the time of an AJD for sites regulated versus not regulated, as in equation (11). The controls for baseline wetland share interacted with event time, or the algorithmic prediction interacted with event time, imply that we compare development for observably similar parcels, where some are regulated and others not. We interpret the AJD as reflecting an ongoing project which causes the development. The AJD identifies the start of development and distinguishes regulated versus non-regulated parcels.

Figure 5 shows the resulting event study graph, using equation (11)[11]. Red points show sites that the Army Corps determined to be regulated and blue points show non-regulated sites. Panel A shows the share of area within 100 meters that is impervious surface, one proxy for development, which remote sensing is well suited to detect. Panel B shows the share that is wetland, which is more challenging for remote sensing to detect. We measure both land use shares from the NLCD.

Figure 5 shows that unregulated development expands developed land and removes wetlands. Panel A shows that in the four years before an AJD, sites have no differential trend in the share of land that is impervious. After an AJD, development follows a linear upward slope, with unregulated (blue) sites experiencing more development than non-regulated (red) sites. After four years, the share of land that is impervious increases by nearly 6pp. Given the persistently linear slope, the additional share of developed land likely exceeds 6% more than four years after the AJD.

Panel B of Figure 5 examines wetland depletion around AJDs. In years before an AJD, regulated (red) sites have no trend in wetlands, and non-regulated (blue) sites have a modest downward trend barely distinguishable from zero. After an AJD, the graph shows no detectable change in wetland area on regulated sites. Non-regulated sites have a significant 0.4pp decline in wetland area after four years. These results collectively suggest that Clean Water Act regulation reduces wetland development.

Sensitivity Analyses: Mechanisms

Figure A5 compares the imputation estimator of Gardner et al. (2024), which addresses potential bias from staggered treatment timing, against the two-way fixed effects results discussed earlier. The overall results for regulated sites and also for non-regulated sites are

[11] See Appendix Figure A13, a version of the same event study graph controlling for the algorithmic predicted change in regulation rather than the wetland map share.

similar between the two estimators. The Gardner et al. estimator does obtain values that are a tenth of a percentage point smaller for both regulated and non-regulated sites, but the differences are statistically insignificant, and the implied effects of regulations is essentially identical across the two methods.

Table A2 incorporates parametric adjustment for differential trends and for a trend break. The first three columns examine impacts on development (share of impervious surfaces), and the last three examine impacts on wetlands. Within each group, the first column reports a standard two-way fixed effects estimator. The second column allows a differential trend for regulated sites. The third column allows for a trend-break in regulated sites. The fitted effect row beneath the regressions shows the estimated change in outcomes after five years for regulated versus non-regulated sites.

Table A2 reaffirms that AJDs are associated with large increases in impervious surfaces and decreases in wetlands. Accounting for pre-trends or allowing for a trend break do not dramatically change the magnitude of the effects. The main estimate in column (1) indicates that after 5 years, an additional 2.6% of the area within 100m of a non-regulated site has become an impervious surface, and an additional 1.4% of the area around a regulated site has become an impervious surface. The difference implies that regulation decreases impervious surfaces by 1.2%, relative to a baseline mean of 10.6%. The corresponding main estimate for wetland share after 5 years in column (4) are -0.30% for non-regulated sites and 0.02% for regulated sites, implying that regulation decreases the wetland share around sites by the difference, -0.32%, relative to a baseline mean of 9.04%. Estimates in columns (2) and (5), which allow for a differential trend in regulated sites, are about a third smaller than the main estimates, but the effect of regulation is still different from zero at the 99% confidence level. Columns (3) and (6), which further allow for a trend break in regulated sites, estimate much larger effects for both regulated and unregulated sites, but differences are less precisely estimated, especially for wetlands.

8 Measured Costs and Benefits of Clean Water Act Regulation

This section provides a partial cost-benefit analysis of land use regulation under the Clean Water Act.

8.1 Costs of Regulation

The regressions from Section 4.2 let us calculate how deregulation affected the market value of non-residential properties. These regressions imply that NWPR increased the value of the mean log transacted non-residential property value by 0.008 to 0.009 (based on the weighted average of the binned estimates in Table A5), or slightly less than one percent. In Table 4, column (1), Panel D, we take these estimates and multiply them by the mean values of transacted properties, which indicates that NWPR increased the mean non-residential property value by $4,400 to $4,500.

Because not all properties transact, we require a method to estimate fair market values for the near-universe of non-residential parcels. Unlike residential markets, where high turnover and asset homogeneity support robust price indices, the non-residential sector—comprising office, industrial, retail, and special-purpose properties—lacks comparable market-based valuation infrastructure. We therefore train a random forest model to predict transaction prices using administrative assessment records, which are available for all parcels regardless of transaction status. Predictor variables include county, land use code, year assessed, assessed value, and property acres. Appendix C.2 discusses the model and its performance in detail. On average, we find a ratio of transaction price to assessed value of 2.52, implying that assessments capture less than 40 percent of market value. This ratio varies substantially across states and counties, reflecting heterogeneous assessment policies and revaluation frequencies.

Column (2) of Table 4 suggests that non-transacting and transacting non-residential parcels have similar values. This random forest extrapolation to the values of parcels that do not transact in our analysis sample therefore does not substantially change our estimate of how NWPR affects values of the mean non-residential parcel. Panel A shows that the mean transacted non-residential parcel has market value of $513,000, while the mean non-

residential parcel overall has mean value of $556,000. The mean parcel overall is almost double the size of the mean transacted parcel, at 27.0 versus 15.5 acres, implying that non-transacting parcels have much lower value per acre than transacting parcels. Panel D indicates that the effect of NWPR on the log value of non-residential parcels is the same out to 3 decimal points for all transacting parcels as for all parcels.

We use the wetland maps and the algorithm to obtain separate estimates of how NWPR affects aggregate property values:

$$\Delta P_1 = \frac{\sum_m (\beta_m T_m)}{\sum_m T_m} P \tag{12}$$

$$\Delta P_2 = \frac{\sum_j (\delta_j \Delta R_j \mathcal{T}_j)}{\sum_j \mathcal{T}_j} P \tag{13}$$

In (12), β_m represents the estimated impact of NWPR on the log value of properties in water resource bin $m \in \{1, 2, \ldots 10\}$ from equation (7). In other words, β_1 represents the effect of NWPR on the log value of non-residential properties where water resources constitute 0 to 10 percent of property area, β_2 is the effect for properties that are 10 to 20 percent water resources, etc. Equation (12) uses the semi-parametric binned estimates from equation (7) rather than the averaged estimate from equation (3) because non-linear effects capture the uneven distribution of water resource share across properties. The term T_m represents the total transacted value of non-residential properties in each bin m, and P represents the total value of all U.S. non-residential properties, including properties that did not transact. Equation (13) is analogous 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 (8), ΔR_j represents the change in probability of regulation from *Rapanos* to NWPR in bin j, and $\mathcal{T}_j$ represents the total value of transacted properties in this bin.

We obtain each term in equations (12) and (13) from earlier results. Panels A and B of Figure 6 shows the coefficients β_m and δ_j. Table A5 shows these estimates alongside the transaction shares, T_m and $\mathcal{T}_j$, and the predicted changes in regulation ΔR_j.

Finally, we multiply the estimated price impacts by the total value of the 27.7 million non-residential properties in our sample of CoreLogic assessment records. The total assessed value of these properties is $6.12 trillion. We estimate that the fair market value of the near-universe of non-residential properties in the U.S. is $P = 13.58$ trillion. This implies

an average transaction price to assessed value ratio of 2.2; however, there is significant heterogeneity in the ratio across counties, land use types, and other observables (Appendix C.2).[12]

Equations (12) and (13) imply large impacts of NWPR on land values. We calculate that NWPR increased the value of the average non-residential property by 0.8% and 0.8%, respectively. Multiplying by the total value of non-residential properties implies an increase in the value of all non-residential properties of $\Delta P_1 = \$114$ billion or $\Delta P_2 = \$111$ billion.[13]

These 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.

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.

[12] 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.

[13] Greenhill et al. 2024 reports that NWPR deregulated lands worth $250 to $380 billion; this figure is calculated by summing the fair market value across all parcels that were deregulated under the rule change and thus captures that total land value of affected parcels. In contrast, our estimate captures the *change* in all land values attributable to NWPR.

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.).[14] 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 wildlife perspective.

8.2 Mitigation Banking Benchmarks of Regulatory Costs

Under the Clean Water Act, many projects that develop wetlands must pay other parties to build wetlands that offset the developed areas. The market prices of these compensatory mitigation offsets provide one informative 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 discussed in Appendix B.4. The mean non-residential parcel in our sample covers 15.5 acres, about 0.83 acres of them wetlands. Column (2) of Table 2 estimates that NWPR deregulated 20.3% of wetlands or 0.17 (0.97*0.193) acres of wetlands per parcel. If deregulation affected all wetlands and no other areas, regulation would cost $25,500 to $26,500 per acre of wetlands. We interpret column (1) to say that NWPR decreased regulation by 12% 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 B of Table 4 indicates is

[14] 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.

0.020 to 0.031 acres. This would imply value per developed wetland acre of $142,000 to $225,000 (4,400/0.031, 4,500/0.020). 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 environmental 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[15] 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.[16]

8.3 Flood Mitigation Benefits

Wetlands provide ecosystem services including water purification, biodiversity, groundwater replenishment, carbon storage, shoreline protection, and flood mitigation. Flood mitigation is feasible to quantify nationally; the other ecosystem services are more difficult to measure.

We combine our estimates of NWPR's effect on regulatory stringency (Table 2) and the effect of regulatory status on land cover (Figure 5) to infer the effect of NWPR on wetland area. We then apply the estimates of how property damages from flooding respond to changes

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

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

wetland area from Taylor and Druckenmiller (2022) to value the associated change in flood protection services.

Table 4 summarizes the results for the wetland map and algorithmic models and for two bounding scenarios for wetland loss.

In the "low" wetland loss scenario, we use the observed difference in wetland area between regulated and non-regulated sites following AJDs (Panel B of Figure 5). Four years after an AJD, wetland cover declined by 0.291 p.p. on regulated sites and 0.530 p.p. on non-regulated sites, implying that deregulation reduces wetland area by 0.238 p.p. 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. In addition, we observe land use changes for only four years after the jurisdictional determination, whereas Figure 5 suggests effects may continue to grow over time. We therefore interpret this estimate as a lower bound on the true effect of regulation on wetland extent.

Panel A of Figure 5 implies that deregulation converts an additional 1.395 p.p. of land to development. Because development is an easier land cover class to detect remotely — its impervious surfaces have distinct spectral signatures and are measured as continuous fractions rather than binary classifications — these estimates are less susceptible to the detection errors that affect wetland mapping.

We multiply these wetland area changes by Taylor and Druckenmiller (2022)'s estimate that one acre of wetlands provides $35,261 in net present value flood protection benefits (3% discount rate). This implies that NWPR reduced the value of wetland flood protection services by $5.8 to $9.1 billion, using the wetland remote sensing, and $33.9 to $53.5 billion, using the impervious area remote sensing. The range within each scenario reflects whether the change in regulatory stringency is estimated using the wetland map or the algorithm.

8.4 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 D of Table 4, column (4), indicates that NWPR increased national land values by $111 billion to $114 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 15 percent.

Panel C of Table 4 reports our estimate of the aggregate increase in flood damages due to NWPR. This statistic ranges more widely, from a loss of $5.8 billion to a loss of $53.5 billion. These estimates have a wide range because we estimate that Clean Water Act-led development has a large detectable effect on impervious surfaces but a smaller magnitude effect on remotely detected wetlands. Thus, our larger estimates of flood damages ($33.9 to $53.5 billion) assume that all newly impervious surfaces represent developed wetlands, while our smaller estimates of flood damages ($5.8 to $9.1 billion) assume that only the decrease in remotely-sensed wetlands causes flood damages.

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 12-20 to 2-3. Here the smaller ratios reflect the use of remotely-sensed impervious surfaces to measure flood damages, and the larger ratios reflect the use of remotely-sensed wetlands to measure flood damages. A smaller portion of these ranges reflect the difference between the wetland map model and the algorithm.

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.

These statistics provide a partial welfare analysis of this law. In the classic and simplest hedonic model (rosen1974hedonic), 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 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 (roback1982wages). In general, not measuring changes in wages due to a policy reform that people value will tend to understate its benefits.

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.

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 over 100 times more likely than residential parcels to have an AJD. 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 $111 to $114 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.

Finally, we do not distinguish what component of that cost reflects 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 these costs would be valuable.

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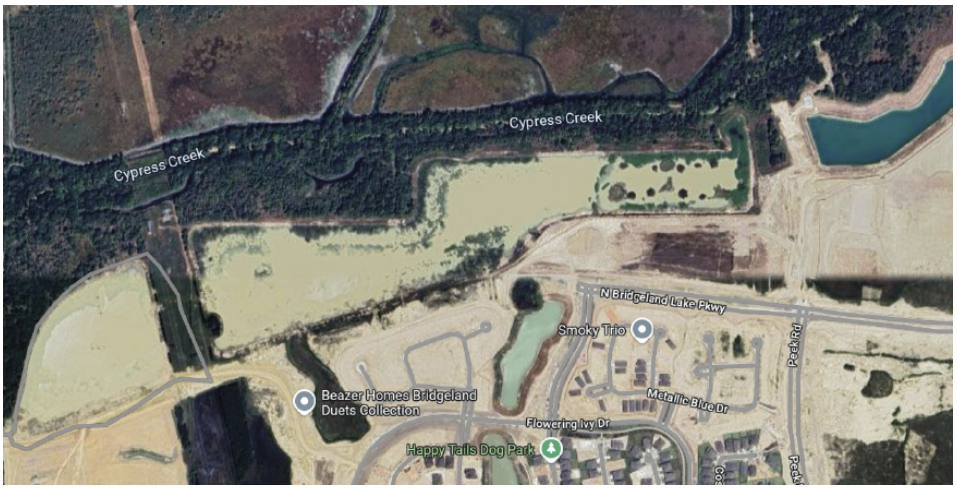
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Figure 1: Development Example From the Bridgeland Master Planned Community, Texas

(A) Aerial Image of Flooding, 2016



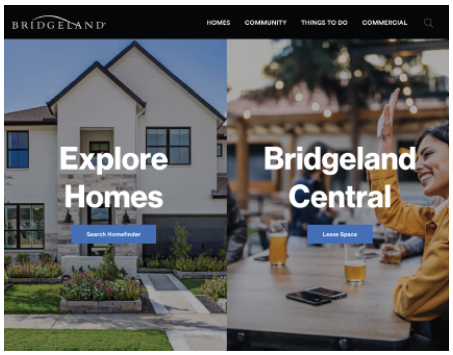
(B) Aerial Image of Development, 2024



(C) Google Street View



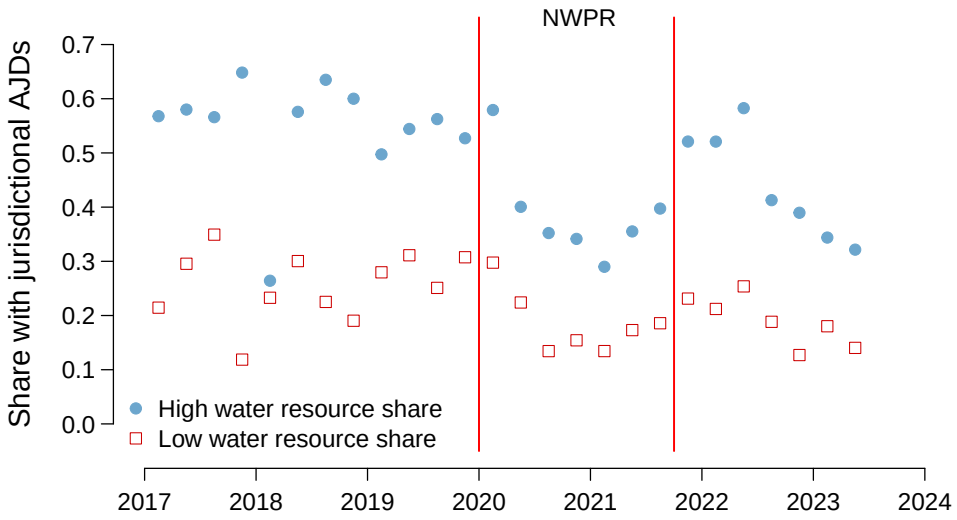
(D) Developer Website



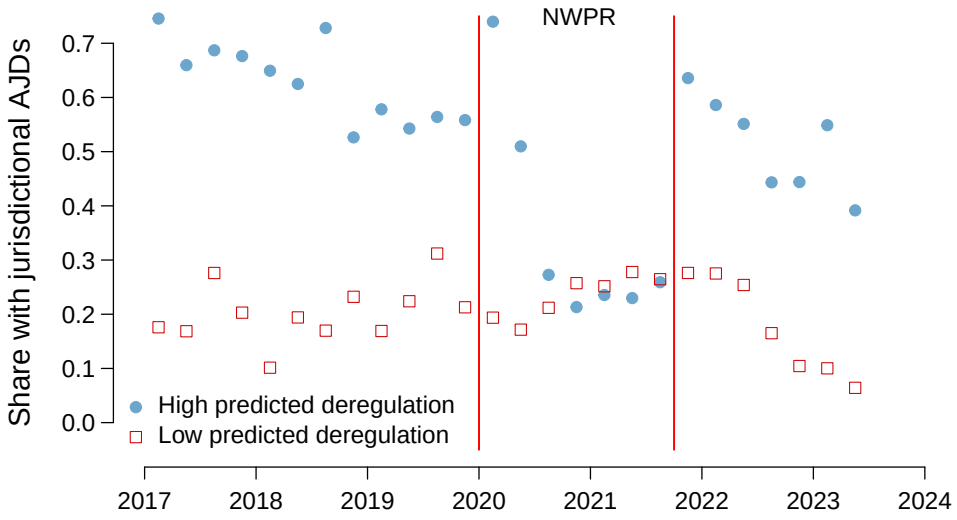
Notes: Panels show imagery of the Bridgeland housing development near Cypress Creek about 25 miles northwest of central Houston, TX, which received jurisdictional AJDs under the Navigable Waters Protection Rule (NWPR) in October 2020. Panel (A) shows aerial imagery from Google Earth of flooding in 2016. 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 Sites Regulated Under the Clean Water Act, 2017-2023

(A) Using Wetland Map



(B) Using Algorithm

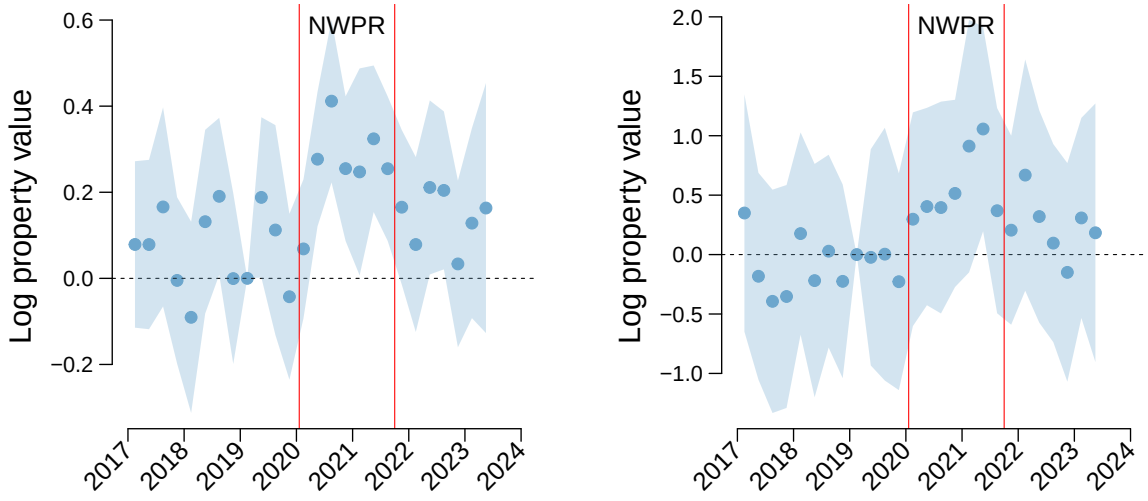


Notes: AJDs are approved jurisdictional determinations. Both panels show the share of AJD sites that are jurisdictional in each year × quarter. In Panel (A), blue circles describe properties above the 75th percentile of water resource share (representing sites with water resource share exceeding 19%) 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 Wetland Inventory water features. In Panel (B), blue circles describe properties above the top 75th percentile of change in probability of regulation during the Navigable Waters Protection Rule (NWPR), scaled by -1 so that more positive values indicate more deregulation under NWPR (ΔRegulation $= p(Rapanos) - p(\text{NWPR})$), from the algorithm. Red squares describe properties below the 36th percentile of the change in probability of regulation under NWPR. 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. The Army Corps began implementing NWPR in AJDs in June 2020.

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

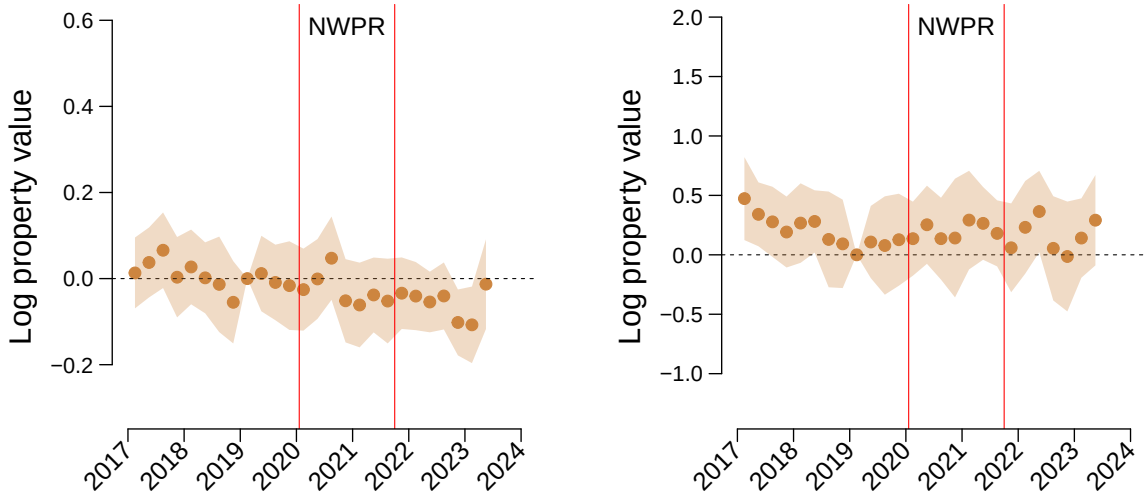
(A) Using Wetland Map, Non-residential

(B) Using Algorithm, Non-residential



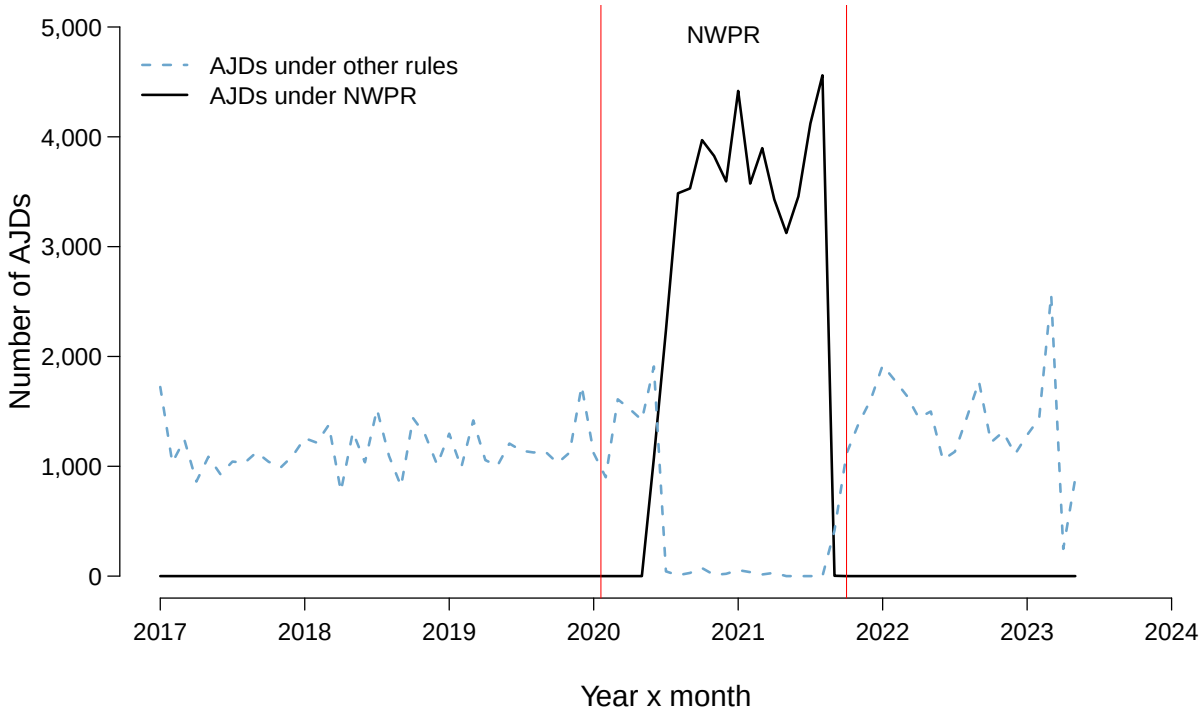
(C) Using Wetland Map, Residential

(D) Using Algorithm, Residential



Notes: Panel (A) shows the effect of water resource share on log values of non-residential properties by year × quarter from equation (6). Panel (B) shows the effect of the change in probability of regulation during the Navigable Waters Protection Rule (NWPR), scaled by -1 so that more positive values indicate more deregulation under NWPR ($\Delta\text{Regulation} = p(Rapanos) - p(\text{NWPR})$), 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.

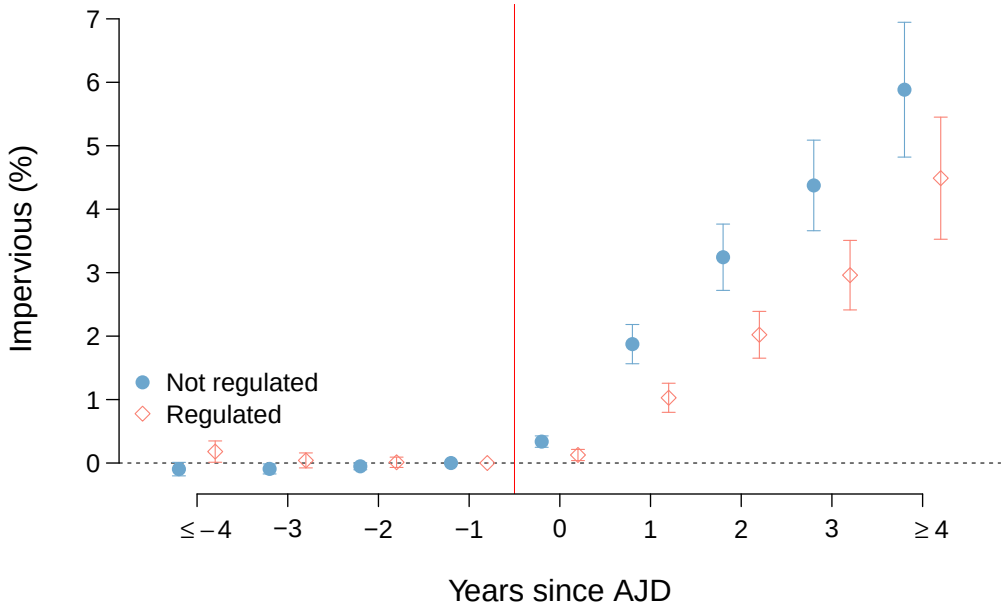
Figure 4: Clean Water Act Approved Jurisdictional Determinations (AJDs), by Rule



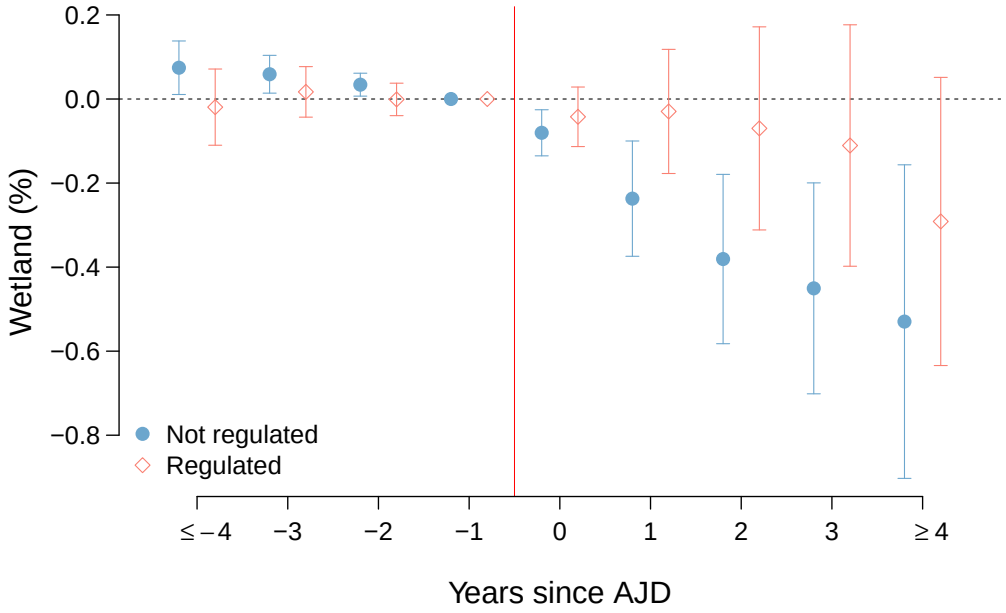
Notes: NWPR is the Navigable Waters Protection Rule. This figure shows the number of Clean Water Act approved jurisdictional determinations (AJDs) each month, separately by rule. The black line shows AJDs under NWPR, and the blue dashed line shows AJDs under Rapanos and the Clean Water Rule (CWR). Vertical 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 5: Development Around Approved Jurisdictional Determinations (AJD), Event Study Graphs

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



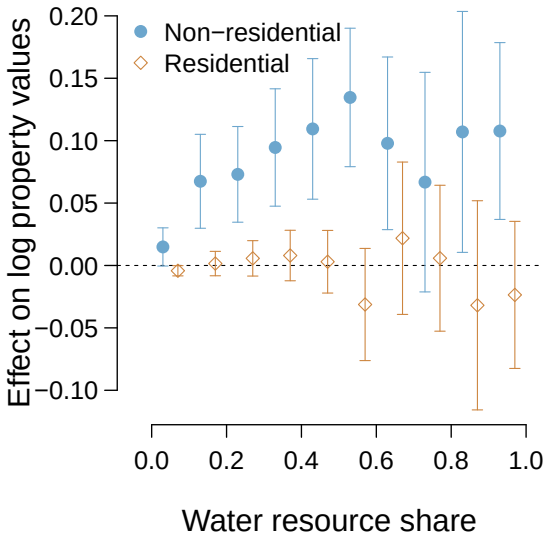
(B) Percent of Area Within 100m Radius that is Wetland



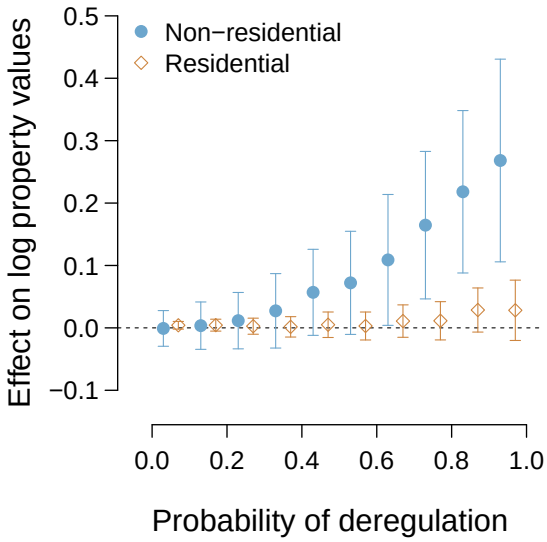
Notes: Points show the share of developed land in Panel (A) and wetlands in Panel (B), as measured by the 2024 National Land Cover Dataset (NLCD) (U.S. Geological Survey 2024), in the years preceding (negative x-axis values) and following (positive x-axis values) an approved jurisdictional determination (AJD). We proxy development using NLCD imperviousness, a continuous measure of the impervious share of land within each 30m pixel (rather than binary categorization), 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 (11). We compute land use values as the share within a 100m radius of each site centroid. Red triangles 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.

Figure 6: Effect of Navigable Waters Protection Rule (NWPR) on Log Property Values, Semi-Parametric Bins

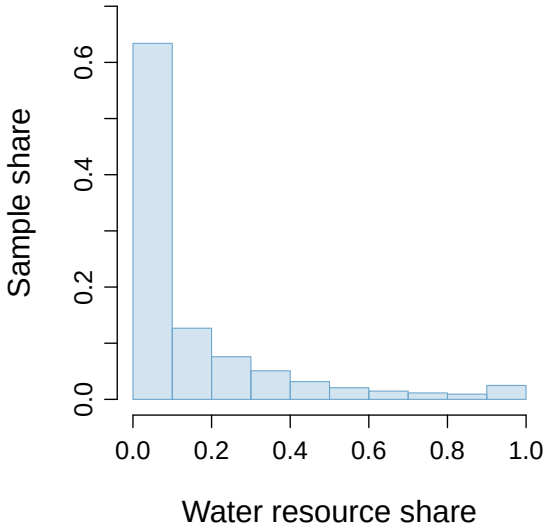
(A) Using Wetland Map



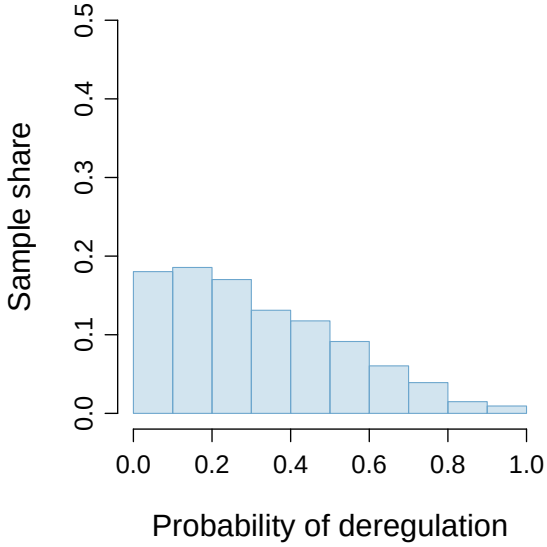
(B) Using Algorithm



(C) Distribution of Non-Residential Wetland Shares



(D) Distribution of Non-Residential Algorithmic Predictions



Notes: Panel (A) shows point estimates for the effect of the Navigable Waters Protection Rule (NWPR) on property values, where wetland share measured via the National Wetland Inventory (NWI) proxies regulation. We separate shares into bins with width of 0.1 from 0 to 1. The reference category is parcels with no National Wetland Inventory (NWI) water resources (share = 0). Vertical lines show 95% confidence intervals. Standard errors are clustered by commuting zone. Panel (B) instead uses the algorithm to estimate the probability of regulation. We scale Panel (B) coefficients by -1 so that, as in Panel (A), more positive values indicate more deregulation. 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.

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)
WFH share (percent)	34.63
	(10.06)
From Algorithm	
Probability regulated under *Rapanos*	0.36
	(0.22)
Probability regulated under NWPR	0.21
	(0.18)
ΔRegulation: *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)
NWPR operating	-0.117***	-0.083***	-0.091***	0.017
	(0.022)	(0.022)	(0.028)	(0.016)
Water resource share	—	0.518***	0.438***	—
		(0.047)	(0.071)	
Water resource share × NWPR operating	—	-0.203***	-0.084	—
		(0.061)	(0.098)	
Probability of regulation under *Rapanos*	—	—	—	1.121***
				(0.098)
Probability of regulation under NWPR	—	—	—	-0.048
				(0.114)
ΔRegulation × NWPR operating	—	—	—	-1.136***
				(0.121)
Constant	0.364***	0.298***	0.300***	-0.036**
	(0.028)	(0.028)	(0.029)	(0.014)
Observations	144,081	144,081	25,292	25,292

Notes: Column (1) shows the change in jurisdiction under 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 operating is an indicator for whether NWPR was in force at the time of the AJD. 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 (4) shows estimates from equation (2), where ΔRegulation represents the change in predicted probabilities of regulation between NWPR and *Rapanos*, scaled by -1 so that more positive values indicate more deregulation under NWPR, i.e. $p(Rapanos) - p(\text{NWPR})$. Column (4) is 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)			
ΔRegulation × 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)			
ΔRegulation × 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)			
ΔRegulation × 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 (4). 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. ΔRegulation equals the change in probability of regulation when NWPR is implemented, scaled by -1 so that more positive values indicate more deregulation (i.e., $\Delta\text{Regulation} = p(Rapanos) - p(\text{NWPR})$). 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 ($M)	0.513	0.490	1,452,943	13,580,729
Property Acres	15.535	27.005	44,039,851	748,559,833
Wetland Acres	0.830	0.838	2,351,941	23,226,662
B. Effect of NWPR on Land Cover				
Effect of NWPR on wetlands ...				
Using wetland map (acres)	-0.003	-0.006	-9,642	-163,903
Using algorithmic (acres)	-0.005	-0.009	-15,226	-258,806
Effect of NWPR on development ...				
Using wetland map (acres)	0.020	0.035	56,520	960,694
Using algorithmic (acres)	0.031	0.055	89,246	1,516,953
C. Effect of NWPR on Wetland Flood Protection				
Flood mitigation value ($) ...				
per ha of wetlands, annual	2,613	—	—	—
per acre of wetlands, present value	35,261	—	—	—
Effect on flood danger ($M, present value) ...				
Using wetland map, low wetland loss	—	—	-340	-5,779
Using algorithmic, low wetland loss	—	—	-536	-9,125
Using wetland map, high wetland loss	—	—	-1,992	-33,875
Using algorithmic, high wetland loss	—	—	-3,146	-53,490
D. Effect of NWPR on Land Values				
Using wetland map (logs)	0.008	—	—	—
Using algorithmic (logs)	0.008	—	—	—
Using wetland map ($M)	0.004	0.004	12,161	113,670
Using algorithmic ($M)	0.004	0.004	11,841	110,682
E. Ratio of NWPR Land Value Benefits to Flood Protection Costs				
Using wetland map, low wetland loss	—	—	35.8	19.7
Using algorithmic, low wetland loss	—	—	22.1	12.1
Using wetland map, high wetland loss	—	—	6.1	3.4
Using algorithmic, high wetland loss	—	—	3.8	2.1
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 (2.22) 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 shows the effects of the Navigable Waters Protection Rule (NWPR) on wetland area and development 4 or more years after an AJD (see Figure 5). Estimates in Panel C multiply estimates in Panel B by the present value 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. The 'low' wetland loss scenario uses estimates of wetland loss Panel B, and the 'high' scenario uses the estimates of development Panel B multiplied by -1, assuming all development occurs on wetlands. Panel D scales the effect of NWPR on land values (see Table A5) by the average transaction price in our analysis sample. Panel E divides estimates in Panel C by the corresponding estimates in Panel D and multiplies by -1.

A Background: Additional Details

A.1 Wetlands

Wetlands include areas with surface water at least some of the time. Wetlands are also called swamps, bogs, playa lakes, prairie potholes, Carolina and Delmarva Bays, pocosins, and vernal pools (Sullivan et al. 2020). The widely-used Cowardin et al. (1979) classification includes streams, lakes, ponds, estuaries, and other water bodies as types of wetlands. Identifying the existence and boundaries of wetlands is complex. Some hydrologists define wetlands as areas where hydrophytic (water loving) plants grow. Scientists and engineers sometimes delineate a wetland's boundary according to the area where a majority of plants are hydrophytic.

Dahl 1990 estimates that in the 1700s, wetlands covered about 11 percent (221 million acres) of the continental US. Since then, development has removed over 50 percent of these original wetlands (Dahl 1990). In response to concerns about continued wetland loss, in 1989 George H. W. Bush set a goal of "No Net Loss" for wetlands. This goal, which subsequent administrations have upheld, meant that development had to offset any wetland loss with a comparable increase in wetland area through restoration. Section 404 of the CWA helps pursue this goal.

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. The FWS's National Wetlands Inventory (NWI) program, the main wetland dataset we use, provides data for this analysis. 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.

A.2 Clean Water Act

As the introduction mentions, Section 404 and wetland permits are largely separate from two other main the Clean Water Act activities: the State Revolving Fund, which provides subsidized 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 Clean Water Act. 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 Clean Water Act 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 Clean Water Act.

A.3 Other Clean Water Act Rules

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. Its implementation was delayed and then stopped in the other 27 states due to litigation. Due to its brevity and similarity to *Rapanos*, we do not discuss or distinguish it.

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.

The main text discusses Approved Jurisdictional Determinations. A parallel process involves a "Preliminary Jurisdictional Determination" (PJD), for approved types of projects (e.g., transmission lines, pipelines, and levee maintenance) whose impacts are generally well understood and small (less than 0.1 acre). In such cases, a developer assumes the water feature is regulated and obtains a 'nationwide permit' that is faster and less costly than a standard permit.

B Data: Additional Details

B.1 CoreLogic

We use property transaction data from CoreLogic (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 its judicial stay. Residential properties have land use codes ($LUSE$) less than 200 and non-residential have codes 200 or greater. In terms of the number of transactions in our sample, non-residential categories in descending order are vacant (400s), commercial (200s), agricultural (500s), industrial (300s), public (600s), recreational (700s), noncoded (998, 999 or missing), residential rural (109, 160), and transport energy (800s).[17] See Table A6 for details.

We note one nuance in how we categorize residential vs non-residential: "residential rural" involves land use codes 109 (cabin) and 160 (rural homesite), which we classify as non-residential despite the codes being below 200. About 14,000 of our sample of 2.8 million, or 0.5% are properties typically represent larger rural parcels with minimal housing structures, making them more similar to non-residential land in their exposure to Clean Water Act 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, ensuring properties are categorized according to their status when transacted.

To locate properties, we use CoreLogic's proprietary parcel-centroid coordinates. For the small set of properties with missing coordinates, we instead use USPS address-derived coordinates provided in the CoreLogic data.

We exclude the following groups of observations as representing erroneous or incorrect records:

1. Observations with a missing CoreLogic parcel identifier (`clip`), which we use to link property details to transaction records.

[17] 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.

Figure A8 uses the same steps to clean an extract of non-residential transactions from 2010 to 2023.

Our benefit-cost comparison uses the CoreLogic assessor data product `property_basic2`, which has information on most non government-owned properties, including properties that did not transact during our sample timeframe. 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, and the assessed value per acre is $\leq$ \$100. This provides 27.7 million nonresidential properties, of which 44% have at least one recorded transaction at any point in time. The property in the assessor sample is 27 acres, and the total acreage is 749 million acres.[18] The mean assessed property value is \$221,000.

We then 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 assessed property (27 acres) results in an estimated 1.15 acres of wetlands per property, and 31.9 million acres of wetlands in total.

The composition of non-residential property transactions differs from the full stock of non-residential properties (Table A6). Commercial properties are overrepresented in transactions (25% versus 19% of the assessor stock), consistent with higher liquidity in commercial real estate markets. Conversely, agricultural and residential rural properties are underrepre-

[18] 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.

sented in transactions relative to their share of the property stock, reflecting longer holding periods typical of farmland and rural parcels. Public properties (e.g., schools, churches, NGOs) account for 6% of the assessor stock but only 2% of transactions, as these properties rarely change hands. Vacant land dominates both samples but is particularly prevalent among transactions (47%), consistent with vacant parcels being acquired for development.

B.2 Approved Jurisdictional Determinations (AJDs)

We use records of approved jurisdictional determinations (AJDs) from the U.S. Army Corps of Engineers (USACE)(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 authority to manage AJDs, so we lack data on most of their AJDs. We are unaware of reasons why AJD coverage would systematically improve under NWPR. AJD levels return to approximately baseline after NWPR ends.

Wetland development can occur without an AJD. Some developers provide a Preliminary Jurisdictional Determination (PJD), which assumes water resources are jurisdictional. Others 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 Clean Water Act or will not get caught.

Figure A9 maps the AJDs. These AJDs cover most areas 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, where development occurs less. AJDs are more common in the wetter areas of the eastern US, 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 A9 also reveals spatial patterns of regulation. Green points are jurisdictional. 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 more 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.

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 the site 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),[19] 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%).

[19] 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.

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 A3. The top row corresponds to the probability of regulation under the rule in force at the time of the determination. The mean probability of regulation is 0.32. The second row plots the site-level probabilities if all AJDs were decided under *Rapanos*, $p(Rapanos)$. The third row shows the site-level probabilities if all decisions were made under NWPR, $p(NWPR)$. As expected, the probabilities of regulation tend to be higher under *Rapanos* (mean = 0.36) 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 $\Delta\text{Regulation} = p(NWPR) - p(Rapanos)$. Most sites (>80%) are predicted to have lower probabilities of regulation under NWPR, with a mean change in probabilities 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:

$$Y_{id} = \alpha p(Rapanos) + \sum_{\tau} \Big(\beta_{\tau} \Delta\text{Regulation} \times \mathbb{1}[q_q = \tau] + \gamma_{\tau} \mathbb{1}[q_q = \tau] \Big) + \delta_d + \epsilon_{id} \tag{14}$$

where Y_{id} is the true regulatory status (AJD outcome) for site i in district d. $p(Rapanos)$ is the probability of regulation under *Rapanos* and ΔRegulation is the change in probability of regulation when NWPR took force, i.e. $\Delta\text{Regulation} = p(\text{NWPR}) - p(Rapanos)$. 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 (14) 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 $p(Rapanos)$ 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. 27.0 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 A11). 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 A12) 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 $13.6 trillion, or 2.22 times the assessed value ($6.12 trillion) of this sample—implying that assessments capture less than 40 percent of market value on average. Yet this headline price-to-assessed ratio overlooks the extreme heterogeneity across space (Figure A12) and land use category (Table A7). 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 $3.45 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 equation (11) to estimate NWPR's land use impacts:

$$L_{ict} = \sum_{\tau} \Big(\beta_\tau \, Y_i \, \mathbb{1}[t = \tau] + \gamma_\tau \, \Delta\text{Regulation}_i \, \mathbb{1}[t = \tau] \Big) + \lambda_{ct} \; + \; \eta_i \; + \; \varepsilon_{ict} \tag{15}$$

L_{it} represents the share of a given land use (developed or wetland) within a 100m radius of site i in year t. Y indicates whether AJD i is jurisdictional. ΔRegulation $\equiv p(\text{NWPR})_i - p(\textit{Rapanos})_i$ equals the change in the probability of regulation between NWPR and *Rapanos*. The event year indicators $\tau \in \{-4, -3, -2, 0, 1, 2, 3, 4\}$ omit $\tau = -1$ as the reference period. The initial and final categories $\tau = -4$ and $\tau = 4$ include all event times before or after the focal period [-4,4]. Point estimates and 95% confidence intervals are shown in Figure A13.

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 Clean Water Act's impacts on land markets.

Figure A1: Examples of Semi-Dry Wetlands

(A) Isolated Wetland



(B) Google Data Center



(C) Moapa Solar Project Satellite Image



(D) Moapa Solar Project Development



Notes: Panel (A) shows an non-stereotypically dry isolated wetland. Panel (B) shows a Google data center built on an isolated wetland. Panel (C) shows a satellite image of the land surrounding the Moapa Solar Project, built on the Moapa River Indian Reservation. Panel (D) is a snapshot of Moapa Solar Project development.

Figure A2: Clean Water Act Development Anecdotes

(A) Georgia

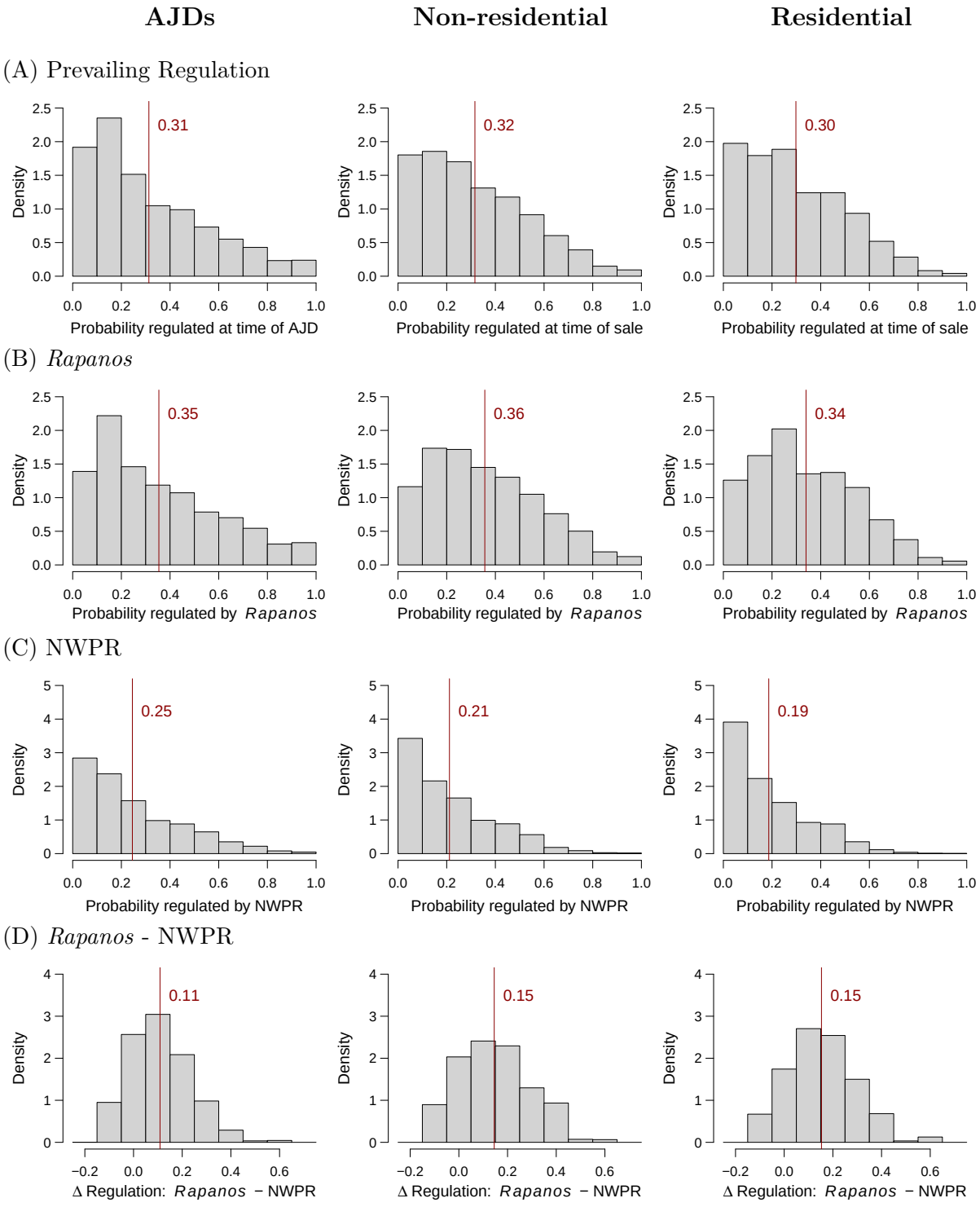


(B) Florida



Notes: Panels (A) and (B) show examples of news headlines attesting to the effects of NWPR on development.

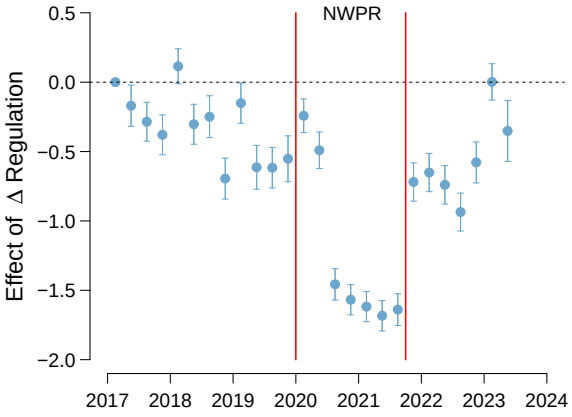
Figure A3: Predicted Probabilities of Regulation, by Sample



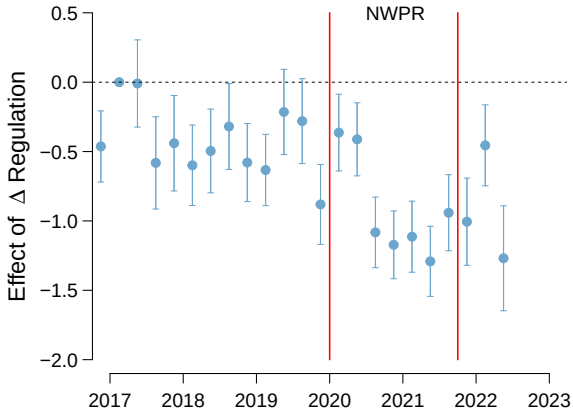
Notes: NWPR is the Navigable Waters Protection Rule. Predicted probabilities of regulation from the machine learning algorithm. Panel (A) shows the probabilities under the rule in force at the time of the approved jurisdictional determination (AJD) or property sale. Panel (B) shows the probabilities under *Rapanos*, $p(Rapanos)$. Panel (C) shows the probabilities under NWPR, $p(\text{NWPR})$. Panel (D) shows the change in probability of regulation under NWPR, scaled by -1 so that more positive values indicate more deregulation (i.e., $\Delta\text{Regulation} = p(Rapanos) - p(\text{NWPR})$). 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 A4: Testing Algorithms for Predicting Changes in the Probability of Regulation

(A) Tabular Model

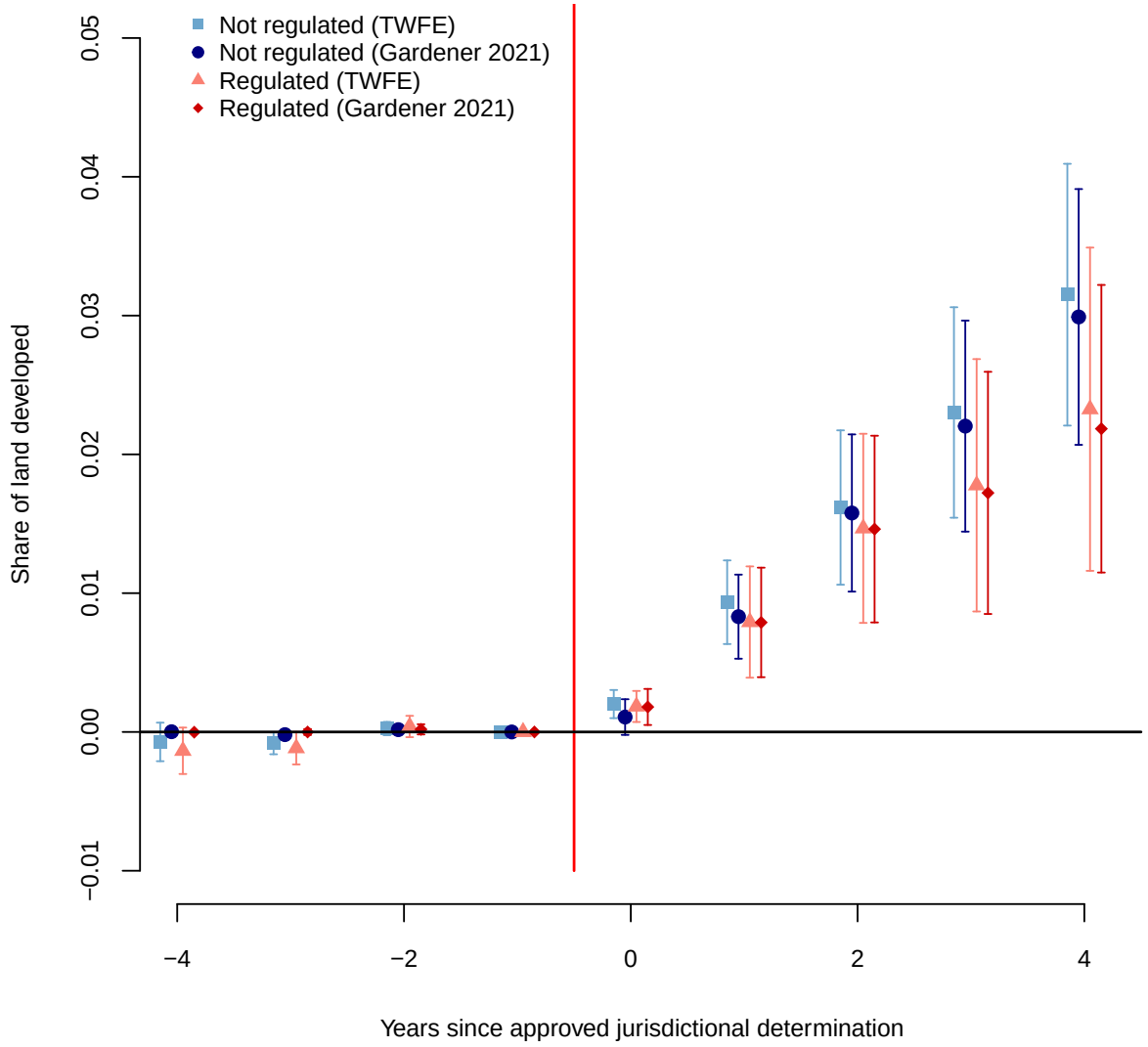


(B) Image-Based Model



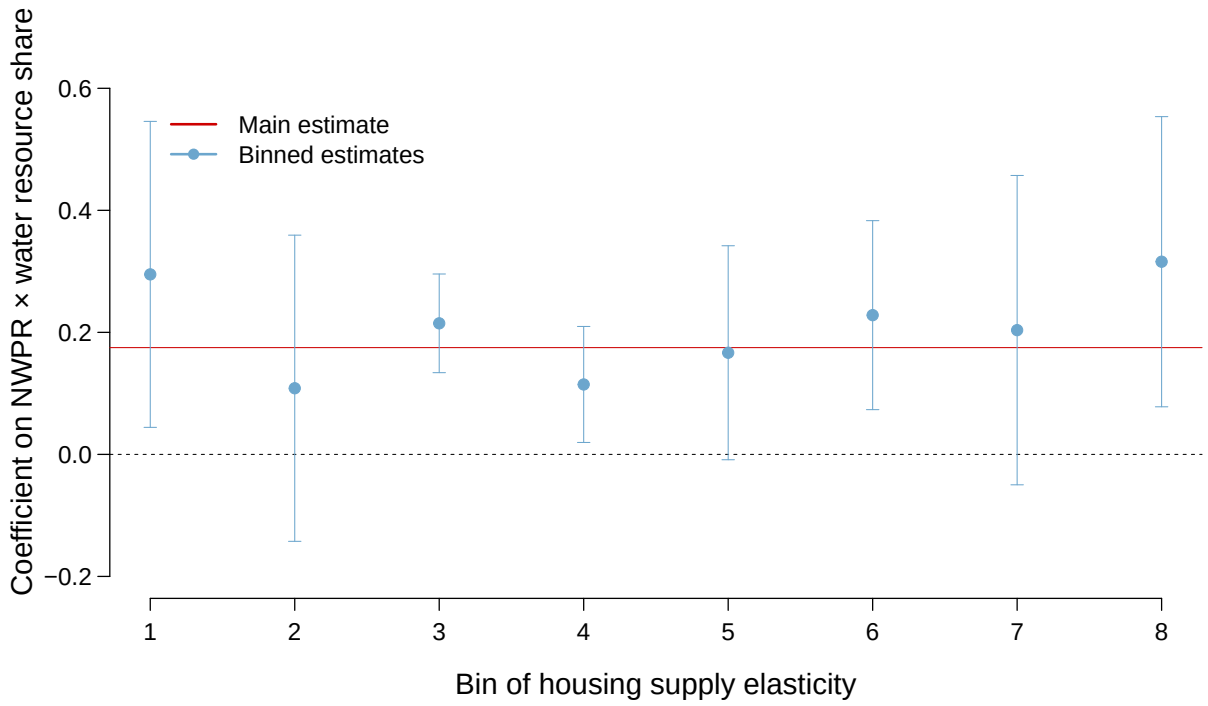
Notes: NWPR is the Navigable Waters Protection Rule. Event studies of the effect of ΔRegulation on jurisdiction from equation (14), scaled by -1 so that more positive values indicate more deregulation (i.e., ΔRegulation = $p(Rapanos) - p(\text{NWPR})$). The event studies are estimated among approved 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 US-ACE 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: Comparison of Event Study and Gardner (2021) Estimates for the Effects of Approved Jurisdictional Determinations on Development



Notes: Points show the share of developed land, as measured by Land Change Monitoring, Assessment, and Projection (LCMAP), in the years preceding (negative x-axis values) and following (positive x-axis values) an approved jurisdictional determination (AJD). Bars show 95% confidence intervals. AJDs determined to be jurisdictional are shown in red and AJDs determined to be non-jurisdictional are shown in blue. Two-way fixed effects (TWFE) estimates correspond to the standard event study estimates, Gardner (2021) corresponds to the imputation estimator proposed in Gardner et al. 2024 and R package Butts and Gardner 2021. All specifications include year and transaction id fixed effects as opposed to commuting zone × year and transaction id fixed effects in Figure 5 due to lack of untreated outcomes in commuting zone × year strata needed to impute potential outcomes. Standard errors are clustered by commuting zone.

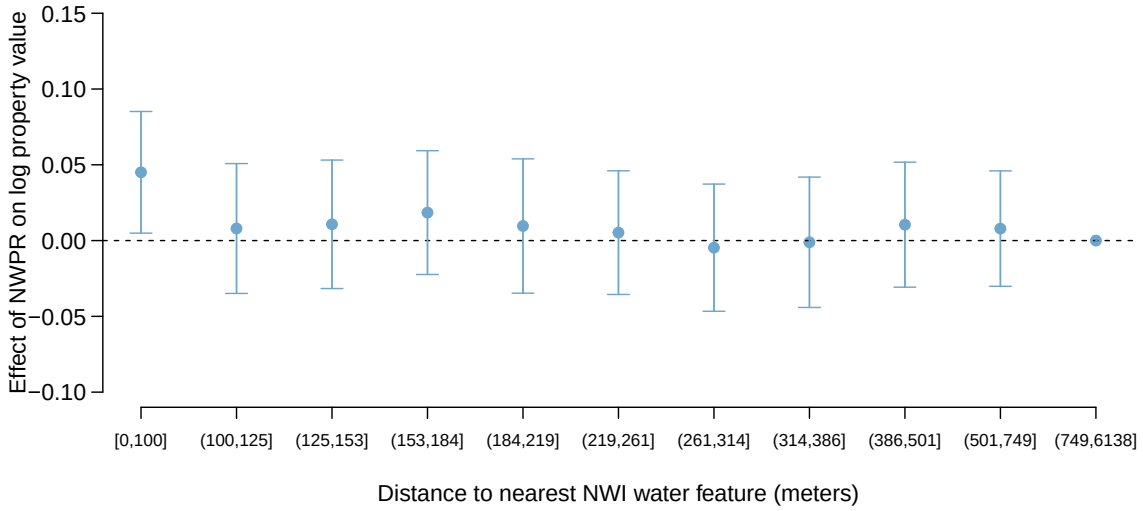
Figure A6: Effect of Navigable Waters Protection Rule (NWPR) on Property Values, by Metro-Level Housing Supply Elasticity



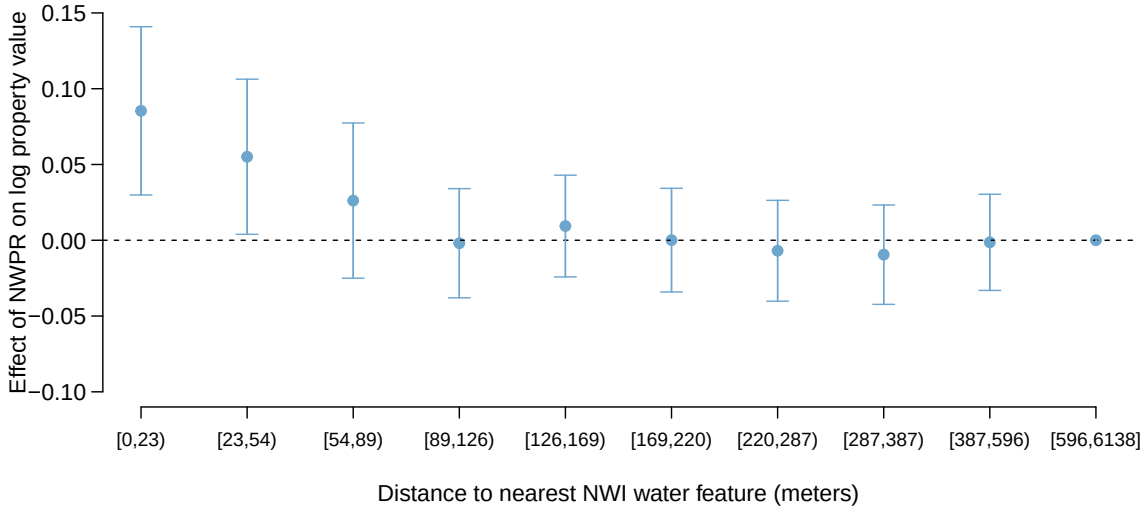
Notes: Lines show heterogeneous price responses by housing supply elasticity bin. Shaded areas show 95% confidence intervals. Estimates are obtained by interacting the term water resource share × NWPR in equation (3) with 8 equally-sized bins of MSA-level housing supply elasticity obtained from Saiz (2010).

Figure A7: Effects of Navigable Waters Protection Rule (NWPR) on Property Values, by Distance to Nearest Wetland

(A) Imposing a break at 100 meters



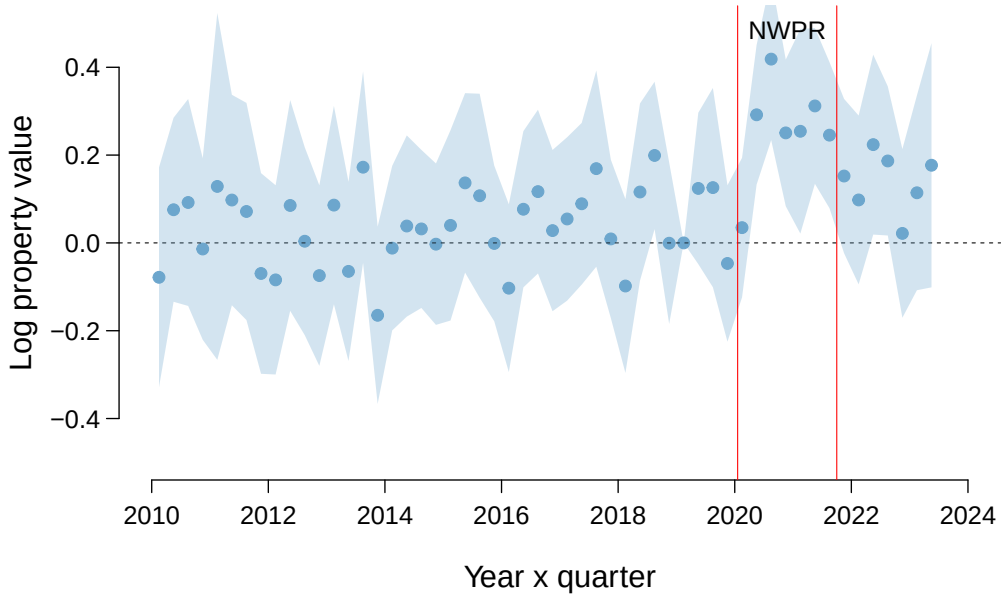
(B) Bins for deciles of distance



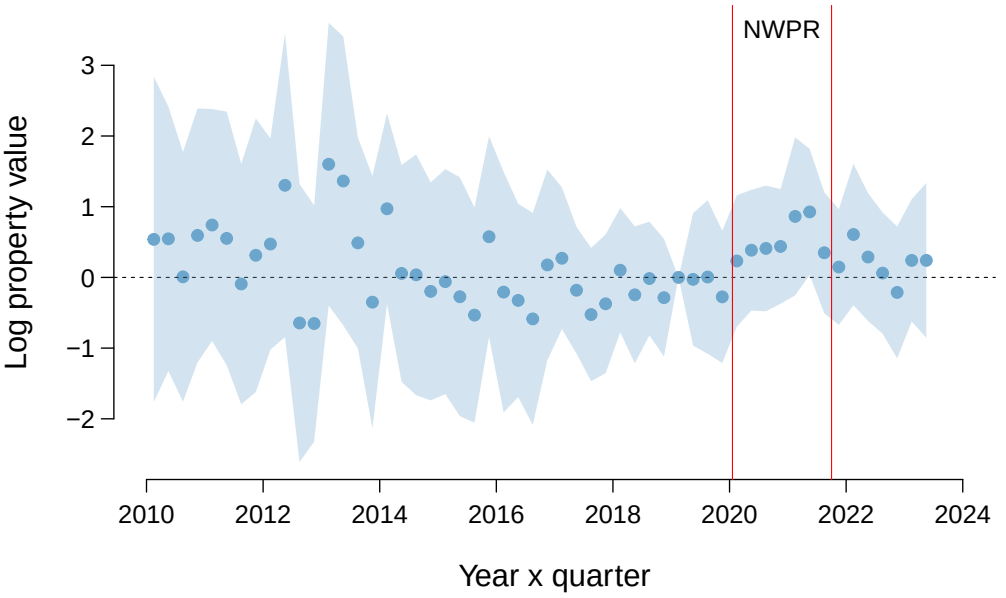
Notes: Both panels show the effect of NWPR on log property value by the distance of the parcel to nearest water feature, as measured by the National Wetlands Inventory (NWI). Panel (A) separates wetland parcels (those with and NWI feature within 100 meters) and non-wetland parcels (those greater than 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 A8: Effect of Navigable Waters Protection Rule on Property Values, Extended Panel

(A) Wetland Map Model

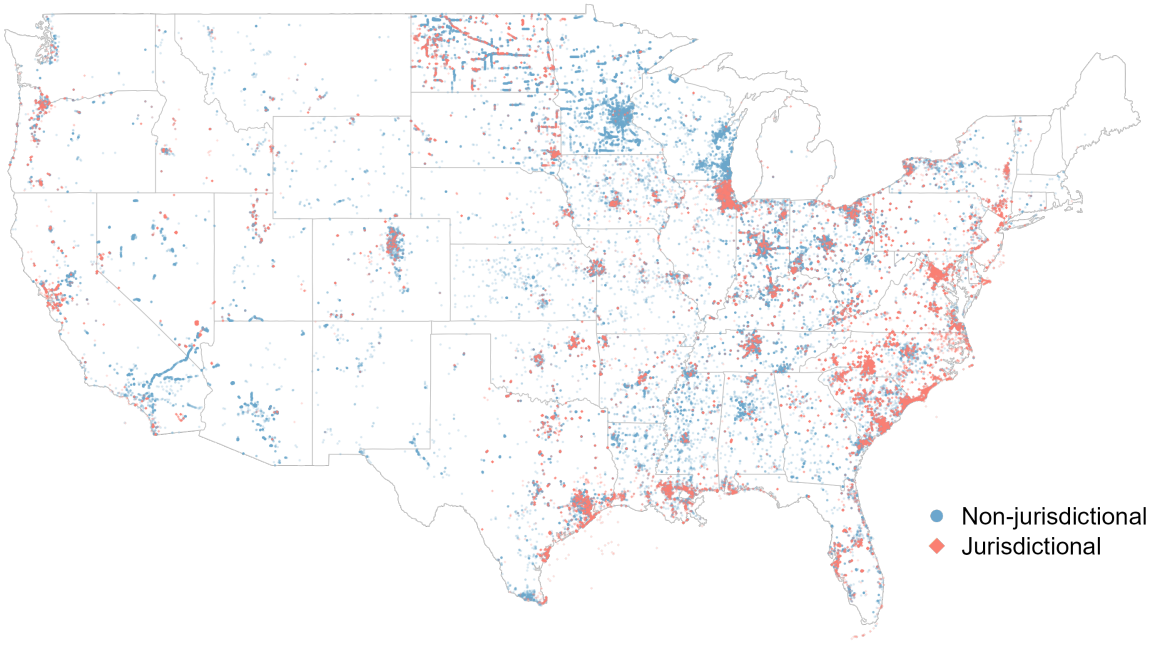


(B) Algorithmic Model



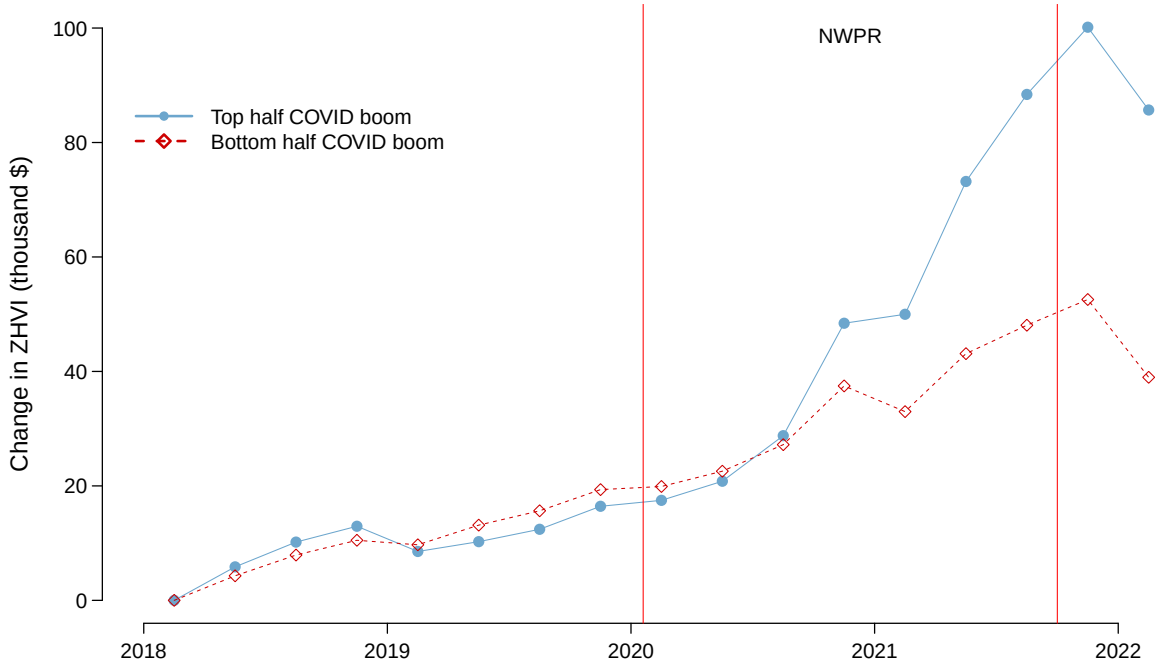
Notes: NWPR is the Navigable Waters Protection Rule. This figure shows estimates from equation (6) and analogous equation using the algorithm, but using CoreLogic non-residential property transaction records extending back to 2010. Panel (A) shows point estimates for coefficients on Water resource share × NWPR by year × quarter. Panel B shows point estimates for coefficients on ΔRegulation × NWPR by year × quarter, where ΔRegulation is the difference, $p(Rapanos) - p(\text{NWPR})$, in predicted probabilities of regulation. 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: 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.

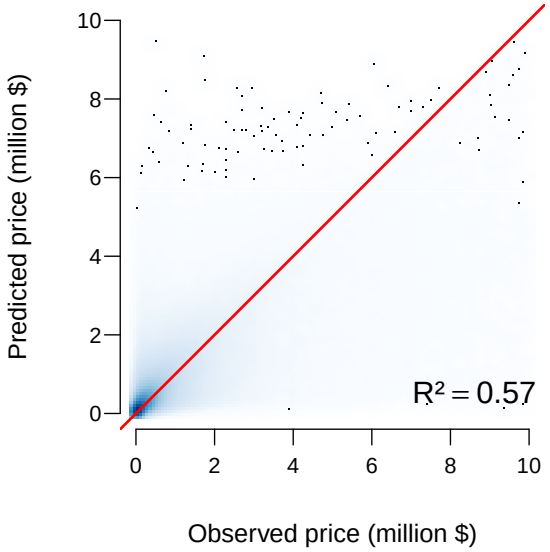
Figure A10: Comparison of Property Value Trends by Size of Local COVID Housing Boom



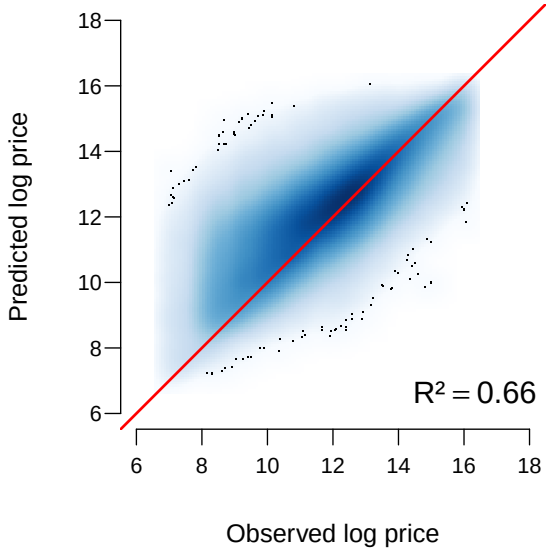
Notes: This figure plots the change in thousands of dollars per property relative to 2018Q1 as measured by the Zillow Home Value Index (ZHVI) (Zillow.com 2025) over the four-year period centered at March 2020, the beginning of the Navigable Waters Protection Rule (NWPR). We convert ZHVI values to 2024 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: Model Performance for Predicting Fair Market Value

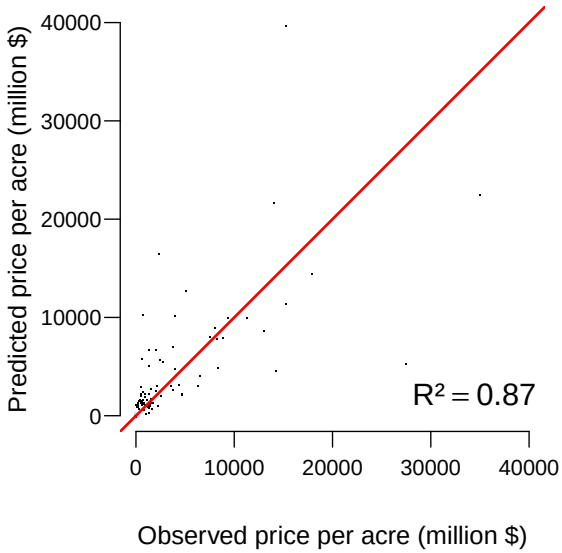
(A) Property-level price



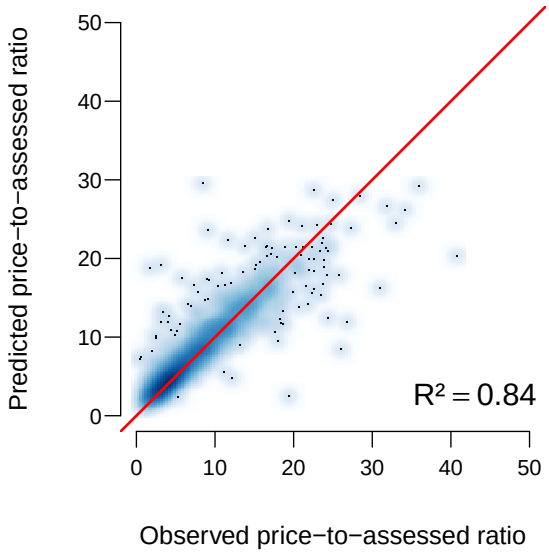
(B) Property-level log price



(C) Property-level price per acre



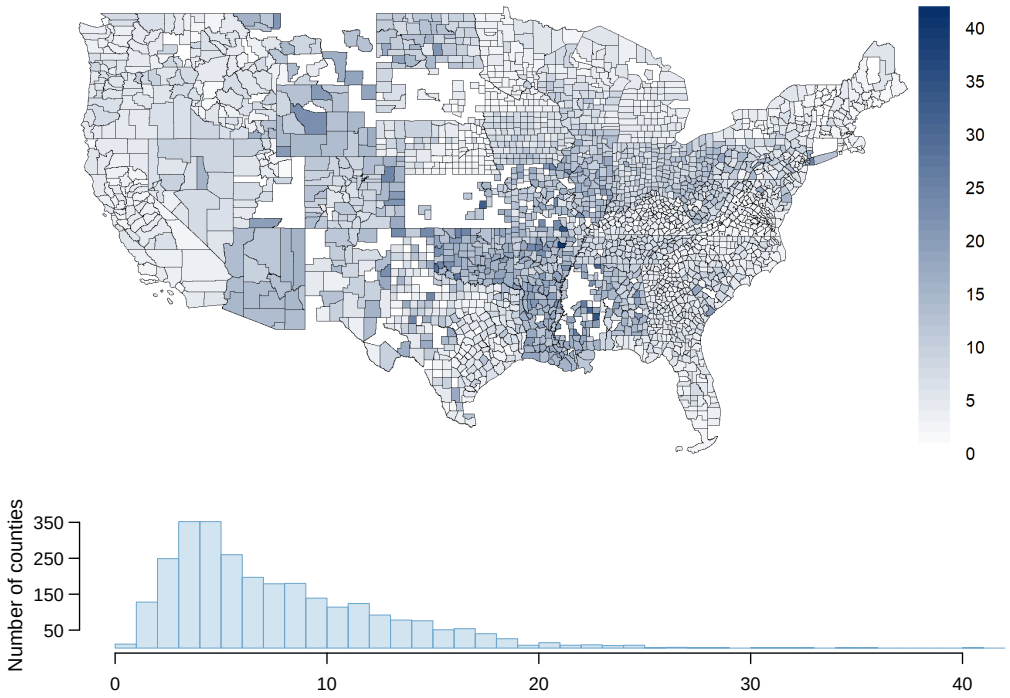
(D) County-level price-to-assessed value ratio



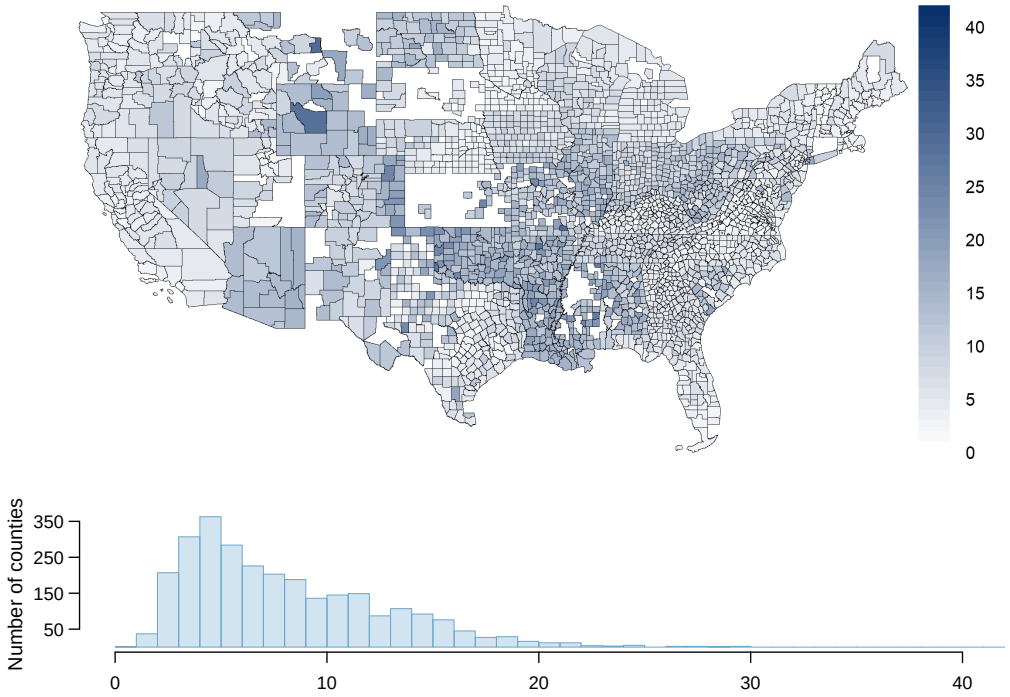
Notes: Plots show observed values (x-axis) against predicted values (y-axis) from the random forest model that predicts property sales price as a function of assessor records (Appendix C.2). All Panels show a model trained to predict property sales prices in levels directly. Panel A shows the correspondence 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 A12: County-level Sales Price to Assessed Value Ratios

(A) Observed price-to-assessed value ratio



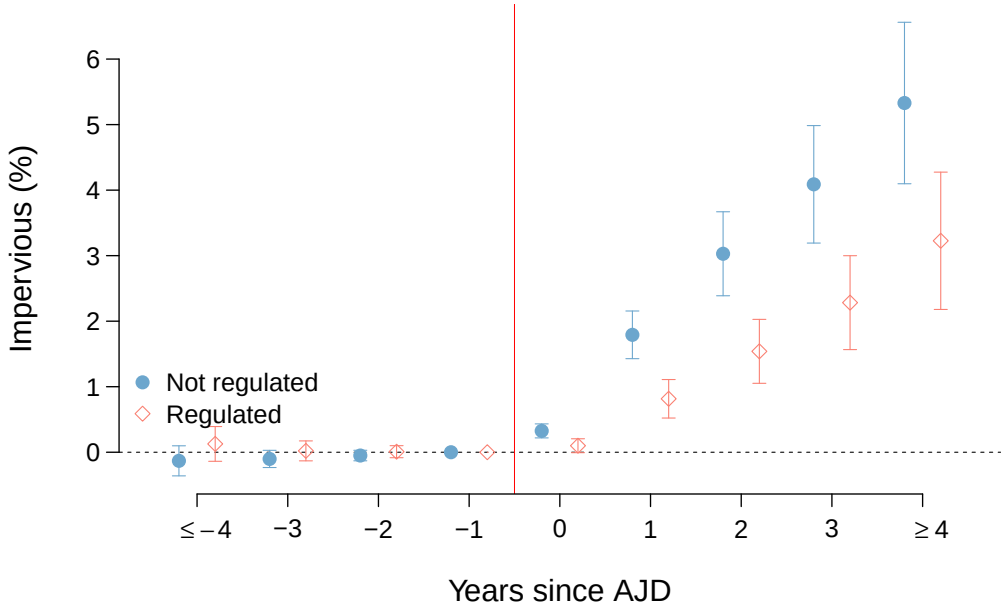
(B) Predicted price-to-assessed value ratio



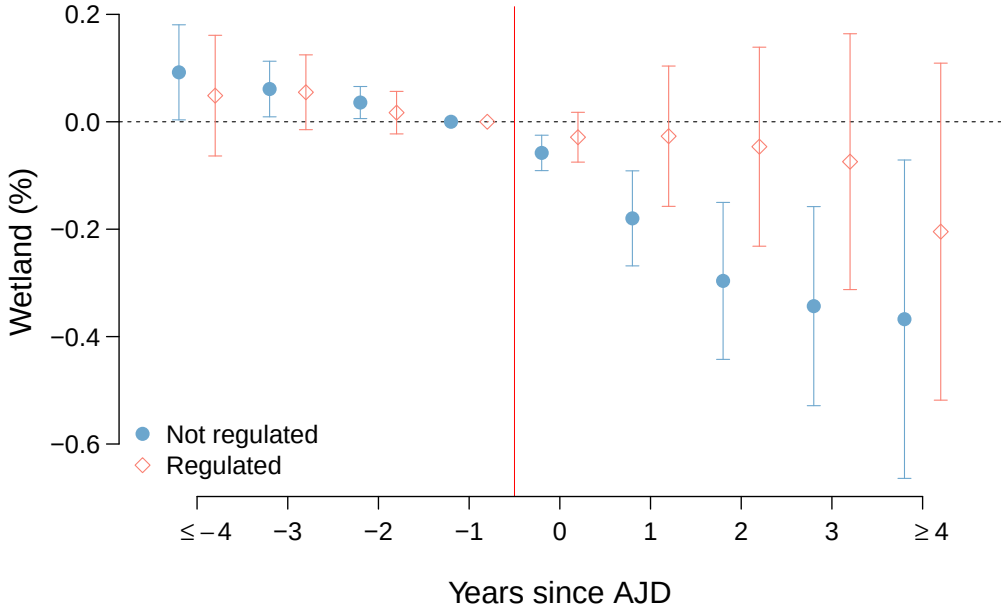
Notes: Maps and histograms show the county-level ratio of sales price to assessed values, as computed in our main sample of 2.8 million non-residential properties that transacted between 2017 and 2023. Panel A shows the observed ratios. Panel B shows the ratios predicted using a random forest (Appendix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

Figure A13: Development Around Approved Jurisdictional Determinations (AJD), Event Study Graphs Using the Algorithm

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



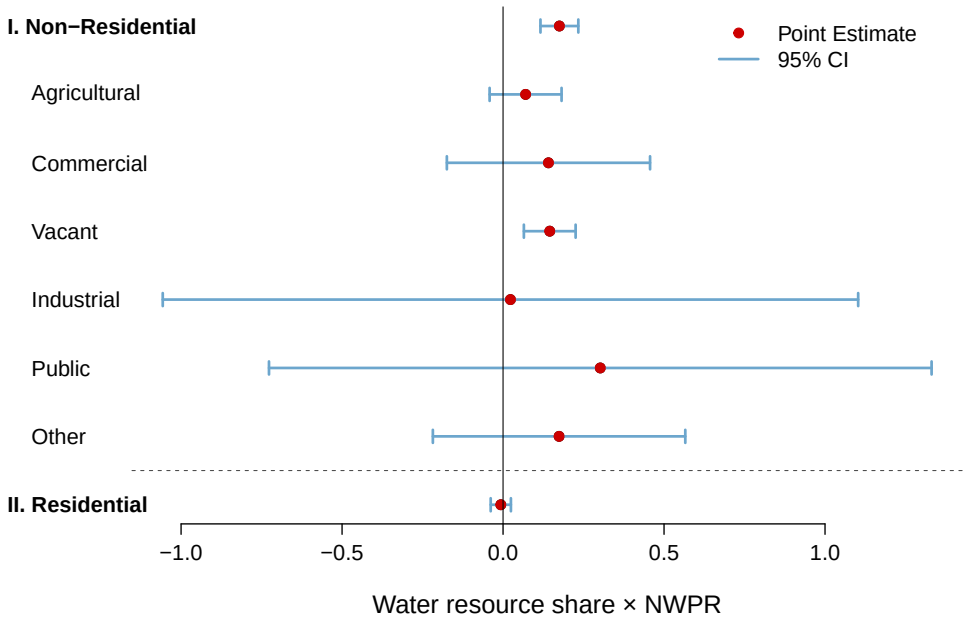
(B) Percent of Area Within 100m Radius that is Wetland



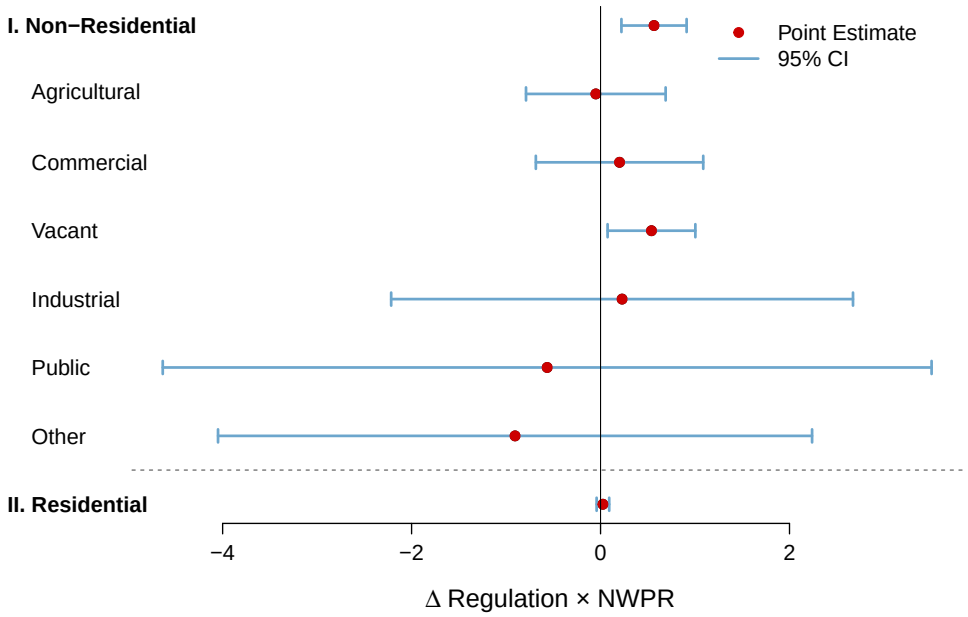
Notes: This figure is analogous to figure 5 but uses parcels' estimated probabilities of regulation from the algorithm rather than water resource shares. Points show the share of developed land (top) and wetlands (bottom), as measured by the 2024 National Land Cover Dataset (NLCD) (U.S. Geological Survey 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 (rather than binary categorization). Event study regressions include commuting zone × year and site fixed effects, and probability of deregulation × event time, following equation (11). We compute land use values as the share within a 100m radius of each site centroid. Red triangles 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.

Figure A14: Effect of Clean Water Act Rules on Log Property Values, by Land Use

(A) Wetland Map Model

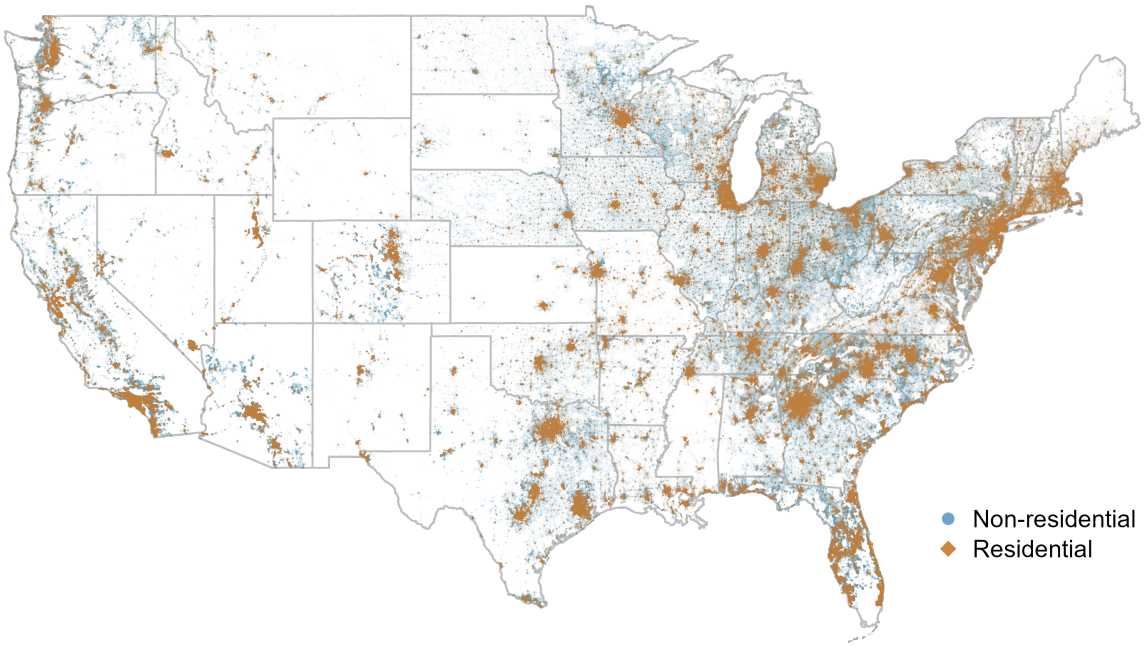


(B) Algorithmic Model



Notes: NWPR is the Navigable Waters Protection Rule. Water resource share equals share in any type of National Wetland Inventory (NWI) polygon. ΔRegulation is the change in probability of regulation under NWPR, scaled by -1 so that more positive values indicate more deregulation (i.e., ΔRegulation = $p(Rapanos) - p(\text{NWPR})$). Estimates in Panel A are from equation (3). Estimates in Panel B are from equation (4). 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 – 533,136; Commercial – 707,105; Vacant – 1,332,395; Industrial – 117,339; Public – 48,416; Other – 25,724.

Figure A15: 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.

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 Approved Jurisdictional Determinations (AJDs) on Land Use

	Developed (impervious)			Wetland		
	(1)	(2)	(3)	(4)	(5)	(6)
Post	2.63***	2.54***	1.09***	-0.295***	-0.275***	-0.184***
	(0.208)	(0.207)	(0.105)	(0.084)	(0.081)	(0.037)
Post × Regulated	-1.23***	-0.875***	-0.754***	0.317***	0.235**	0.282***
	(0.195)	(0.171)	(0.145)	(0.117)	(0.096)	(0.080)
Regulated × τ	—	-0.051***	-0.052***	—	0.012**	0.014**
		(0.009)	(0.010)		(0.005)	(0.005)
Post × τ	—	—	0.985***	—	—	-0.065*
			(0.114)			(0.039)
Post × Regulated × τ	—	—	-0.094	—	—	-0.019
			(0.092)			(0.039)
Fitted effect: $\tau = 5$						
Non-Regulated	2.63	2.54	6.01	-0.295	-0.275	-0.510
Regulated	1.39	1.66	4.79	0.022	-0.040	-0.326
Difference	1.23	0.875	1.22	-0.317	-0.235	-0.184
P-value difference	[0.000]	[0.000]	[0.003]	[0.007]	[0.014]	[0.326]
Pre- dep. var. mean	10.58	10.58	10.58	9.04	9.04	9.04
NWI×τ interactions	Yes	Yes	Yes	Yes	Yes	Yes
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
CZ-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Number of AJDs	143,119	143,119	143,119	143,119	143,119	143,119
Observations	2,146,785	2,146,785	2,146,785	2,146,785	2,146,785	2,146,785

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 captured by τ (year minus year of AJD) and includes the years 2016 to 2023. Dependent variable means represent years before an AJD. Regulated is a dummy for whether a property was deemed jurisdictional under the AJD. Cols (2) and (5) allows for a differential linear trend among regulated properties, cols (3) and (6) further allow the 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. Standard errors are clustered by commuting zone. ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

Table A3: 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		
ΔRegulation × NWPR	0.576***	0.607***
	(0.178)	(0.225)
ΔRegulation × 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. 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. 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 change in the probability of regulation estimates from equation (4). ΔRegulation equals the change in probability of regulation when NWPR is implemented, scaled by -1 so that more positive values indicate more deregulation (i.e., ΔRegulation $= p(Rapanos) - p(\text{NWPR})$), where probabilities are estimated using a machine learning algorithm. 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 A4: Effect of the Navigable Waters Protection Rule (NWPR) on Property Values, by Water Resource Share Bin, Triple Difference

	Dependent Variable: Log property value
Non-residential × NWPR × ...	
Water resource share = 0	-0.2128***
	(0.0469)
Water resource share ∈ (0, 0.1]	-0.1954***
	(0.0469)
Water resource share ∈ (0.1, 0.2]	-0.1538***
	(0.0480)
Water resource share ∈ (0.2, 0.3]	-0.1378***
	(0.0511)
Water resource share ∈ (0.3, 0.4]	-0.1050**
	(0.0522)
Water resource share ∈ (0.4, 0.5]	-0.1164**
	(0.0531)
Water resource share ∈ (0.5, 0.6]	-0.0791
	(0.0481)
Water resource share ∈ (0.6, 0.7]	-0.0755
	(0.0524)
Water resource share ∈ (0.7, 0.8]	-0.1546***
	(0.0588)
Water resource share ∈ (0.8, 0.9]	-0.1141**
	(0.0545)
Water resource share ∈ (0.9, 1]	-0.1151**
	(0.0495)
FE: Zip × year × month	Yes
Log property acres	Yes
Log distance to town, city	Yes
Log population density	Yes
Work from home share	Yes
Observations	7,720,109

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. Estimates are from a triple difference specification where the outcome variable is log property sales price and the treatment is the three-way interaction between NWPR, Water resource share (binned into increments of 0.1, with a separate bin for Water resource share = 0), and Non-residential. The regression includes zip × year fixed effects as well as controls for log property acres, distance to town and city, population density, and work from home share. All controls are interacted with indicators of NWPR and Non-residential. Standard errors are clustered by commuting zone. ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$.

Table A5: Aggregating the Economic Impact of the Navigable Waters Protection Rule (NWPR) on Land Values

	Δ Regulation	Effect of Regulation	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 algorithm-estimated change in probability of regulation. Column (2) shows the estimated effect of a change in regulation on log property sale price (the β_j from equation (8)). 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 ΔRegulation from Column (1) with the effect of regulation 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 A6: Composition of Non-Residential Properties: Transactions vs. Assessor Stock

Land Use Type	Trans. No.	Trans. %	Assessor No.	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 A7: 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	2.35	12.7	3.68
Agricultural	6.89	442.3	0.98	3.45	7.8	3.51
Commercial	5.12	18.2	2.58	4.44	243.5	1.72
Public	1.78	54.7	0.74	1.19	21.8	1.61
Industrial	1.05	7.4	0.81	1.31	175.7	1.61
Noncoded	0.85	19.5	0.08	0.24	12.1	2.98
Residential_rural	0.61	11.6	0.12	0.31	26.9	2.67
Recreational	0.33	7.4	0.11	0.18	24.5	1.68
Transport_energy	0.22	2.7	0.06	0.12	43.7	1.85
Total	**27.72**	**748.6**	**6.12**	**13.58**	**18.1**	**2.22**

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