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

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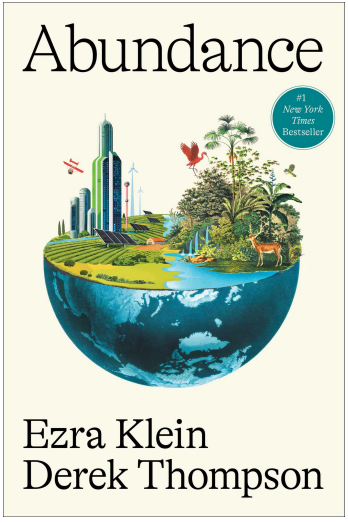
Disclosures: Druckenmiller and Shapiro co-own a patent pending on a machine learning system for predicting Clean Water Act regulation, with free access for non-commercial use. Taylor serves on the board of The Earth Partners LP, a company with an interest in mitigation banking. Property data provided by CoreLogic, now Cotality.

Motivation: Environmental Regulation of Land Use

Country	Policy	Description
Australia	Environment Protection and Biodiversity Conservation Act	Sensitive development requires environmental approval
Brazil	Forest Code	Limits land conversion in sensitive biomes
China	Environmental Protection Law (2014 revision)	Environmental reviews of development
European Union	Water Framework Directive	Constrains development near water bodies
India	Coastal Regulation Zone Notification	Coastal zoning restricts construction
South Africa	National Environmental Management Act	Environmental impact assessments required
U.S.	Clean Water Act	Limits development on wetlands
U.S.	Endangered Species Act	Protects sensitive habitats
U.S.	National Environmental Policy Act	Requires environmental impact assessments

- Protect ecosystem services, but decrease development & distort spatial growth?

Motivation: Environmental Regulation of Land Use



Motivation: Clean Water Act

- **Regulation**
  - "Regulatory ping-pong": $\geq$6 White House, Supreme Court rules in last decade
  - Permitting reform: PERMIT Act (passed House, Dec 2025); Senate bill (2026)
  - Focus here: 2020 Navigable Waters Protection Rule (NWPR)

- **Stakeholders: compliance is costly**
  - "*The Number 1 challenge in the United States when it comes to permitting is not local, it's not state, it is the federal wetlands permit administered by the Army Corps*" — Microsoft President Brad Smith (Halverson 2025)

- **Major cities built on former wetlands**
  - Boston's South End, London's East End, Eastern Mexico City, much of Jakarta, much of New Orleans

Results Preview

- **Regulatory stringency**: NWPR decreases Clean Water Act regulation by about 40%
- **Land markets**: NWPR increases value of non-residential properties about 1%
  - Larger effects for more-deregulated properties; near zero for built-up residential
- **Mechanisms**: NWPR increases permitting, impervious surfaces; decreases wetlands
- **NWPR costs and benefits**
  - Land value benefits: $71 to $106 billion. Flood mitigation costs: $6 to $9 billion
  - Welfare: general equilibrium shifts; uninsured flood damages; other ecosystem services
- **Beyond anecdotes, *Abundance***
  - Environmental land use regulation has large compliance costs, environmental benefits

Tests of Internal Validity / Extensions

- Event study graphs around NWPR's implementation and vacatur
- Wetland map v. machine learning algorithm
- Non-residential v. built-up residential (triple difference)
- COVID: property-level controls (Ramani et al. 2024); size of local housing boom
- Extended panel back to 2010
- Semi-parametric bins for extent of deregulation
- Distance to wetlands (spillovers)
- Sub-categories of land use (e.g., vacant)

What is New Here?

- **Clean Water Act's land use regulation**
  - Compliance costs: phone interviews on 103 permits in 1999 (Sunding & Zilberman 2002); fees, mitigation, litigation (EPA & Army Corps 2021; Liu 2025)
  - Hydrological and legal analysis (Boyle et al. 2017; Sullivan et al. 2020; Keiser et al. 2021; Brinkerhoff et al. 2024; Gold 2024; Greenhill et al. 2024, 2025)
- **Costs of other U.S. environmental regulations** (Becker & Henderson 2000; Greenstone 2002; Walker 2013; Jacobsen et al. 2023; Shapiro & Walker 2025; Auffhammer et al. 2020; Frank et al. 2025; Tabarrok 2026; Keiser & Shapiro 2019; Flynn & Marcus 2025; Jerch 2026)
- **Economics of wetlands** (Stavins & Jaffe 1990; Taylor & Druckenmiller 2022; Aronoff & Rafey 2026)
- **Land use regulation** (Sims & Schuetz 2009; van der Kroft et al. 2025; Soltas & Gruber 2026; Balboni & Shapiro 2025)

Overall First national ex post economic, environmental impact of Clean Water Act's land use regulation

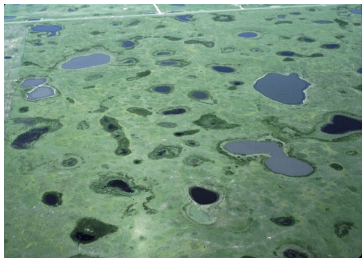
Overview

- **Background**
- Data
- Regulatory stringency
- Property values
- Mechanisms
- Measured costs and benefits
- Conclusions

Background on Wetlands: Stereotypically Wet









Notes: Elkhorn Slough wetland, Monterey, California; swamp, southern Louisiana; prairie pothole wetlands, northern Great Plains; mangroves, Florida Everglades

Background on Wetlands: Not Always Wet









Notes: Isolated wetland; data center on an isolated wetland; Moapa solar project site, Nevada (ephemeral washes non-jurisdictional); Moapa solar development.
Sources: Wetlands Professional (2024); Sussina (2024); Google Maps (2022); Google Earth (2022).

Background: Clean Water Act

- **1972 Clean Water Act**
  - Wastewater treatment grants, industrial permits (not focus today)
  - Section 404: restricts "dredge and fill material" in jurisdictional waters
  - Includes seemingly dry land (seasonal wetlands, ephemeral streams, drained waters)
  - Exempts routine agriculture, but not new agricultural uses or conversions

- **Regulatory requirements**
  - Hire wetland consultant → Army Corps jurisdictional determination → wetland permit
  - Change project design, leave areas undeveloped, buy or build wetland offsets; delay, uncertainty
  - Industries: solar, wind, transmission, data centers, factories, roads, oil/gas drilling, etc.
  - Example: road in Olympic National Park affects 0.04 acres of wetlands, 1.35 miles of streams; mitigation: $205,000 for 0.08 acres of wetlands, $3,000,000 fish passage (GAO 2024)

- **Enforcement**: fines, remediation

Background: Clean Water Act Rules

- ***Rapanos* (2006)**
  - Kennedy: “significant nexus” (biological, chemical, physical connections)
  - Enforced before 2020 and after NWPR’s 2021 vacatur

- **Navigable Waters Protection Rule (NWPR, 2020)**
  - Implements Scalia’s *Rapanos* plurality opinion
  - Deregulates isolated wetlands, ephemeral streams

- **Other rules**
  - Clean Water Rule (2018–19, 23 states): sought to clarify *Rapanos*
  - 2023 Rule: essentially *Rapanos*
  - *Sackett* (2023): resembles NWPR

Background: Timing of Navigable Waters Protection Rule

- **Beginning**
  - Oct 2019: repeal 2015 Clean Water Rule (signals deregulation, not NWPR details)
  - Jan 2020: EPA signs final rule
  - June 2020: Army Corps implements final rule
  - Regressions: NWPR from Feb 1, 2020 to Aug 31, 2021; event studies: reference quarter 2019q1

- **Ending**
  - Aug 2021: court vacates NWPR; Appeals Court rules on *Sackett*
  - Jan 2022: Supreme Court agrees to hear *Sackett*
  - Oct 2022: *Sackett* oral arguments (first case, first day)
  - May 2023: *Sackett* decided; sample ends

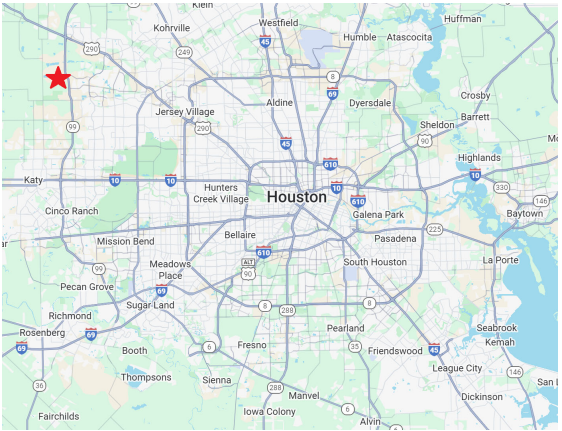
Background: Case Study of Bridgeland Master Planned Community

Flood-prone

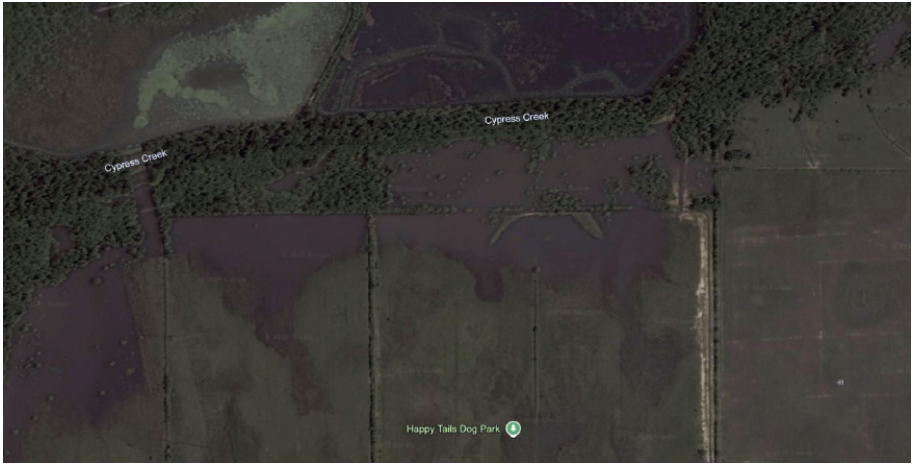
- Cypress Creek → Houston
- Major risk of flooding in 30 yrs: over 80% of properties (First Street)
- Oct 2020: 80 acres of wetlands, 20 miles of ditches and streams found non-jurisdictional under NWPR

Development

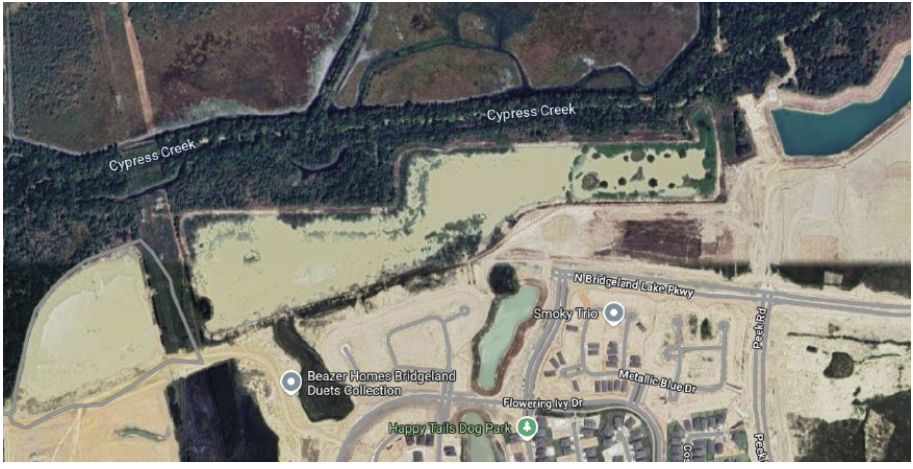
- 11,500 acres; 20,000 homes
- Homes: $300,000 to $2,900,000 (Zillow)
- Chevron R&D campus



Background: Bridgeland Case Study, Flooding (2016)



Background: Bridgeland Case Study, Development (2024)



Background: Bridgeland Case Study, Development (2024)

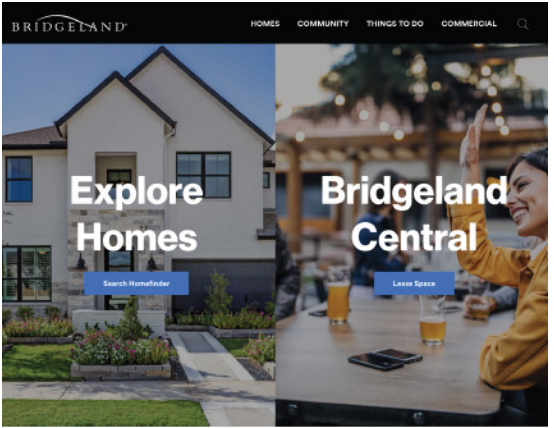


Background: Bridgeland Case Study, Development (2024)

Google Street View



Developer Website



"A land of limitless opportunity"

Overview

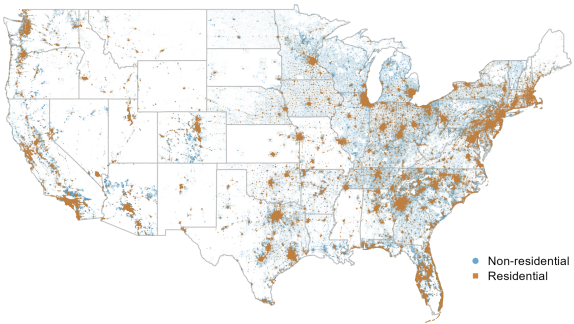
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Data: Outcomes

- **CoreLogic transactions, 2017–2023**
  - Non-residential: 2.9 million
  - Residential: 4.1 million (random 1 in 5 sample; $\geq$1 building per acre)

- **National Land Cover Database**
  - Impervious surface, wetlands
  - 30m pixels, annual
  - Within 100m

CoreLogic



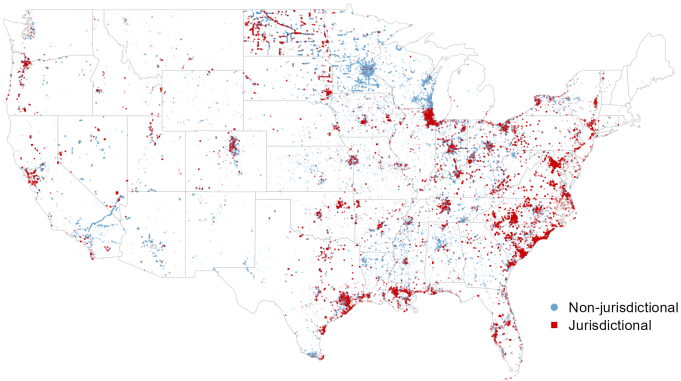
Data: Approved Jurisdictional Determinations

Sample period

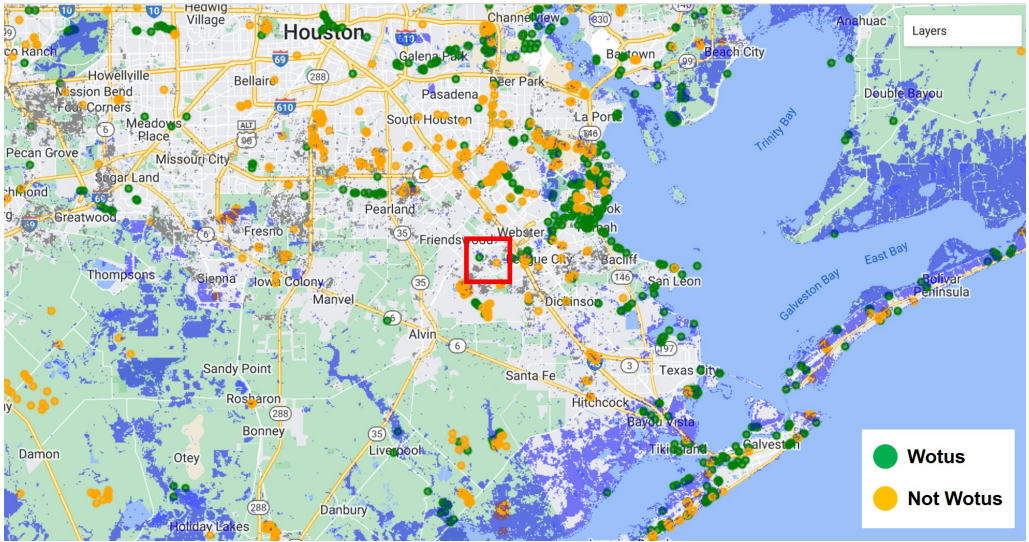
- Jan 2017 - May 2023

Approved Jurisdictional Determinations (AJDs)

- 143,000
- Army Corps
- Legally binding for 5 years
- 32% regulated

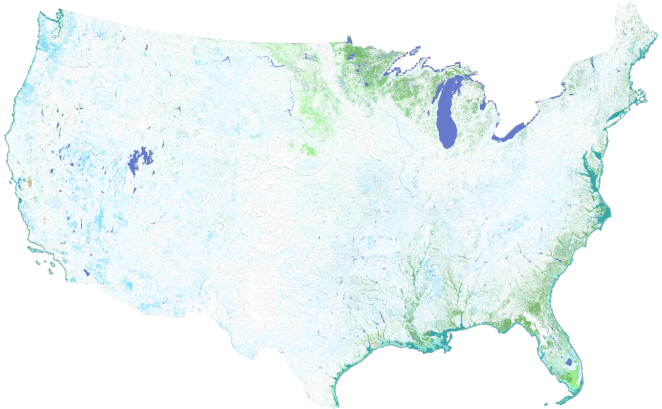


Data: Approved Jurisdictional Determinations - Houston Area



Data: Jurisdiction, Controls

- **National Wetlands Inventory**
  - Most comprehensive national dataset of known wetlands; used in 75% of surveyed AJDs
  - “Wetland share”: all NWI water features within 100m (7.3% of non-residential area)



Data: Jurisdiction, Controls

- **Algorithm: probability of regulation under *Rapanos*, NWPR**
  - Ridge regression with two-way feature interactions
  - Features: NWI, NHD, elevation, gNATSGO, PRISM, NLCD, Army Corps district, satellite imagery embeddings, rule
  - 79% accuracy on spatially held-out test set; well calibrated
  - Versus CNN (Greenhill et al. 2024, 2025): similar accuracy, better detects NWPR's sharp change Model comparison

- **Baseline property value**
  - Random forest prediction of 2016 sale price from assessor records

- **COVID boom controls** (Ramani et al. 2024)
  - Distance to town, metro; population density; work from home share

Mean Characteristics of Non-Residential Properties

Property area	20.73
	(146.47)
Price	526,577
	(1,144,951)
ln(Price)	11.84
	(1.72)
ln(Predicted 2016 sale price)	12.39
	(1.34)
Wetland share (percent)	4.79
	(13.91)
ln(Distance to metro)	3.44
	(1.16)
ln(Distance to town)	1.14
	(1.14)
Population density decile	4.37
	(2.93)
Work from home share (percent)	34.60
	(9.48)
From algorithm	
Probability regulated under *Rapanos*	0.33
	(0.19)
Probability regulated under NWPR	0.19
	(0.18)
Estimated deregulation: *Rapanos* - NWPR	0.14
	(0.14)
Observations	2,903,767

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Regulatory Stringency: Econometrics

- Wetland map:

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

  - Y_{ict}: AJD i in commuting zone c on day t is jurisdictional
  - W_i: Wetland share within 100m
  - N_{it}: AJD adjudicated under NWPR

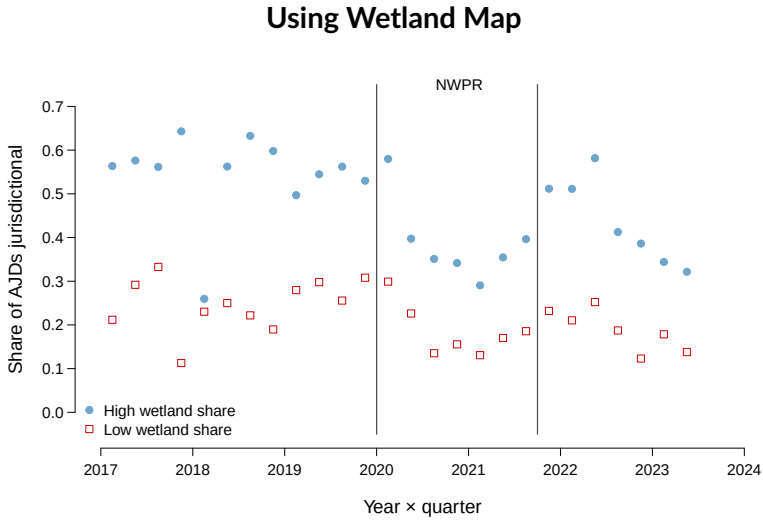
- Algorithm:

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

  - p_{iR}, p_{iN}: Probability of regulation under *Rapanos*, NWPR
  - $(p_{iR} - p_{iN})$: Estimated deregulation. Perfect algorithm: $\alpha_1 = 1$, $\alpha_2 = 0$, $\beta = -1$

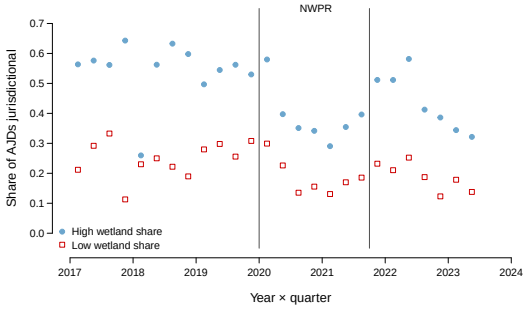
- Inference: cluster by commuting zone
- Sample: all AJDs (wetland map); held-out test set (algorithm)

Share of AJDs That Are Regulated, by Quarter

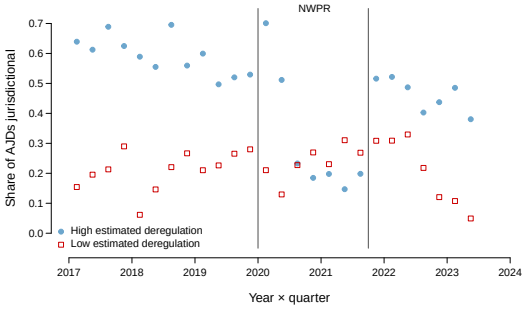


Share of AJDs That Are Regulated, by Quarter

Using Wetland Map



Using Algorithm



Effect of NWPR on Regulatory Stringency

$$Y_{ict} = \gamma N_{it} + \varepsilon_{ict}$$

	Dependent variable: regulated	
	(1)	(2)
NWPR AJD	-0.116***	-0.083***
	(0.022)	(0.022)
Wetland share	—	0.512***
		(0.047)
Wetland share × NWPR AJD	—	-0.197***
		(0.061)
Constant	0.363***	0.298***
	(0.028)	(0.029)
Observations	142,973	142,973

Share of AJDs regulated: 36% under *Rapanos*; NWPR decreases it by 12 percentage points

Effect of NWPR on Regulatory Stringency - Wetland Map

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

	Dependent variable: regulated	
	(1)	(2)
NWPR AJD	-0.116***	-0.083***
	(0.022)	(0.022)
Wetland share	—	0.512***
		(0.047)
Wetland share × NWPR AJD	—	-0.197***
		(0.061)
Constant	0.363***	0.298***
	(0.028)	(0.029)
Observations	142,973	142,973

NWPR decreases probability of regulation by 8 pp with no mapped wetlands, 28 pp if fully wetland

Effect of NWPR on Regulatory Stringency - Algorithm

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

	Dependent variable: regulated	
	(1)	(2)
NWPR AJD	-0.116***	-0.001
	(0.022)	(0.017)
Probability of regulation under *Rapanos*	—	1.013***
		(0.112)
Probability of regulation under NWPR	—	0.197
		(0.126)
Estimated deregulation × NWPR AJD	—	-1.124***
		(0.139)
Constant	0.363***	-0.069***
	(0.028)	(0.014)
Test set	—	Yes
Observations	142,973	29,861

Mean non-residential property: probability of regulation falls from 33% to 19% (42% decline)

Overview

- Background
- Data
- Regulatory stringency
- **Property values**
  - **Event study, differences in differences**
  - Extensions, sensitivity analyses
- Mechanisms
- Measured costs and benefits
- Conclusions

Property Values: Econometrics

- Event study:

$$\ln(P_{izct}) = \sum_{\tau} \left(\beta_\tau W_i \mathbb{1}[q_q = \tau] + (\mathbb{1}[q_q = \tau] X_{izt})' \gamma_\tau \right) + \alpha W_i + X'_{izt}\theta + \eta_{zt} + \varepsilon_{izct}$$

- Differences in differences:

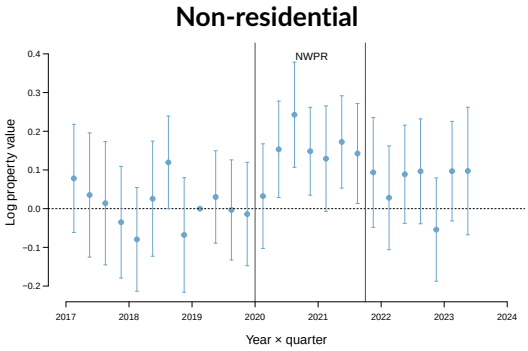
$$\ln(P_{izct}) = \beta W_i N_t + \alpha W_i + X'_{izt}\gamma_1 + (N_t X_{izt})'\gamma_2 + \eta_{zt} + \varepsilon_{izct}$$

  - P_{izct}: Transaction price (property i, zip code z, commuting zone c, year $\times$ month t)
  - W_i: Wetland share within 100m. N_t: Feb 2020 to Aug 2021
  - X_{izt}: Predicted 2016 sale price, acres, COVID controls
  - η_{zt}: Zip code $\times$ year $\times$ month fixed effects
  - Use all properties, not only those with AJDs

Algorithm

NWPR Effect on Log Property Values - Wetland Map

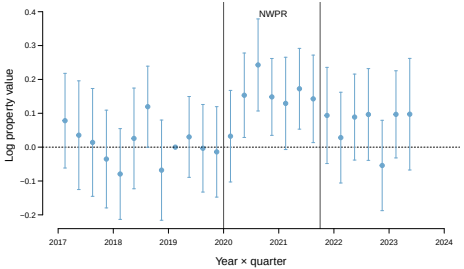
$$\ln(P_{izct}) = \sum_{\tau} \left(\beta_\tau W_i \mathbb{1}[q_q = \tau] + (\mathbb{1}[q_q = \tau] X_{izt})' \gamma_\tau \right) + \alpha W_i + X'_{izt}\theta + \eta_{zt} + \varepsilon_{izct}$$



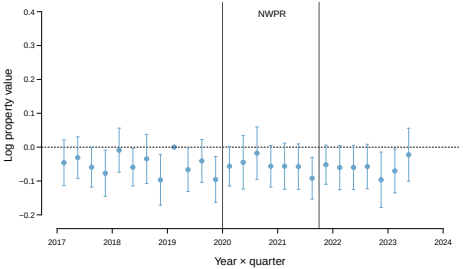
NWPR Effect on Log Property Values - Wetland Map

$$\ln(P_{izct}) = \sum_{\tau} \left(\beta_\tau W_i \mathbb{1}[q_q = \tau] + (\mathbb{1}[q_q = \tau] X_{izt})' \gamma_\tau \right) + \alpha W_i + X'_{izt}\theta + \eta_{zt} + \varepsilon_{izct}$$

Non-residential



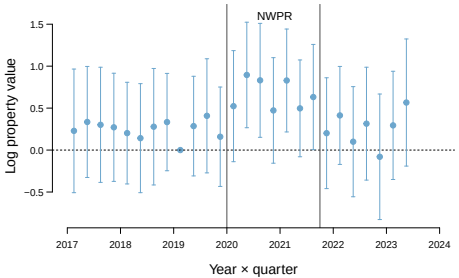
Residential



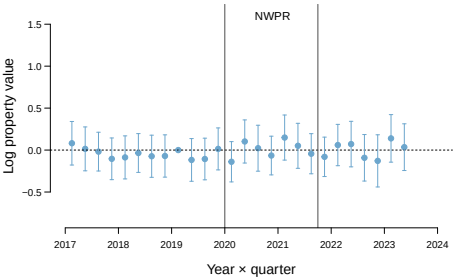
NWPR Effect on Log Property Values - Algorithm

$$\ln(P_{izct}) = \sum_{\tau} \left(\beta_\tau \mathbb{1}[q_q = \tau](p_{iR} - p_{iN}) + (\mathbb{1}[q_q = \tau]X_i)'\gamma_\tau \right) + \alpha_1 p_{iR} + \alpha_2 p_{iN} + \eta_{zt} + X_i'\delta + \varepsilon_{izct}$$

Non-residential



Residential



Effect of NWPR on Log Property Values - Wetland Map

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

	Dependent variable: log property value		
	(1)	(2)	(3)
A. Non-residential properties			
Wetland share × NWPR	0.101***	0.102***	0.125***
	(0.021)	(0.021)	(0.021)
Observations	2,903,767	2,903,767	2,903,767
B. Residential properties			
Wetland share × NWPR	-0.006	-0.002	0.004
	(0.010)	(0.010)	(0.010)
Observations	4,145,422	4,145,422	4,145,422
C. Non-residential vs. residential			
Wetland share × NWPR	0.107***	0.103***	0.121***
× Non-residential	(0.021)	(0.021)	(0.021)
Observations	7,049,189	7,049,189	7,049,189
Zip × year × month FE	Yes	Yes	Yes
Log predicted 2016 sale price	Yes	Yes	Yes
Log distance to town, metro	—	Yes	Yes
Population density decile	—	Yes	Yes
Work from home share	—	Yes	Yes
Log property acres	—	—	Yes

Fully wetland non-residential property: +13% under NWPR. Wetland price penalty falls from 29% to 19%

Effect of NWPR on Log Property Values - Algorithm

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

	Dependent variable: log property value		
	(1)	(2)	(3)
A. Non-residential properties			
Estimated deregulation × NWPR	0.402***	0.368***	0.409***
	(0.098)	(0.098)	(0.104)
Observations	2,903,767	2,903,767	2,903,767
B. Residential properties			
Estimated deregulation × NWPR	0.073**	0.074**	0.053
	(0.037)	(0.036)	(0.036)
Observations	4,145,422	4,145,422	4,145,422
C. Non-residential vs. residential			
Estimated deregulation × NWPR	0.386***	0.343***	0.415***
× Non-residential	(0.091)	(0.091)	(0.095)
Observations	7,049,189	7,049,189	7,049,189
Zip × year × month FE	Yes	Yes	Yes
Log predicted 2016 sale price	Yes	Yes	Yes
Log distance to town, metro	—	Yes	Yes
Population density decile	—	Yes	Yes
Work from home share	—	Yes	Yes
Log property acres	—	—	Yes

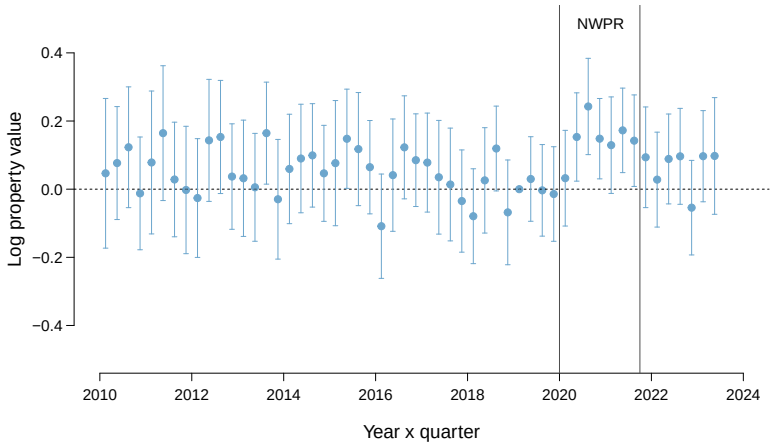
Correcting for measurement error in algorithm (Proctor et al. 2023): 0.721 (0.297)

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  - Main results: Event study, differences in differences
  - **Extensions, sensitivity analyses**
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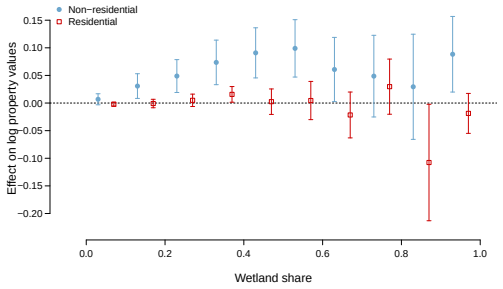
Effect of NWPR on Log Property Values, Extended Panel

$$\ln(P_{izct}) = \sum_{\tau} \left(\beta_\tau W_i \mathbb{1}[q_q = \tau] + (\mathbb{1}[q_q = \tau] X_{izt})' \gamma_\tau \right) + \alpha W_i + X'_{izt}\theta + \eta_{zt} + \varepsilon_{izct}$$



Property Values: Semi-Parametric Bins - Wetland Map

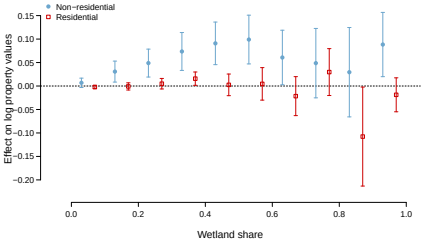
$$\ln(P_{izct}) = \sum_{m \neq 0} \left(\alpha_m \mathbb{1}[W_i \in m] + \beta_m \mathbb{1}[W_i \in m] N_t \right) + X'_{izt}\gamma_1 + (N_t X_{izt})'\gamma_2 + \eta_{zt} + \varepsilon_{izct}$$



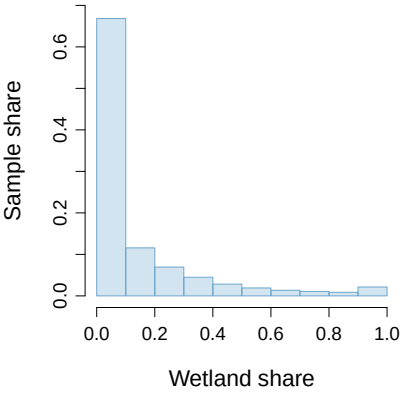
Property Values: Semi-Parametric Bins - Wetland Map

$$\ln(P_{izct}) = \sum_{m \neq 0} \left(\alpha_m \mathbb{1}[W_i \in m] + \beta_m \mathbb{1}[W_i \in m] N_t \right) + X'_{izt}\gamma_1 + (N_t X_{izt})'\gamma_2 + \eta_{zt} + \varepsilon_{izct}$$

Regression estimates



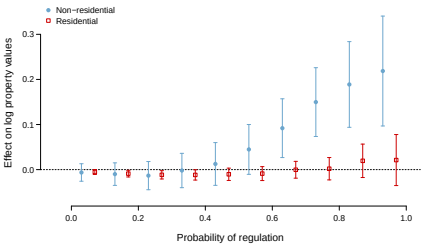
Distribution of observations



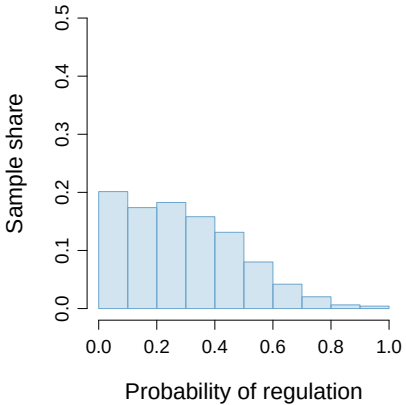
Property Values: Semi-Parametric Bins - Algorithm

$$\ln(P_{izct}) = \sum_{m \neq 0} \left(\alpha_{1m} \mathbb{1}[p_{iR} \in m] + \alpha_{2m} \mathbb{1}[p_{iN} \in m] + \beta_m^N \mathbb{1}[p_{it} \in m] \right) + X'_{izt}\gamma_1 + (N_t X_{izt})'\gamma_2 + \eta_{zt} + \varepsilon_{izct}$$

Regression estimates

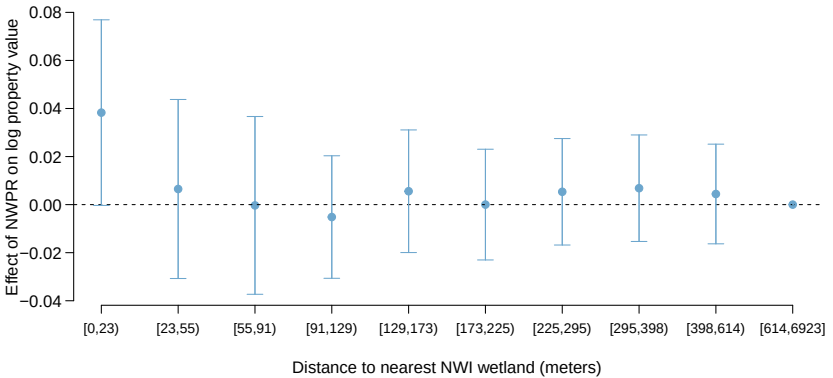


Distribution of observations



Effect of NWPR on Log Property Values, Distance to Wetlands

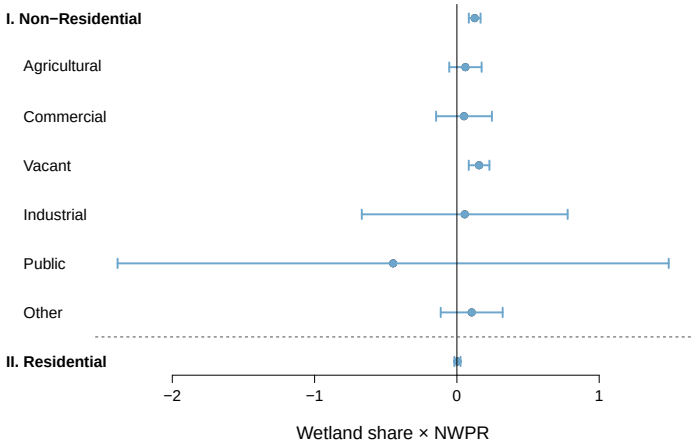
$$\ln(P_{izct}) = \sum_{d \neq 10} \beta_d \mathbb{1}[\text{Dist}_i \in d] + \sum_{d \neq 10} \gamma_d \mathbb{1}[\text{Dist}_i \in d] N_t + X'_{izt}\delta_1 + (N_t X_{izt})'\delta_2 + \eta_{zt} + \varepsilon_{izct}$$



No price gradient between 100m and 6km: little evidence that NWPR reallocated demand from nearby properties

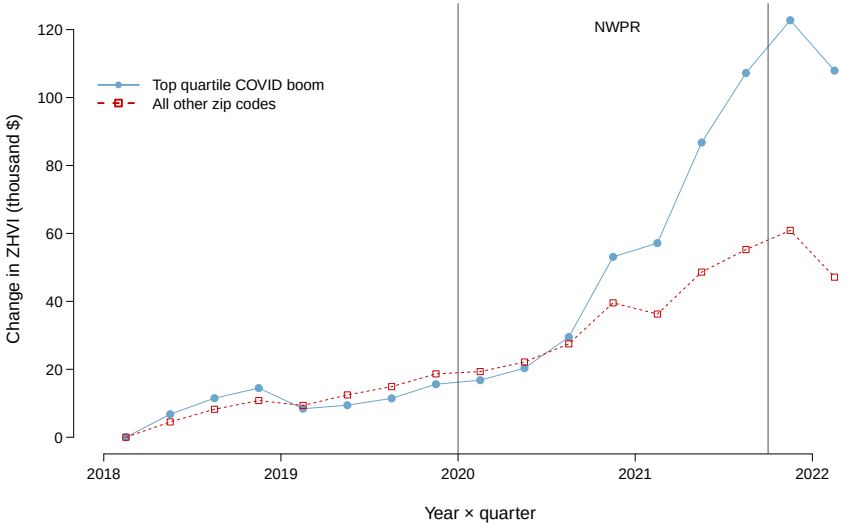
Property Values: by Land Use

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



Observations: Non-residential – 2,903,767; Residential – 4,145,422; Agriculture – 536,063; Commercial – 830,547; Vacant – 1,240,314; Industrial – 160,972; Public – 47,013; Other – 88,858

Trends in Zillow Home Value Index, by Size of COVID Housing Boom



Property Values: by Size of COVID Housing Boom

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

	Dependent variable: log property value	
	(1)	(2)
A. Wetland map model		
Wetland share × NWPR	0.125***	0.128***
	(0.021)	(0.024)
Wetland share × NWPR × COVID top affected	—	-0.013
		(0.043)
Observations	2,903,767	2,758,787
B. Algorithmic model		
Estimated deregulation × NWPR	0.409***	0.467***
	(0.104)	(0.133)
Estimated deregulation × NWPR × COVID top affected	—	-0.247
		(0.216)
Observations	2,903,767	2,758,787
Zip × year × month FE	Yes	Yes
Log predicted 2016 sale price	Yes	Yes
Log distance to town, metro	Yes	Yes
Population density decile	Yes	Yes
Work from home share	Yes	Yes
Log property acres	Yes	Yes

C_z: zip code with top-quartile March 2020 trend break in Zillow Home Value Index

Overview

- Background
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- Regulatory stringency
- Property values
- **Mechanisms**
- Measured costs and benefits
- Conclusions

News About Development Under NWPR

Georgia

The Washington Post
Democracy Dies in Darkness

Trump rule eases effort to strip-mine near Okefenokee Swamp

November 25, 2020 More than **5 years ago**

216



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

Florida

Florida Phoenix

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

CULTURE & SOCIETY ENVIRONMENT POLITICS & LAW WORKING & THE ECONOMY

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

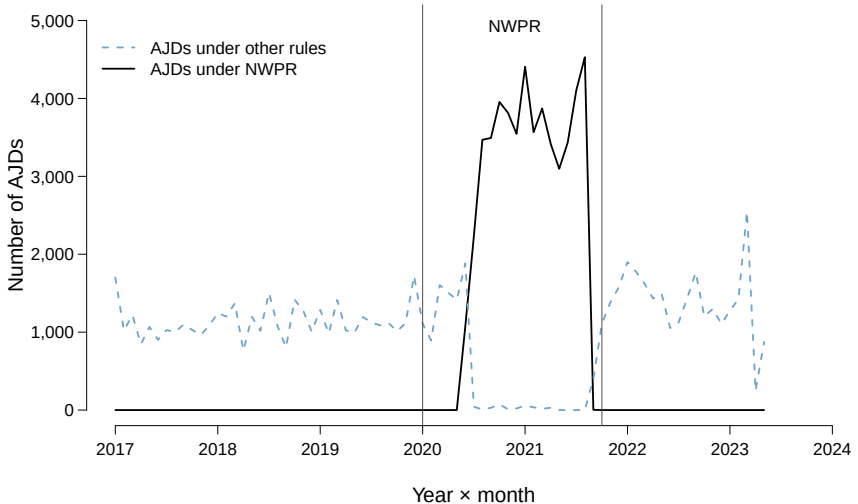
'This was the last forest in Orlando,' says ecologist who grew up there

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



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

Clean Water Act Approved Jurisdictional Determinations, by Rule



AJDs per month: 1,150 before NWPR; 3,600 under NWPR; 1,400 after. NWPR adds about 2.7 years' worth

Land Use: Econometrics

- First step: use pre-AJD observations (Borusyak, Jaravel, and Spiess 2024):

$$L_{ict} = \lambda_{ct} + \eta_i + u_{ict} \tag{1}$$

- Event study:

$$\delta_{ict} = \sum_{\tau \neq -1} \left(\alpha_\tau + \beta_\tau D_i + \gamma_\tau W_i \right) \mathbb{1}[t - E_i = \tau] + \varepsilon_{ict}$$

- Differences in differences:

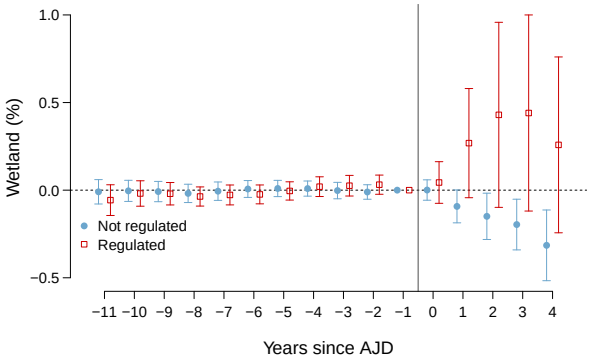
$$\delta_{ict} = \beta D_i \mathbb{1}[t \geq E_i] + \alpha \mathbb{1}[t \geq E_i] + \gamma W_i \mathbb{1}[t \geq E_i] + \varepsilon_{ict}$$

- Extensions: linear pre-trend, trend break models

i, c, t: site, commuting zone, year. L_{ict}: land use within 100m (NLCD). τ: event time. D_i: site not regulated. W_i: wetland share. E_i: year of AJD; if site never has an AJD, $E_i = \infty$. $\delta_{ict} \equiv L_{ict} - \hat{L}(0)_{ict}$: residualized outcomes. $\hat{L}(0)_{ict}$: fitted values from (1). Sample: AJDs issued under NWPR and 100,000 never-treated properties. Bootstrap standard errors, resampling commuting zones.

Land Use Around NWPR Jurisdictional Determinations: Wetlands

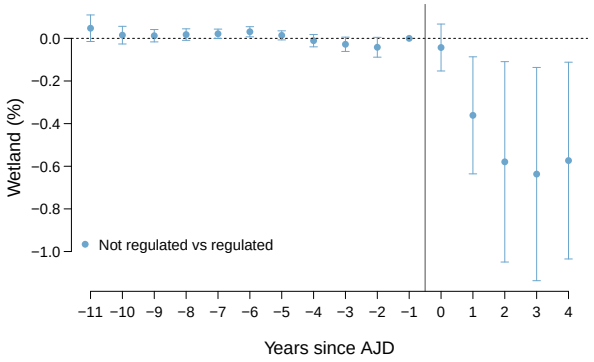
$$\delta_{ict} = \sum_{\tau \neq -1} \left(\beta_{\tau,NR} \, \mathbb{1}[D_i = 1] + \beta_{\tau,R} \, \mathbb{1}[D_i = 0] + \gamma_\tau \, W_i \right) \mathbb{1}[t - E_i = \tau] \; + \; \varepsilon_{ict}$$



i, c, t: site, commuting zone, year. $\delta_{ict} \equiv L_{ict} - \hat{L}(0)_{ict}$: land use, residualized. τ: event time. D_i: site not regulated. W_i: wetland share.

Land Use Around NWPR Jurisdictional Determinations: Wetlands

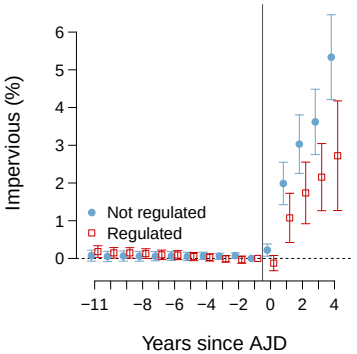
$$\delta_{ict} = \sum_{\tau \neq -1} \left(\alpha_\tau + \beta_\tau D_i + \gamma_\tau W_i \right) \mathbb{1}[t - E_i = \tau] + \varepsilon_{ict}$$



i, c, t: site, commuting zone, year. $\delta_{ict} \equiv L_{ict} - \hat{L}(0)_{ict}$: land use, residualized. τ: event time. D_i: site not regulated. W_i: wetland share.

Land Use Around NWPR Jurisdictional Determinations: Impervious

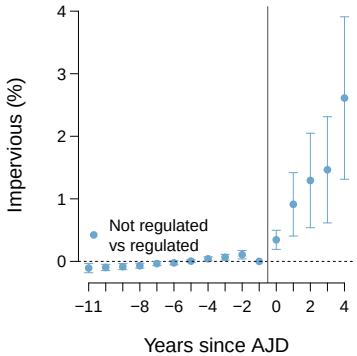
$$\delta_{ict} = \sum_{\tau \neq -1} \left(\beta_{\tau,NR} \, \mathbb{1}[D_i = 1] + \beta_{\tau,R} \, \mathbb{1}[D_i = 0] + \gamma_\tau \, W_i \right) \mathbb{1}[t - E_i = \tau] \; + \; \varepsilon_{ict}$$



i, c, t: site, commuting zone, year. $\delta_{ict} \equiv L_{ict} - \hat{L}(0)_{ict}$: land use, residualized. τ: event time. D_i: site not regulated. W_i: wetland share.

Land Use Around NWPR Jurisdictional Determinations: Impervious

$$\delta_{ict} = \sum_{\tau \neq -1} \left(\alpha_\tau + \beta_\tau D_i + \gamma_\tau W_i \right) \mathbb{1}[t - E_i = \tau] + \varepsilon_{ict}$$



i, c, t: site, commuting zone, year. $\delta_{ict} \equiv L_{ict} - \hat{L}(0)_{ict}$: land use, residualized. τ: event time. D_i: site not regulated. W_i: wetland share.

Effect of NWPR Jurisdictional Determinations on Land Use

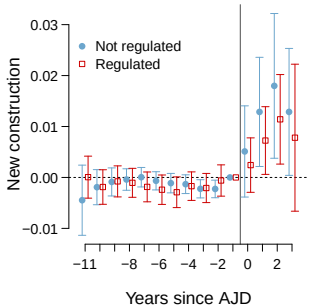
$$\delta_{ict} = \beta\, D_i \mathbb{1}[t \geq E_i] + \alpha \mathbb{1}[t \geq E_i] + \gamma\, W_i\, \mathbb{1}[t \geq E_i] + \varepsilon_{ict}$$

	Developed (impervious) (%)			Wetland (%)		
	(1)	(2)	(3)	(4)	(5)	(6)
Post-AJD	1.713***	1.646***	0.735*	0.365*	0.386	0.617***
	(0.417)	(0.378)	(0.404)	(0.221)	(0.236)	(0.237)
Post-AJD × Non-regulated	1.396***	1.373***	0.312	-0.533***	-0.529***	-0.455**
	(0.374)	(0.371)	(0.292)	(0.203)	(0.202)	(0.178)
Non-regulated × Event time		0.010***	0.007***		-0.002	-0.001
	–	(0.002)	(0.002)	–	(0.001)	(0.001)
Post-AJD × Event time			0.479***			-0.115***
	–	–	(0.146)	–	–	(0.033)
Post-AJD × Non-regulated			0.475***			-0.033
× Event time	–	–	(0.139)	–	–	(0.032)
Fitted effect: Event time = 4						
Non-regulated	3.109	3.019	4.862	-0.167	-0.143	-0.431
Regulated	1.713	1.646	2.651	0.365	0.386	0.155
Difference	1.396	1.373	2.211	-0.533	-0.529	-0.586
P-value difference	[0.000]	[0.000]	[0.000]	[0.009]	[0.009]	[0.007]
Pre-AJD dep. var. mean	20.890	20.890	20.890	5.390	5.390	5.390
NWI × Event time interact.	Yes	Yes	Yes	Yes	Yes	Yes
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
CZ × year FE	Yes	Yes	Yes	Yes	Yes	Yes
Number of AJDs	56,003	56,003	56,003	56,003	56,003	56,003
Number of sites	155,690	155,690	155,690	155,690	155,690	155,690
Observations	2,335,350	2,335,350	2,335,350	2,335,350	2,335,350	2,335,350

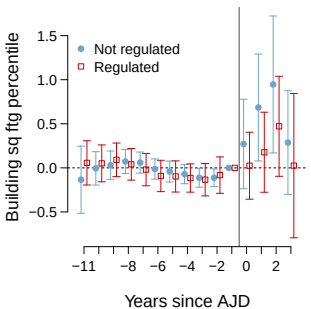
Deregulation: impervious +1.4 pp (baseline 20.9%); wetlands −0.5 pp (baseline 5.4%)

New Construction Around NWPR Jurisdictional Determinations

New construction



Building square footage percentile



- CoreLogic assessor records: larger point estimates for non-regulated sites, but difference insignificant
- Caveats: coverage focuses on residential sites; misses parking lots, roads

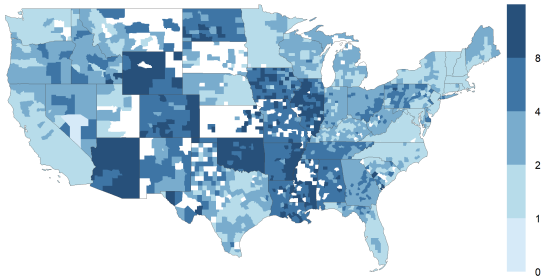
Overview

- Background
- Data
- Regulatory stringency
- Property values
- Mechanisms
- **Measured costs and benefits**
- Conclusions

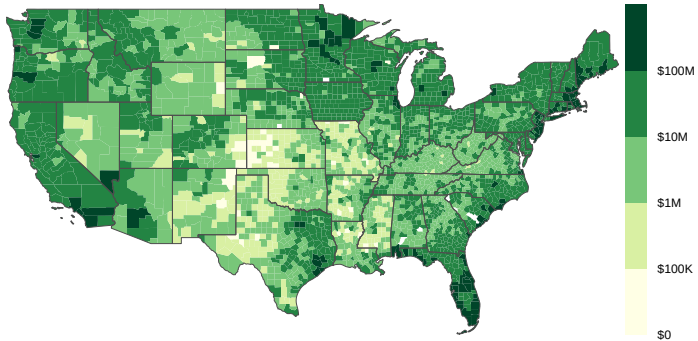
Property Values: Random Forest for Non-Transacting Properties

- Most properties do not transact in a given year
  - Predictors: assessed value & year, sale year, acreage, land use, county FE
  - Test set R^2: 0.68; per acre: 0.75, v. 0.08 to 0.72 in Nolte (2020)
  - Predicts test set total value within 1.2%
  - U.S. non-residential properties: \$11 trillion, 1.9$\times$ assessed value
  - County ratios of price to assessed value posted publicly

Ratio of predicted price to assessed value



Property Values: Total Estimated NWPR Benefits, by County



- National total estimated NWPR benefits: $71 billion (wetland map); $106 billion (algorithm)
- Mean non-residential property: $2,630 to $3,910, about 1%

Land Values: Mitigation Banking Benchmark

- **Mean non-residential property**
  - NWPR decreases probability of regulation by 9.4 percentage points
  - Regulation decreases share of land developed by 1.4 percentage points
  - 27 acres $\rightarrow$ NWPR converts 0.036 acres of wetland to impervious surface
  - NWPR increases property value by $2,630

- **Offset price that would explain all of the land value effect**: $74,000 per developed wetland acre

- **Evidence on offset prices**
  - Army Corps, median state: $56,000 to $109,000 per acre (EPA & Army Corps 2020)
  - Florida: $88,000 per credit (Aronoff & Rafey 2026)
  - Permits often require 1 to 2 acres of offsets per acre developed

- Mitigation banking could account for much of the land value impact

Flood Damages from Wetland Loss (Taylor & Druckenmiller 2022)



FIGURE 1. WETLANDS IN THE UNITED STATES

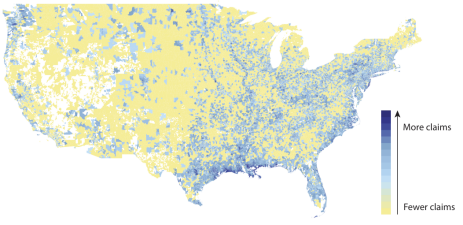


FIGURE A1. NFIP FLOOD INSURANCE CLAIMS

- One acre of wetlands provides $35,262 in present value flood mitigation (3% discount rate)
- We use county-level values

Land Value Benefits Versus Flood Protection Costs of NWPR

	Mean property		National total	
	(1)	(2)	(3)	(4)
A. Property characteristics				
Number of transactions / properties	—	—	2,903,767	27,107,001
Property value ($M)	0.527	0.409	1,529,057	11,073,523
Property acres	20.727	27.188	60,185,636	736,983,565
NWI wetland acres	1.513	2.045	4,394,825	55,446,699
B. Effect of NWPR on …				
Land values (logs)	0.0078	—	—	—
Land values ($M)	0.0030	0.0026	8,677	71,391
NLCD wetland acres	-0.0107	-0.0141	-31,064	-382,091
Wetland flood protection loss ($M)	—	—	702	8,746
C. Ratio of NWPR land value benefits to flood protection costs				
	—	—	12.4	8.2
Transacted Properties	Yes	—	Yes	—
All Properties	—	Yes	—	Yes

Algorithm: land value benefits $106 billion; flood protection costs $5.8 billion; ratio 18 Algorithm

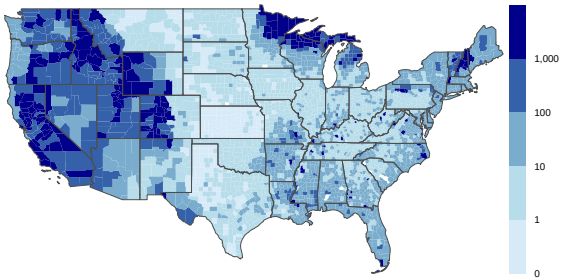
Benefit-Cost Ratios Under Alternative Flood Mitigation Values

		Wetland map			Algorithm		
Source	Geography	Land value ($M)	Flood cost ($M)	Ratio	Land value ($M)	Flood cost ($M)	Ratio
A. As reported							
Taylor & Druckenmiller	National	71,391	8,746	8.2	105,862	5,780	18.3
Gourevitch et al.	National	71,391	1,986	35.9	105,862	906	116.9
Aronoff & Rafey	Florida	10,023	1,201	8.3	18,693	1,386	13.5
B. Restricted to Florida							
Taylor & Druckenmiller	Florida	10,026	401	25.0	18,698	524	35.7
Gourevitch et al.	Florida	10,026	57	174.9	18,698	76	245.9
Aronoff & Rafey	Florida	10,023	1,201	8.3	18,693	1,386	13.5

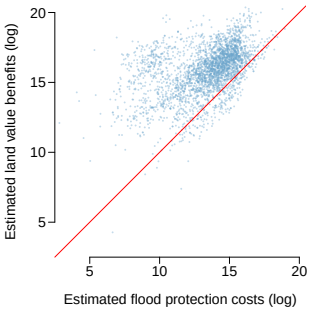
Sources: Taylor & Druckenmiller (2022); Gourevitch et al. (2026); Aronoff & Rafey (2026)

Land Value Benefits Versus Flood Protection Costs, by County

Ratio of benefits to costs



Benefits versus costs



- Ratio < 1 in under a tenth of counties, mostly in central Great Plains
- Correlation 0.47: limited scope for spatial targeting

Welfare Interpretation: Increase in Land Values

- **Local welfare consequences** (Rosen 1974)
  - But, non-marginal policy change
  - Panel data, not cross-section
  - Supply of developed land shifts out

- **Hedonics**: lower bound on willingness to pay (WTP) (Banzhaf 2021)
  - Simulations: if 50% of people receive public good, hedonics = 0.75$\times$WTP
  - If 10% receive public good, hedonics = 0.92$\times$WTP
  - Our analysis sample: wetlands are 7.3% of non-residential, 2.5% of residential land area

- **Other caveats**:
  - Exclude local shifts in wages (Roback 1982)
  - Exclude parcels with missing location, acreage, etc. ($<$1% of non-residential land value)
  - Exclude capitalization of wetlands' environmental benefits

Welfare Interpretation: Ecosystem Services

- **Flood estimates cover insured residential dwellings** (Taylor & Druckenmiller 2022)
  - 16%–35% of flood damages insured? (CBO 2019; Amornsiripanitch et al. 2025; Blickle et al. 2025)
  - Non-residential properties: about 25% of flood damages (CBO 2019)

- **Ecosystem services besides flood mitigation**
  - Water, food, carbon sequestration, water quality, biodiversity, recreation, ...
  - Meta-analyses (300+ estimates, 100+ papers): flood mitigation 55% in most recent; 25%–37% averaging across studies
  - But, many stated preference studies, wide range

	Brouwer et al. (1999)	de Groot et al. (2012)	Brander et al. (2013)	Bilkovic et al. (2025)	Average	Average weighted by number of studies
	(1)	(2)	(3)	(4)	(5)	(6)
A. Ecosystem Services						
Flood control	**38.1%**	**13.6%**	**43.0%**	**55.1%**	**37.4%**	**29.5%**
Number of underlying studies	30	95	38	29	–	–
Number of underlying observations	103	305	66	43	–	–

Welfare Interpretation: Synopsis

- **Land market benefits exceed flood mitigation costs**
  - Likely robust to most caveats on the last two slides
  - Consequence of accounting for other ecosystem services: ambiguous

- **May understate ecosystem costs more than land market benefits**
  - Ecologists rank wetlands among most valuable ecosystems per area (Zedler & Kercher 2005; Costanza et al. 2014)
  - Nutrient cycling, habitat, biodiversity hardest to monetize
  - Restored wetlands may not recover services (Moreno-Mateos et al. 2012); irreversibility (Arrow & Fisher 1974)

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Conclusions

- **Environmental land use regulation: substantial impact on land values, environment**

- **NWPR...**
  - Decreased wetland regulation by about 40%
  - Increased non-residential land value by $71 to $106 billion
  - Expanded impervious surfaces, decreased wetlands
  - Land value benefits $>$ flood mitigation costs, by a factor of 8 or more

- **Open questions**
  - Other environmental statutes, federal-state interactions, permitting reform
  - Spatially resolved values of wetlands' other ecosystem services
  - Components of costs: delay, uncertainty, fees, project redesign
  - Protection of other ecosystems: grasslands, forests, deserts

Algorithms for *Rapanos* v. NWPR

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

Tabular Model (Here)

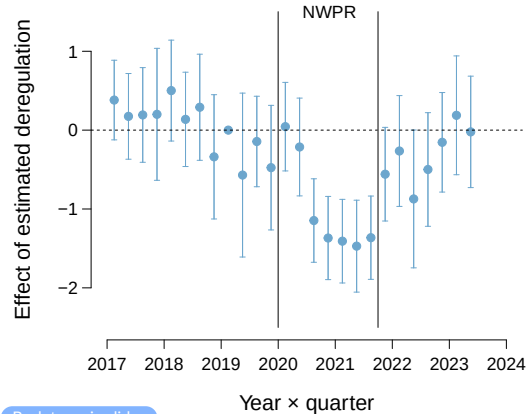
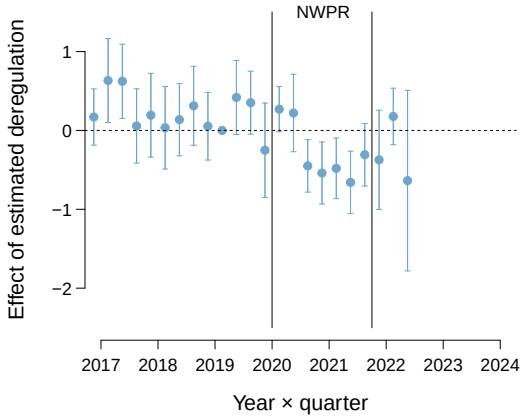
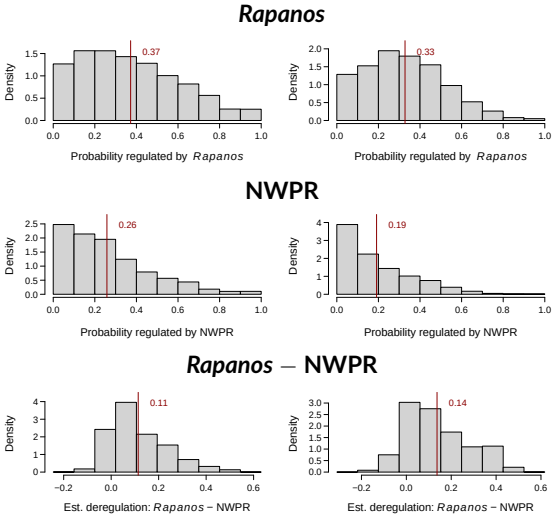


Image-Based Model (Greenhill et al. 2024)



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Predicted Probabilities of Regulation



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Property Values: Econometrics

- Algorithm:

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

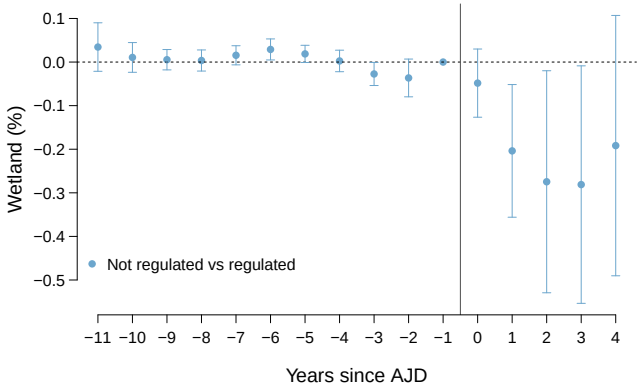
- Equivalent: $-\beta^A$ is the effect of regulation at time of sale, $p_{it} \equiv p_{iR}(1 - N_t) + p_{iN}N_t$
- Event study:

$$\begin{aligned}\ln(P_{izct}) = &\sum_{\tau \neq 2019q1} \left(\beta_\tau \mathbb{1}[q_q = \tau](p_{iR} - p_{iN}) + (\mathbb{1}[q_q = \tau]X_i)'\gamma_\tau \right) \\ &+ \alpha_1 p_{iR} + \alpha_2 p_{iN} + \eta_{zt} + X_i'\delta + \varepsilon_{izct}\end{aligned}$$

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Land Use Around NWPR AJDs: Wetlands, Using Algorithm

$$\delta_{ict} = \sum_{\tau \neq -1} \left(\alpha_\tau + \beta_\tau D_i + \gamma_\tau (p_{iR} - p_{iN}) \right) \mathbb{1}[t - E_i = \tau] + \varepsilon_{ict}$$



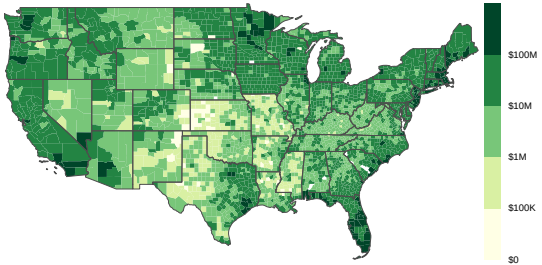
Land Value Benefits Versus Flood Protection Costs - Algorithm

	Mean property		National total	
	(1)	(2)	(3)	(4)
A. Property characteristics				
Number of transactions / properties	—	—	2,903,767	27,107,001
Property value ($M)	0.527	0.409	1,529,057	11,073,523
Property acres	20.727	27.188	60,185,636	736,983,565
NWI wetland acres	1.513	2.045	4,394,825	55,446,699
B. Effect of NWPR on …				
Land values (logs)	0.0127	—	—	—
Land values ($M)	0.0056	0.0039	16,260	105,862
NLCD wetland acres	-0.0058	-0.0075	-16,883	-203,937
Wetland flood protection loss ($M)	—	—	422	5,780
C. Ratio of NWPR land value benefits to flood protection costs				
	—	—	38.5	18.3
Transacted Properties	Yes	—	Yes	—
All Properties	—	Yes	—	Yes

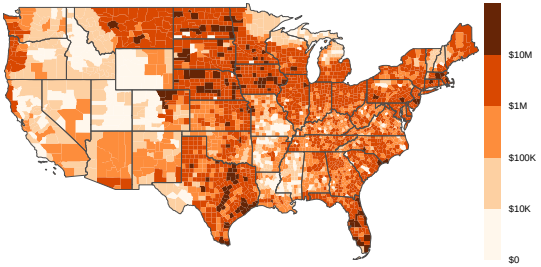
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NWPR Land Value Benefits and Flood Protection Costs, by County

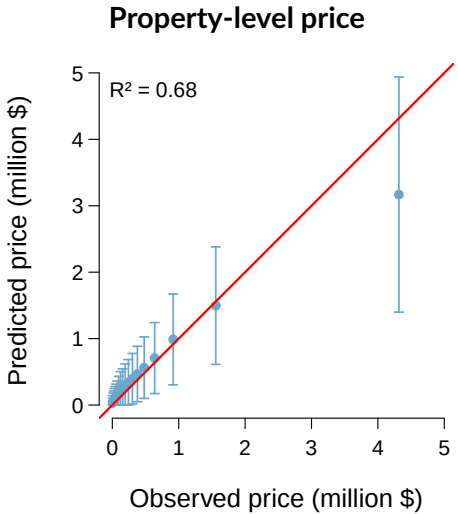
Land value benefits

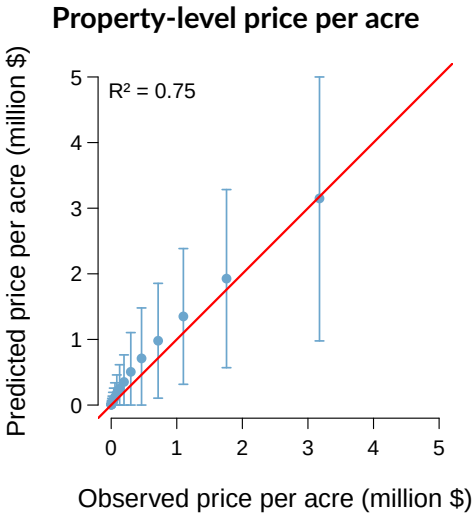


Flood protection costs



Random Forest: Predicted Versus Observed Values





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Ecosystem Service Shares of Wetland Value, Meta-Analyses

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