Private Equity and Biodiversity Offset Markets*

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Abstract

We study the real effects of private equity (PE) in the U.S. biodiversity offset market, where federal law requires firms that damage wetlands and streams to purchase credits from approved providers, known as mitigation banks. We construct a novel project-level dataset covering all U.S. mitigation banks, combining regulatory records with ownership information, geospatial ecological measures, and detailed data on financial safeguards. We find that PE entry is concentrated where portfolio companies generate credit demand and in jurisdictions with stable water regulation. PE-backed banks front-load credit release and operate at larger scale, and banks accelerate credit release after PE acquisition. PE entry expands effective supply and increases participation in geographically segmented markets, but financial safeguards do not scale proportionally with project size, leading to lower protection per unit of credit, and service areas with PE-backed banks experience higher growth in human pressure. Our results reveal a core tension: private capital can deepen conservation markets while outpacing the regulatory safeguards designed to protect long-term environmental outcomes.

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1 Introduction

Under the Clean Water Act, firms whose construction, infrastructure, or land-use projects unavoidably damage wetlands or streams must offset that damage through approved compensatory mitigation. The principal compliance vehicle is the purchase of credits from mitigation banks: dedicated restoration sites that generate tradable offsets in advance of permitted impacts. The resulting market is the world's largest biodiversity offset market, with approximately USD 3.6 billion in annual transactions (BenDor et al., 2023), far exceeding U.S. nature-based carbon credit markets and water-quality trading programs (Green Finance Institute, 2024).

Because credit demand is tied to permitting activity rather than voluntary environmental preferences, it is both predictable and locally concentrated. Mitigation bank sponsors supply credits by investing in ecological restoration, and the market has historically been served by landowners, environmental consultancies, nonprofits, and state agencies. In recent years, however, private equity (PE) investors have entered at scale.[1] By 2025, PE-backed banks operate in roughly half of the watershed areas with active mitigation bank activity.

The entry of PE into this market raises a natural question for finance. Mitigation banks are capital-intensive projects: sponsors must acquire land, fund restoration work, and post financial assurance before any credits can be sold. Revenue arrives only when regulators approve the release of credits, typically in stages over several years. Early-stage releases are tied to administrative milestones largely under the sponsor's control (securing site protection, posting financial instruments, completing initial construction), while later releases depend on ecological performance verified through multi-year monitoring. At the same time, each bank may sell credits only within a regulator-defined geographic service area, which fragments the market into local segments with limited entry and predictable demand. This combination of capital intensity, delayed payoffs, and localized market power makes mitigation banking

[1] Bloomberg, August 20, 2024, Kyle Bass Beefs Up Property Bets Targeting Scarce Resources.

attractive to private equity, but it also creates an intertemporal tension: PE investors face high-powered incentives (Kaplan and Strömberg, 2009; Boucly et al., 2011) to accelerate cash-flow realization, yet ecological gains materialize gradually and cannot be brought forward at the same pace. Ownership structure therefore shapes the divergence between the timing of financial returns and the timing of environmental outcomes.

Despite the rapid growth of private capital in conservation finance, little is known about how ownership structure shapes the supply and ecological effectiveness of biodiversity offsets. We address this question by constructing a novel project-level dataset covering the universe of U.S. mitigation banks. The data combine regulatory records on bank characteristics and credit release schedules from the U.S. Army Corps of Engineers (RIBITS) with ownership information from PitchBook, satellite-based ecological measures linked to bank service areas through geospatial shapefiles, and financial obligation data extracted from digitized regulatory documents using large language models. The resulting panel tracks each bank from approval through credit release and sale, linking sponsor identity and ownership changes to market-level competition and landscape-level ecological trajectories. Using these data, we study how PE entry and ownership reshape credit supply, local competition, ecological conditions, and regulatory safeguards.

Our analysis is organized around two margins: *where and why PE enters* (selection) and *what changes conditional on that entry* (treatment). To formalize the intuition, we build a simple conceptual framework grounded in heterogeneous discount rates and PE's information advantage through portfolio companies, which yields three testable predictions: (i) PE-backed sponsors front-load credit release, because the gain from accelerating cash flows is larger when the effective discount rate is higher; (ii) PE entry is concentrated in markets with high demand, strong regulatory persistence, and mature supply-side permitting frameworks; and (iii) per-credit financial safeguards are diluted under PE ownership, because the fixed-cost component of financial assurance does not scale with project size. All three predictions emerge from the same primitives, so the framework speaks to both margins jointly: selection

and treatment are complementary consequences of the underlying ownership heterogeneity rather than independent phenomena, a structure that disciplines the interpretation of the empirical evidence we document below.

On the selection margin, we find that PE entry into mitigation banking is systematically patterned across space. On the demand side, PE investors are significantly more likely to sponsor banks in watersheds where their existing portfolio firms operate in sectors that routinely generate credit demand. The effect is large: having portfolio companies in a state nearly triples the probability of mitigation bank entry relative to the unconditional baseline rate. On the supply side, PE entry is disproportionately concentrated in states with independent wetland regulatory frameworks. The estimated odds of PE entry in state-regulation jurisdictions are six to ten times those in federal-only states, with the differential peaking in the post-2023 period of greatest federal uncertainty.

On the treatment margin, PE ownership accelerates credit deployment and intensifies competition. PE-backed banks release a larger share of credits in the early years following approval and reach initial credit-release milestones roughly one-third faster than non-PE banks, pointing to front-loading of cash flows. Evidence from buyouts of existing banks shows that ownership shifts the timing of credit deployment within banks: acquiring a young, non-PE bank raises the wetland credit release ratio by 4.3 percentage points relative to matched controls, indicating that the pattern reflects changes in behavior rather than differences in project type. At the market level, PE entry coincides with a persistent decline in local concentration, with HHI reductions of 0.03 in wetland markets and 0.11 in the more spatially constrained stream markets. PE entry is also followed by increased entry from both PE-backed and non-PE-backed banks and lower exit rates. These market-level patterns reflect equilibrium responses within geographically segmented markets; while the matched stacked DID estimates indicate that concentration declines even relative to observationally similar service areas that did not receive PE entry, part of the effect likely reflects PE's selection into growing markets.

These operational gains do not, however, coincide with better ecological trajectories in the areas PE enters. The Clean Water Act's no-net-loss mandate implies that service-area ecological conditions should remain stable if compensatory mitigation functions correctly. Using the satellite-derived Human Influence Index (HII) as a measure of anthropogenic pressure, we find that service areas of PE-backed banks experience a sustained increase in HII relative to matched non-PE entrants. Adding time-varying development controls attenuates the absolute effect by 25%, consistent with PE selecting into higher-growth areas, and controlling additionally for project scale attenuates the remaining effect by a further 15%, for a total reduction of 36% relative to the uncontrolled baseline. The proportional HII growth differential is largely unchanged by development controls but modestly attenuated by scale, indicating that anthropogenic pressure grows faster in PE service areas even conditional on development intensity and project size. Conditions at the bank site itself—where restoration occurs—are indistinguishable between PE and non-PE banks, and the effect replicates at the broader watershed level, indicating that PE involvement does not impair on-site restoration but is associated with development trajectories that outpace offsetting across the service area. Crucially, the PE buyout design reveals that this ecological divergence is overwhelmingly selection-driven: banks that switch from non-PE to PE ownership show no change in service-area HII. The HII gap thus reflects where PE enters—high-development-trajectory markets—rather than what PE does after entry.

A structural feature of the regulatory framework is consistent with these patterns: although PE-backed banks post higher total financial assurance, the elasticity of safeguards with respect to project scale is only 0.19–0.21, far below proportionality. Doubling project size raises total safeguards by just 14–16%, so per-credit financial protection falls by roughly 40%. This dilution arises from the fixed-cost component of regulatory assurance requirements and applies to any large-scale operator, not only PE. The combination of PE's larger scale, structurally diluted per-credit safeguards, and faster-growing anthropogenic pressure in the markets PE selects into points to a regulatory architecture whose financial protections

were not designed for institutional-scale deployment.

Taken together, the evidence shows that private capital reshapes biodiversity offset markets along multiple dimensions. PE participation is concentrated in markets with strong demand and stable regulation, accelerates the timing of credit supply, and expands market activity, but weakens the alignment between credit issuance and long-term ecological outcomes. This divergence reflects both PE's selection into high-development-trajectory environments and the structural underscaling of financial safeguards with project size. The implication is not that private capital is incompatible with conservation goals, but that the existing regulatory architecture was calibrated for smaller, independently operated banks and does not adequately safeguard outcomes when institutional capital operates at scale. Effective policy design must ensure that financial protection and stewardship incentives scale with project size.

Related Literature. This paper contributes to three literatures. First, we contribute to the literature on the real effects of private equity ownership. A large body of work shows that PE can relax financing constraints, reorganize production, and affect product quality, employment, and stakeholder welfare across a wide range of sectors.[2] In settings involving quasi-public goods or intensive government subsidy, Eaton et al. (2020) and Gupta et al. (2024) show that PE ownership can create operational value while redistributing surplus away from stakeholders. We study a setting that differs from prior PE contexts in a structural way. In sectors such as healthcare or food services, PE can accelerate revenue by improving operational throughput, because the output itself (a surgery, a meal) can be produced faster. In mitigation banking, later-stage credits depend on ecological processes (vegetation establishment, hydrological restoration) that unfold on biological timescales and cannot be compressed by managerial effort. PE can accelerate the administrative milestones that trig-

[2] See, among others, Davis et al. (2014), Agrawal and Tambe (2016), Bernstein and Sheen (2016), Cohn et al. (2021), Fracassi et al. (2022), Ewens et al. (2023), Kumar (2023), Howell et al. (2024), Kirti and Sarin (2024), Spaenjers and Steiner (2024), Bai and Wu (2024), Johnston-Ross et al. (2025), Gao et al. (2025), Gornall et al. (2025), Davis et al. (2025), Abramova and Barrios (2025), and Bellon (2025).

ger early credit release but cannot accelerate the ecological performance that justifies those credits. Revenue recognition is therefore structurally decoupled from output quality by regulatory design, and it is precisely this wedge that PE's discount-rate advantage exploits. In addition, financial safeguards contain fixed-cost components that generate mechanical dilution at scale, a regulatory feature absent from most other PE settings. These institutional features make mitigation banking a distinctive laboratory for studying how PE ownership reshapes intertemporal production decisions when revenues are staged and the underlying output is a long-horizon public good. A closely related strand emphasizes that PE investors select into assets already positioned for superior performance (Guo et al., 2011; Acharya et al., 2013; Biesinger et al., 2023). Our setting sharpens this point: because mitigation credit demand is locally observable through portfolio companies and regulatory stability varies across jurisdictions, selection is doubly strategic, and we treat it as a first-order object of interest rather than a confound.

Second, we contribute to the literature on the financing of biodiversity and nature conservation. Existing work examines aggregate financing needs (Karolyi and Tobin-de la Puente, 2023), corporate perceptions and disclosure of biodiversity risks (Giglio et al., 2026; Gjerde et al., 2026), investor engagement (Sautner, 2025), and the pricing of nature-related risks in financial markets (Giglio et al., 2025; Garel et al., 2024).[3] A growing set of studies examines how financing constraints are addressed when market returns are insufficient. Flammer et al. (2025a) show that conservation is often supported through hybrid structures combining public, philanthropic, and private capital, while the blended-finance literature emphasizes how such structures can crowd in private investment for projects with high social value but limited stand-alone financial returns (Flammer et al., 2024, 2025b; Fenichel and Dean, 2024; Hoffmann and Vladimirov, 2025; Kotchen and Vogt, 2025). Related evidence documents persistent funding constraints faced by biodiversity-oriented entrepreneurial ventures that are partially alleviated by mission-driven and hybrid investors (Cao et al., 2026). We high-

[3] See also Chen et al. (2023), Hoepner et al. (2023), Canipek et al. (2024), Coqueret et al. (2025), Chen et al. (2025), Garel et al. (2026), and Liu et al. (2026).

light a complementary dimension: even when capital is successfully mobilized, conservation outcomes depend on how ownership incentives and regulatory design jointly organize the supply of ecological offsets.

Third, we contribute to the literature on the design and performance of environmental markets. Compliance carbon markets can reduce emissions and induce innovation (Martin et al., 2014; Colmer et al., 2025), but may also give rise to financial speculation, leakage, and tax avoidance (Bartram et al., 2022; Chen, 2024; Chen et al., 2026). Voluntary carbon markets offer greater flexibility, yet face persistent challenges in establishing additionality, delivering credible biodiversity co-benefits, and avoiding greenwashing (Calel et al., 2025; Zhou and Almond, 2025; Allen et al., 2026; Kim et al., 2024). Related research highlights how market design shapes environmental effectiveness across settings such as water, land, and conservation programs.[4] Our findings identify ownership heterogeneity as a central but largely overlooked determinant of environmental market performance. Rather than asking whether these markets function under idealized conditions, we examine how they operate when scaled by investors with high-powered incentives and finite horizons. The effectiveness of market-based environmental regulation depends not only on its formal design but also on how ownership structure shapes the timing and scale of production.

The remainder of the paper is organized as follows. Section 2 provides institutional background. Section 3 describes data construction. Section 4 presents motivating stylized facts and develops testable predictions from a conceptual framework grounded in heterogeneous discount rates and differential information about local demand (formal model and proofs in Appendix B). Section 5 reports empirical results. Section 6 concludes.

2 Institutional Background

Mitigation banking in the United States is shaped by five institutional features that are central to our analysis: the regulatory origin of credit demand, the organization and timing

[4] See Ayres et al. (2021), Aronoff and Rafey (2025), Rafey (2023), Aspelund and Russo (2025), and Blume and Vallee (2025).

of credit supply, the geographic segmentation of markets through service areas, the financial safeguards designed to protect long-term ecological outcomes, and the heterogeneity in state-level wetland regulation. Additional legal history, governance standards, and crediting methodologies are provided in Appendix A.

2.1 Regulatory Origin and Compliance-Driven Demand

Activities that risk degrading wetlands, streams, or endangered species habitat have been regulated in the United States since the 1970s. Wetlands provide critical ecosystem services, including flood mitigation whose economic value has been documented at scale (Taylor and Druckenmiller, 2022). Section 404 of the Clean Water Act (CWA) prohibits the discharge of dredged or fill material into jurisdictional waters without a permit from the U.S. Army Corps of Engineers (USACE). Sections 7 and 10 of the Endangered Species Act (ESA) impose parallel requirements for habitat supporting listed species. Under both statutes, regulated entities whose projects cause unavoidable ecological harm must compensate for that harm through approved offsetting activities, a principle commonly known as "no net loss." Although most banks focus on wetland or stream credits under the CWA, a single bank may generate multiple credit types, including species habitat credits under the ESA, so the two regulatory regimes can govern the same project.

The regulatory framework governing these offsets was consolidated by the 2008 Compensatory Mitigation Rule. The Rule established three principles that define the modern offset market. First, it created a preference hierarchy that generally favors the purchase of credits from mitigation banks over credits from in-lieu fee (ILF) programs and over permittee-responsible mitigation, conditional on credit availability and watershed fit.[5] Second, it imposed uniform ecological and procedural standards across all mitigation mechanisms. Third, it codified the transfer of long-term liability from the permittee to the mitigation bank

[5] In-lieu fee programs collect payments from permittees and pool the funds for mitigation projects administered by a third party, typically a government agency or nonprofit. Permittee-responsible mitigation requires the developer itself to carry out compensatory restoration. The 2008 Rule generally disfavors both alternatives when mitigation bank credits are available.

sponsor once credits are purchased.

These features produce demand that is fundamentally different from voluntary environmental markets. Credit purchases are mandatory inputs into the permitting process: a developer cannot proceed with a permitted activity until compensatory mitigation has been secured. As a result, credit demand is closely tied to local construction, infrastructure, and land-development activity rather than to voluntary environmental preferences or market sentiment. This compliance-driven demand is both predictable and geographically concentrated, features that make the market attractive to financial investors and that we exploit empirically in our analysis of PE entry.

2.2 Mitigation Banks and Credit Supply

A mitigation bank is a site where ecological restoration, enhancement, or preservation is carried out in advance of development impacts. The bank generates credits that quantify the ecological uplift produced by the restoration, typically measured in acres for wetlands or linear feet for streams, though many jurisdictions now use multi-attribute functional assessment tools.[6] Credits are tradable: once released by the regulator, they may be sold to developers seeking to offset permitted impacts within the bank's designated service area. Bank sponsors range from landowners and regional environmental consultancies to nonprofits and state agencies (U.S. Army Corps of Engineers and Environmental Protection Agency, 2008). Most operate at small scale: in our data, non-PE sponsors average 1.6 banks across 1.3 states, compared with 5.8 banks across 4.2 states for PE-backed sponsors.

From the sponsor's perspective, establishing a mitigation bank requires substantial upfront capital. The sponsor must acquire land, design and implement ecological restoration, post financial assurance, secure perpetual site protection (typically through a conservation easement), and fund monitoring and adaptive management. These investments are made largely before any credits can be sold and are mostly sunk.

Revenue arrives only as credits are released and subsequently sold. The USACE ap-

[6] See Appendix A for additional detail on credit methodologies.

proves a credit release schedule for each bank, specifying the conditions under which credits become available. Early-stage releases are typically tied to the completion of administrative and financially controlled milestones: securing site protection, posting financial assurance, executing the mitigation banking instrument, and completing initial construction. These milestones are largely under the sponsor's direct control. Later releases are contingent on the achievement of ecological performance benchmarks, such as the establishment of target vegetation communities, restoration of hydrological function, or attainment of habitat metrics verified through multi-year field monitoring.

This staged structure creates a pronounced intertemporal mismatch between investment outlays and cash-flow realization. In a typical bank instrument, an initial tranche of approximately 15% of total potential credits may be released upon completion of administrative steps, with subsequent tranches of 15–25% linked to construction and planting activities. The remaining credits are released only after independent verification of ecological milestones by the USACE and participating agencies. Because early milestones are under the sponsor's control while later milestones depend on ecological outcomes, there is scope for sponsors facing high-powered financial incentives to accelerate the former relative to the latter. This feature is central to our analysis of PE ownership and credit release dynamics.

2.3 Bank Types

Mitigation banks differ along several institutional dimensions that affect their regulatory environment, permitting process, and operational structure. Our empirical analysis controls for the following distinctions:

Wetland and stream banks. Most banks generate credits for wetland or stream impacts (or both). Wetland credits compensate for damage to marshes, swamps, and other aquatic ecosystems under the CWA. Stream credits compensate for impacts to linear waterways, measured in linear feet. Because stream service areas are typically more spatially constrained than wetland service areas, competition dynamics may differ across the two markets.

Conservation banks. Conservation banks generate credits for impacts to endangered or threatened species habitat under the ESA, operating under distinct regulatory regimes and ecological performance requirements. Their credit methodologies and approval processes differ from those of wetland and stream banks. Because conservation banks operate under a distinct regulatory regime, involve different crediting methodologies, and represent a small share of total market activity (fewer than 4% of all banks), we exclude them from the main empirical analysis.

DOT-sponsored banks. Mitigation banks sponsored by state Departments of Transportation support large infrastructure projects with predictable permitting schedules and dedicated administrative resources. Their institutional structure and funding sources differ from privately sponsored banks.

Umbrella mitigation banks. Umbrella programs coordinate multiple smaller restoration sites under a single mitigation banking instrument. This structure changes administrative complexity and the timing of credit releases relative to stand-alone banks.

2.4 Service Areas and Local Market Structure

Each mitigation bank is authorized to sell credits only within a designated service area, defined by ecological and hydrological boundaries. In practice, service areas are typically delineated at the level of eight-digit Hydrologic Unit Codes (HUC-8 watersheds), which approximate regional drainage basins. Credits are not transferable across service areas, and entry requires site-specific regulatory approval within a given service area.

These constraints produce a geographically segmented market. Because supply cannot be easily imported from adjacent regions, competition within a service area is determined by the number and ownership of approved banks operating within it. Many service areas contain only a handful of active banks, resulting in market structures characterized by oligopoly or local monopoly. The Herfindahl–Hirschman Index (HHI), computed from released or withdrawn credits within a service area, provides a natural measure of local market

concentration.

The localized nature of the market has two implications for our analysis. First, PE entry into a service area represents a discrete, observable change in local competitive conditions, allowing us to implement stacked difference-in-differences designs that exploit the timing of PE entry across service areas. Second, because developers must purchase credits within a specific service area, the relevant unit of analysis for market structure and ecological outcomes is the service area rather than a broader geographic region.

2.5 Financial Safeguards

Mitigation banking instruments impose two financial obligations designed to protect long-term ecological outcomes. First, financial assurance requirements ensure that sufficient funds are available to complete required restoration activities and to address potential project failure or sponsor noncompliance. These assurances may take the form of surety bonds, letters of credit, escrow accounts, or other approved financial instruments. Second, long-term management funds (LMFs) finance perpetual stewardship activities after credits have been released, including site monitoring, maintenance, and adaptive management. Both requirements are specified ex ante in the mitigation banking instrument and reflect regulatory assessments of project scale, complexity, and risk.

The 2008 Compensatory Mitigation Rule specifies how financial assurance amounts are set. Under 33 C.F.R. §332.3(n)(2), the district engineer determines the assurance amount in consultation with the project sponsor, considering "the cost of providing replacement mitigation, including costs for land acquisition, planning and engineering, legal fees, mobilization, construction, and monitoring" (U.S. Army Corps of Engineers and Environmental Protection Agency, 2008). Several of these mandated cost categories (legal fees, mobilization, site surveys, baseline engineering) are largely invariant to the number of credits a bank produces. In a representative cost example from the EPA's Bank Instrument Review Workbook, lump-sum items account for approximately 42% of the total financial assurance estimate (Knauer

et al., 2022).[7] The financial instruments used to post assurance reinforce this pattern: letters of credit carry minimum annual fees regardless of facility size, and performance bond premiums follow tiered, declining rate schedules, so the per-dollar cost of posting assurance falls with project scale.

From a regulatory design perspective, these safeguards are intended to ensure that sponsors internalize the long-horizon costs of ecological stewardship. In principle, larger projects should carry proportionally larger financial obligations. However, the combination of fixed regulatory cost components and declining-rate instrument pricing means that per-credit financial protection can fall as projects grow, even without any negotiated concession from the regulator. This structural feature motivates our analysis of per-credit financial safeguards for PE-backed versus non-PE-backed banks and informs the safeguard prediction in Section 4.4 (formal model in Appendix B).

2.6 State Regulatory Heterogeneity

The geographic scope of federal wetland protection is governed by the CWA's definition of "waters of the United States" (WOTUS). This boundary determines which wetlands and waters are subject to federal permitting under Section 404. Because the WOTUS definition has been repeatedly redefined through federal rulemaking and litigation, the reach of federal jurisdiction has varied substantially over time.[8]

In this environment, states differ in whether they maintain independent regulatory programs that extend wetland protection beyond the federal WOTUS boundary. Following the Environmental Law Institute's synthesis of state strategies for protecting non-WOTUS waters (Environmental Law Institute, 2023), we distinguish between two types of states:

[7] The IWR's implementation guide further notes that the assurance amount should cover the beneficiary's administrative costs, with the National Fish and Wildlife Foundation recommending a 10% overhead above projected remediation costs (U.S. Army Corps of Engineers, 2016).

[8] Major changes include the 2015 Clean Water Rule (Obama administration), the 2020 Navigable Waters Protection Rule (Trump administration), the 2023 revised WOTUS rule, and the Supreme Court's decision in *Sackett v. EPA* (2023). Each redefinition shifted the boundary of federal jurisdiction, creating uncertainty about which wetlands and waters are protected.

- **State-regulation states:** States that operate their own permitting programs covering at least some wetlands and waters outside federal WOTUS jurisdiction. In these states, effective wetland protection is not wholly contingent on the federal WOTUS boundary, providing a regulatory backstop during periods of federal uncertainty.

- **Federal-only states:** States without independent dredge-and-fill permitting coverage for non-WOTUS waters, where effective wetland protection is substantially more dependent on federal jurisdiction and associated CWA permitting pathways.

This distinction has direct implications for mitigation credit markets. In state-regulation states, the scope of regulated impacts is broader and more stable over time, generating thicker and more predictable demand for mitigation credits. In federal-only states, demand is more sensitive to shifts in federal jurisdiction. For PE investors evaluating mitigation banking as a capital deployment opportunity, regulatory stability and market thickness are first-order considerations. This institutional variation motivates our analysis of whether PE entry is disproportionately concentrated in states with independent regulatory frameworks, particularly during periods of federal regulatory uncertainty.

3 Data

We construct a dataset covering the near-universe of U.S. mitigation banks over the period 1980–2025 by linking four types of information: (i) regulatory records on bank characteristics and credit activity from the USACE's Regulatory In-lieu Fee and Bank Information Tracking System (RIBITS); (ii) ownership information from PitchBook and Preqin, matched to bank sponsors to identify PE involvement; (iii) satellite-based ecological measures linked to bank service areas through geospatial shapefiles; and (iv) financial obligation data extracted from digitized mitigation banking instruments using large language models. This section describes each component. Detailed matching procedures, LLM prompts, and classification criteria are provided in Appendix C.

3.1 Bank Characteristics and Ownership Classification

RIBITS records bank-level information on sponsor identity, approval date, bank type, service area delineation, credit generation, credit releases and withdrawals, and regulatory status. As of September 2025, RIBITS lists 4,909 mitigation banks and bank sites. We use the full universe of banks as the starting point of our analysis.

To identify PE involvement, we match bank sponsors to company and investor records in PitchBook using a two-step procedure. First, we extract the email domain associated with each bank's listed sponsor and match it to PitchBook entities through WRDS. This domain-based matching links 1,656 banks (approximately 34% of the sample) to PitchBook records. We classify a bank as PE-backed if its matched entity exhibits a private equity background based on keyword matching across PitchBook fields (PrimaryInvestorType, CompanyFinancingStatus, OwnershipStatus, and Universe).

Second, given known limitations in commercial PE datasets (Phalippou, 2026), we implement a supplemental validation step for unmatched sponsors. We query PitchBook's web interface directly for available sponsor domains, and for remaining cases we apply a conservative LLM-based screening procedure that evaluates whether the sponsor is funded, controlled, or affiliated with PE investors based on publicly available information. All prompts and classification criteria are reported in Appendix C.

The procedure identifies 534 PE-backed mitigation banks, representing 11.24% of all banks. After excluding In-Lieu Fee (ILF) program sites, PE-backed banks account for 17.25% of the remaining sample. Detailed distributions by bank type and status are reported in Appendix C.

3.2 Credit Releases and Withdrawals

For each bank, RIBITS reports the approved credit types (wetland, stream, or species habitat) and the maximum number of credits that may ultimately be generated. Our empirical analysis focuses on wetland and stream credits, which account for the vast majority of mar-

ket activity. Conservation banks generating species habitat credits are excluded because they operate under the ESA rather than the CWA, with distinct crediting and approval processes. The registry tracks both credit releases, which record when credits become available for sale according to the regulator-approved schedule, and credit withdrawals, which record when credits are sold and applied to offset specific permitted impacts. These two series allow us to observe the timing and intensity of credit supply (releases) and realized demand (withdrawals) at the bank–year level, forming the basis for our analysis of credit deployment dynamics in Section 5.2.

3.3 Financial Obligations from Mitigation Banking Instruments

Mitigation banking instruments (MBIs) specify the financial assurance and long-term management fund (LMF) requirements for each bank, as described in Section 2.5. We obtain MBI documents from RIBITS in PDF format. Because these documents vary in length, structure, and formatting across jurisdictions, we use a large language model (GPT-5.1) to systematically extract the required financial assurance and LMF amounts. When multiple tranches or phased requirements are described, we aggregate them to construct total amounts at the bank level. We validate the extracted data through manual checks; the full extraction protocol and validation details are described in Appendix C. The resulting measures capture ex ante financial obligations imposed at the time of bank approval and form the basis for the analysis in Section 5.5.

3.4 Ecological Measures

To assess ecological conditions within each bank's service area, we employ the Human Influence Index (HII), a satellite-derived measure that quantifies cumulative anthropogenic pressure on terrestrial ecosystems (Venter et al., 2016). HII integrates multiple dimensions of human activity, including population density, land use, infrastructure, and accessibility, into a single index and is available at approximately 1 km resolution for the period 2001–2020.

We compute the mean HII at three geographic scales. First, the *bank service area*, the

regulatory boundary within which a bank's credits may offset permitted impacts, is the primary unit for the ecological analysis because the no-net-loss mandate operates within this boundary. Second, the *bank site*, the specific parcel where restoration occurs, captures conditions at the point of mitigation activity. Third, the *HUC-8 watershed*, a hydrologic unit defined by the U.S. Geological Survey, provides a broader geographic aggregation that pools all banks within the same watershed. We merge HII annually to the bank–year panel at the service-area and bank-site levels and to the HUC-8–year panel for watershed-level analyses. Unlike vegetation-based indices such as NDVI, HII directly measures the human footprint that threatens wetland and stream integrity. We discuss limitations and complementary ecological measures (the Biodiversity Habitat Index and the Bioclimatic Ecosystem Resilience Index) in Appendix C.

3.5 Land-Cover Controls

Following Rafey (2023), we obtain land-cover data from the National Land Cover Database (NLCD), produced by the Multi-Resolution Land Characteristics (MRLC) Consortium. The NLCD provides 30-meter resolution land-cover classifications for the conterminous United States on an annual basis. We aggregate the raster data to the HUC-8 watershed level and construct three composition variables: *Urban Density* (developed land share), *Agricultural Density* (agricultural land share), and *Wetland Density* (wetland land share). To capture dynamic land-use change, we also compute Δ *Urban Density* and Δ *Wetland Density* as annual log differences. These variables serve as time-varying controls in the state-regulation analysis of PE entry determinants (Section 5.1.2), helping distinguish the regulatory-stability channel from confounding differences in baseline land composition or contemporaneous development pressure. NLCD classification codes, the spatial aggregation procedure, and further details on the Annual NLCD are provided in Appendix C.

4 Stylized Facts

The U.S. mitigation banking market develops well before PE capital arrives. This section documents three features of the market that motivate our empirical design: PE enters existing local markets rather than creating new ones, PE-backed banks release credits more intensively, and PE ownership coincides with rapid geographic expansion.

4.1 Market Structure and Evolution

Figure 1 places PE entry in the longer-run market context. Panel (a) reports the number of active mitigation banks over time. The sector expands steadily from the mid-1990s onward, with early growth almost entirely driven by non-PE banks. PE-backed banks are largely absent until the mid-2000s and only begin to appear in meaningful numbers after 2010. Even at the end of the sample period, they remain a minority of active institutions.

Panel (b) shifts the unit of observation from banks to service areas at the HUC-8 watershed level. Despite their limited numbers, PE-backed banks rapidly expand their geographic reach. The number of service areas with PE participation rises sharply over time, almost entirely through entry into areas already served by non-PE banks. Service areas exclusively served by PE-backed banks are uncommon throughout the sample.

Viewed jointly, these patterns indicate that PE sponsors tend to enter existing local mitigation markets rather than opening new ones. Consequently, PE entry is more likely to influence outcomes through competitive interactions, credit release decisions, and changes in local concentration than through market creation. These features motivate our emphasis on service-area-level variation and the timing of PE entry in the empirical analysis.

4.2 Credit Release Patterns

Credit release is the primary channel through which mitigation banks supply regulatory offsets to developers, determining both the timing and scale of effective mitigation. Figure 2 documents how cumulative released credits evolve over time for PE-backed and non-PE-

backed banks across major credit categories.

Across wetland and stream credits,[9] cumulative releases increase steadily, reflecting the growing role of mitigation banking in regulatory compliance. Throughout the sample, non-PE-backed banks account for the majority of released credits, given their dominant presence. At the same time, credit supply from PE-backed banks accelerates sharply after the mid-2010s and becomes economically meaningful across both credit types.

Strikingly, the contribution of PE-backed banks to released credits grows faster than their share of active banks documented earlier. This divergence points to higher release intensity among PE-backed banks, conditional on participation. The pattern is especially pronounced for wetland and stream credits, which comprise the bulk of mitigation supply and are closely linked to infrastructure and real estate development.

The expansion of PE-backed credit supply occurs primarily along the intensive margin. Rather than introducing new credit categories, PE-backed banks scale up the release of credit types that already dominate the market. PE-backed banks thus operate within established regulatory constraints while emphasizing the pace and volume of monetization.

4.3 A Case Study: Resource Environmental Solutions (RES)

To anchor these aggregate patterns in a concrete institutional setting, we examine Resource Environmental Solutions (RES), one of the largest mitigation banking and ecological restoration platforms in the United States. Founded in 2007 in Louisiana, RES develops and manages restoration projects that generate regulatory offsets for wetlands, streams, and species habitats, serving developers subject to federal environmental regulations.

In June 2016, KKR acquired a controlling stake in RES, framing the transaction as a platform investment designed to support national expansion. RES later attracted additional private equity capital, including an investment by Onex Partners in 2022, with continued participation from KKR. Figure 3 illustrates how RES's geographic footprint evolves around

[9] Species credits generated by conservation banks are shown separately in Appendix Figure C.1. Because conservation banks operate under the ESA rather than the CWA and represent fewer than 4% of all banks, they are excluded from the causal analysis in Sections 5.2–5.5.

the KKR acquisition. Prior to 2016, RES approvals are geographically concentrated. In the post-acquisition period, new approvals increase sharply and extend across a much broader set of states and watersheds.

Two features are noteworthy. First, post-buyout growth reflects entry into new regions rather than incremental expansion around existing sites. Second, the expansion displays coordinated, multi-region deployment that suggests centralized planning and enhanced access to capital. Although RES need not be representative of all PE-backed banks, its trajectory provides a clear illustration of how PE ownership can coincide with rapid spatial scaling.

Motivated by this case, the next sections examine whether similar patterns characterize PE-backed mitigation banks more broadly and how such expansion relates to credit supply, market structure, and ecological outcomes.

4.4 Testable Predictions

The institutional features documented in Section 2 and the aggregate patterns above suggest that ownership structure shapes both where capital flows and how credit supply is deployed. To discipline the empirical analysis, we develop a stylized two-period model that derives three testable predictions from a small set of primitives: heterogeneous discount rates, differential information about local demand, and operational cost advantages. The full model, formal proofs, and a mapping of predictions to empirical tests are in Appendix B.

Prediction 1: Front-loading of credit release. *PE-backed banks release a larger share of credits early.*

Each sponsor equates the marginal benefit of shifting revenue forward with the marginal acceleration cost. Since PE discounts future cash flows more steeply, this benefit is larger for PE: moving a dollar forward saves more when the effective discount rate is higher. PE therefore pushes harder on early milestones. This is feasible because early milestones (securing site protection, posting financial instruments, completing initial construction) are administratively controlled rather than tied to demonstrated ecological outcomes.

Prediction 2: Strategic market selection. *PE entry is concentrated in markets with high credit demand, stable regulatory frameworks, and mature supply-side permitting environments.*

Three forces drive selection. On the demand side, PE's information advantage through portfolio companies allows it to identify high-demand service areas that non-PE sponsors cannot distinguish from average markets. On the regulatory persistence margin, PE's higher hurdle rate means it enters only markets where the profitability threshold is cleared, selecting toward higher and more persistent demand. On the supply side, PE benefits disproportionately from mature regulatory frameworks: because PE pushes harder on early milestones, it incurs higher acceleration costs at the optimum, so the cost reduction from a streamlined permitting process is larger for PE than for non-PE sponsors. This supply-side channel requires no additional assumption; it follows directly from the same discount-rate heterogeneity that drives Prediction 1.

Prediction 3: Financial safeguard dilution. *If PE's cost advantage is sufficiently large, PE operates at larger scale and per-credit financial assurance is lower.*

PE's lower operational costs raise per-credit profit and therefore optimal scale. Since financial assurance includes a substantial fixed component that does not scale with the number of credits, larger projects mechanically dilute per-credit financial protection. The dilution arises from the interaction between PE's larger operating scale and a safeguard structure designed for smaller, independently operated banks, not from PE negotiating special regulatory treatment. If financial assurance were fully proportional to project size, the dilution would vanish regardless of PE's scale advantage.

A central feature of the framework is that all three predictions emerge from the same primitives. Discount-rate heterogeneity drives where PE enters, how it operates, and which regulatory environments it favors; information advantages sharpen demand-side targeting; and operational efficiency interacts with safeguard design to produce dilution at scale. Selec-

tion and treatment are thus complementary consequences of the same underlying ownership heterogeneity rather than independent phenomena. Table B.1 in Appendix B maps each prediction to its corresponding empirical test.

5 Empirical Results

Our empirical analysis proceeds in two blocks. Section 5.1 characterizes the determinants of PE entry, examining both demand-side and supply-side selection. Sections 5.2–5.5 study outcomes conditional on entry: credit release dynamics, market structure, ecological conditions, and financial safeguard mechanisms.

5.1 Determinants of PE Entry

Prediction 2 of the conceptual framework implies that PE entry is concentrated in markets with high demand intensity and supply-side regulatory maturity. We test the demand-side and supply-side components of this prediction in turn.

5.1.1 Demand-Side Selection: Portfolio Company Exposure

PE investors may possess superior information about local credit demand through their existing portfolio companies in sectors subject to environmental permitting. More broadly, common ownership of both credit-consuming firms and credit-producing banks creates a potential demand-side synergy: the PE investor can coordinate entry with anticipated permitting needs, reducing demand uncertainty. We test whether this demand-side channel predicts entry by estimating the following linear probability model at the PE investor–watershed–year level:

$$\text{PEbuildNewBank}_{p,h,t} = \beta\, \text{PEBusinessInvolve}_{p,s(h),t-1} + \mathbf{Z}'_{h,t-1}\gamma + \alpha_p + \delta_h + \lambda_t + \varepsilon_{p,h,t}, \quad (1)$$

where $\text{PEbuildNewBank}_{p,h,t}$ indicates whether PE investor p sponsors a mitigation bank entry in HUC-8 watershed h in year t. The key explanatory variable, $\text{PEBusinessInvolve}_{p,s(h),t-1}$,

equals one if investor p has active portfolio companies in state $s(h)$ in year $t-1$ in industries likely to generate mitigation credit demand (real estate, infrastructure, construction, utilities, mining). The lag ensures that portfolio exposure predates the entry decision. The vector $\mathbf{Z}_{h,t-1}$ captures time-varying local market conditions, including the lagged number of banks, an indicator for no prior credit releases, and the lagged HHI. All specifications include PE investor, HUC-8, and year fixed effects. Standard errors are clustered at the PE investor level.

Table 2 presents estimates of equation (1). Local PE presence increases the probability of mitigation bank entry by approximately 0.2 percentage points (Column 1), an estimate that remains stable after controlling for local market structure (Columns 2–3). Although modest in absolute terms, this effect is large relative to the unconditional entry rate of 0.11% among observations without prior local PE presence (Table 1, Panel C), corresponding to a roughly 180% proportional increase. The low baseline reflects the size of the opportunity set: each year contains approximately 70,560 investor–HUC-8 observations but only about 114 entry events. The stability of the coefficient across specifications indicates that the result is not driven by differences in competition or market saturation across watersheds.

5.1.2 Supply-Side Selection: State Regulatory Environment

We next examine whether supply-side regulatory conditions shape PE entry decisions. As described in Section 2.6, state-regulation states maintain independent wetland programs that generate thicker and more predictable credit markets. PE investors seeking regulatory stability should be disproportionately attracted to such jurisdictions, particularly during periods of federal uncertainty.

Figure 4 overlays bank locations on the state classification. PE-backed banks are present under both regulatory regimes, but among post-2020 entrants they are relatively more concentrated in state-regulation states, suggesting that PE investors sort toward jurisdictions offering regulatory continuity. Figure 5 confirms this pattern dynamically: the cumulative number of PE-backed banks rises faster in state-regulation states, with the divergence be-

coming pronounced after 2016.

We formally test this sorting using a panel at the HUC-8 service-area-by-year level, where $PE\ Entry_{it}$ indicates PE-backed bank establishment. We interact $State_i$ (an indicator for state-regulation jurisdictions)[10] with indicators for three federal policy periods: Period 1 (Obama-era Clean Water Rule, beginning 2016), Period 2 (Trump-era 2020 Navigable Waters Protection Rule), and Period 3 (post-2023 WOTUS rule and subsequent judicial adjustments). The omitted category is the pre-2016 baseline. We estimate random-effects panel logit models:

$$\Pr(PE\ Entry_{i,t} = 1 \mid X_{it}, u_i) = \Lambda\left(\sum_{p\in\{1,2,3\}} \beta_p\, state_i \times \mathbf{1}\{t \in p\} + \mathbf{X}'_{i,t}\boldsymbol{\gamma} + u_i\right), \tag{2}$$

where $\Lambda(\cdot)$ is the logistic CDF and u_i is a service-area random effect. Controls include NLCD land-cover shares and, in Column (3), annual changes in developed and wetland area.

Table 3 reports the results. The interaction coefficients are positive and highly significant across all periods and specifications. In Column (1), the estimated odds ratios for state-regulation service areas are approximately 6.0× (Obama era), 4.9× (Trump era), and 10.2× (Post-2023) relative to federal-only areas in the baseline period. The strongest differential emerges in the Post-2023 period, when federal jurisdiction was most uncertain. Results are robust to adding land-cover composition and trend controls (Columns 2–3); covariates enter with expected signs.

Summary. PE entry into mitigation banking is doubly strategic, consistent with Prediction 2. On the demand side, PE investors enter where their portfolio companies generate credit demand, consistent with a demand-side synergy in which the same ownership structure spans both credit supply and credit consumption. While the data cannot distinguish whether this channel operates through pure information (observing portfolio company permitting

[10] The state classification follows the Environmental Law Institute's synthesis of state strategies for protecting non-WOTUS waters (Environmental Law Institute, 2023).

pipelines) or through internalized demand (directing affiliated firms toward the investor's own banks), the magnitude of the effect suggests more than passive information. On the supply side, they disproportionately select state-regulation jurisdictions, with the differential intensifying during federal regulatory uncertainty. This two-dimensional selection informs the interpretation of all subsequent results, which examine outcomes conditional on entry.

5.2 Credit Release Dynamics at the Bank Level

The strategic entry documented above raises a natural follow-up: does PE ownership change how banks operate once inside the market? Prediction 1 states that PE sponsors front-load credit release. Early-stage releases are tied to administrative milestones under the sponsor's direct control, while later releases depend on ecological performance.

5.2.1 Life-Cycle Dynamics of Credit Releases

We compare PE-backed banks (treated at initial approval) with never-PE-backed banks using two bank–year outcomes: the annual credit release ratio of wetland or stream credits, both scaled by total approved credits. We estimate an event-study specification:

$$Y_{i,t} = \sum_{k \in \mathcal{K},\, k \neq 0} \beta_k \cdot \Big(\mathbf{1}\{t - g_i = k\} \times \text{PE Entry}_{i,t} \Big) + \mathbf{X}_i' \gamma + \alpha_i + \delta_t + \epsilon_{i,t}, \tag{3}$$

where g_i is the bank's approval year and $\mathcal{K}$ is the event window (e.g., $k \in [0, 8]$), with the founding year as the reference period. The specification includes bank and year fixed effects; standard errors are clustered at the bank level.

Figure 6 plots the estimated β_k for wetland (Panel a) and stream (Panel b) credit release ratios. PE-backed banks release a significantly larger share of credits in the first several years following approval, with differences attenuating over the life cycle, as expected if PE sponsors front-load deployment to accelerate cash flows.

5.2.2 Early-Stage Credit Release Milestones

To further isolate the timing channel, we test whether PE-backed banks reach initial credit release milestones faster.[11] Using transaction-level data from RIBITS, we aggregate releases occurring within 180 days of one another into milestone-level events and estimate:

$$InitReleaseCost_i = \beta_1 \,\text{PE-backed}_i + \mathbf{X}_i'\gamma + \lambda_t + \alpha_i + \delta_s + \varepsilon_i, \tag{4}$$

where $InitReleaseCost_i$ measures the number of days from approval to the initial credit release. Controls include bank-type indicators and the log of initial credits. To mitigate the influence of extreme delays, we restrict the sample to banks with time to initial release of at most 550 days (one and a half year). The specification includes approval-year, bank-type, and USACE district fixed effects; standard errors are clustered at the district level.[12]

Table 4 reports the results. PE-backed banks reach the initial credit release milestone approximately 18 days earlier in the most saturated specification. Relative to the sample mean of about 70 days (Table 1, Panel D), this represents roughly a quarter reduction, indicating that PE ownership substantially accelerates the administrative steps required for early monetization. The estimates are stable across specifications.

5.2.3 PE Buyouts

The founding-time comparisons above could reflect selection (PE chooses to sponsor banks that are positioned for early credit release) rather than a treatment effect of PE ownership. To separate selection from treatment, we exploit banks that switch from non-PE to PE ownership after founding. The sample contains 48 such PE buyouts, restricted to banks with wetland credits, acquired at ages one through six, and approved from 2005 onward. We estimate the effect on the wetland credit release ratio using the Callaway and Sant'Anna

[11] In a typical mitigation bank instrument, the initial release milestone triggers approximately 15% of total potential credits, while subsequent early milestones tied to construction and planting commonly release an additional 15–25%.

[12] We cluster at the district level (41 clusters) rather than the bank-type level to avoid the small-cluster bias. Results are qualitatively identical under both clustering choices.

(2021) doubly-robust difference-in-differences estimator (DRIMP with inverse probability tilting), with the acquisition year as the treatment date. Covariates include the log of released wetland credits, lagged bank stock of wetland credits, the log of maximum wetland credit, and the lagged release ratio. Standard errors are clustered at the bank level.

Figure 7 reports the event-study estimates. The pre-treatment average effect is 0.012 and statistically insignificant, providing no evidence of differential pre-trends. The post-treatment average is +0.096 ($p = 0.002$), indicating that PE acquisition is associated with an increase in the wetland credit release ratio of approximately 9.6 percentage points. The event-time coefficients reveal that the effect builds gradually, reaching 0.255 by six years after acquisition, with the largest and most significant increases emerging at $k = +5$ and $k = +6$. The economic logic is direct: when a PE investor acquires a bank, the new owner's higher effective discount rate creates an incentive to complete the administrative milestones that trigger credit releases (site protection, posting of financial instruments, initial construction) more aggressively. The growing pattern over event time is consistent with sustained acceleration of credit release rather than a one-time jump, strengthening the case for the discount-rate mechanism underlying Prediction 1.

5.3 Market Structure at the Service Area Level

If PE-backed banks deploy credits more aggressively, the effects should be visible in local market structure. PE entry may intensify competition through scale and rapid deployment, or alternatively may allow PE sponsors to dominate local markets. This section evaluates these competing forces using a stacked difference-in-differences (DID) design.

5.3.1 Difference-in-Differences Specification

Let g_h denote the first year in which service region h experiences PE-backed bank entry. For each treated region, we select three matched control regions that (i) share at least one state with the treated region and (ii) are closest in pre-entry HHI and number of active banks in year $g_h - 1$. Controls must remain untreated by PE until at least $g_h + 5$. We restrict

the sample to region-experiments with positive pre-entry credit activity. The estimating equation is:

$$Y_{h,t} = \delta \cdot \left(\text{PE Entry}_{h,e(h)} \times \text{Post}_{t \geqslant g_{e(h)}}\right) + \mathbf{X}'_{h,t}\gamma + \alpha_h + \lambda_t + \mu_{e(h)} + \varepsilon_{h,t}, \tag{5}$$

where α_h, λ_t, and $\mu_{e(h)}$ are region, year, and experiment (stack) fixed effects, respectively. Standard errors are clustered at the region level. To assess pre-trends, we also estimate an event-study variant replacing the single interaction with event-time indicators $\mathbf{1}\{t - g_{e(h)} = k\} \times \text{PE Entry}_{h,e(h)}$, normalizing $\beta_{-1} = 0$.

This matched-and-stacked design identifies treatment effects from within-experiment variation, avoiding the negative-weighting issues that can arise in two-way fixed-effects estimators under staggered adoption.

5.3.2 Market Concentration and Competition

Our outcome variable is the Herfindahl–Hirschman Index (HHI) of credit activity within a service region, computed using accumulated released or withdrawn credits and excluding In-Lieu Fee program credits.

Tables 5 and 6 report the results. The coefficient on Post × PE Entry is negative and statistically significant across all specifications. In wetland markets, PE entry reduces the HHI by 0.030 (released) and 0.030 (withdrawn) in the most saturated specifications (Columns (3) and (6)). In stream markets, the reductions are larger (0.105 and 0.116), reflecting the stronger competitive impact in more spatially constrained markets. The persistence of the effect after conditioning on the number of incumbent banks indicates that PE entry affects competition not only through the extensive margin but also through changes in relative market shares.

Figure 8 presents event-study estimates. Pre-entry coefficients are close to zero, supporting the parallel-trends assumption. Post-entry, concentration declines persistently. The decline emerges gradually in wetland markets and more immediately in stream markets, where

geographic constraints limit the scope for gradual adjustment. The similarity of patterns across released- and withdrawn-credit measures indicates that the decline reflects sustained changes in market shares rather than transitory timing differences.

5.3.3 Entry–Exit Dynamics

To decompose the concentration decline, we examine how PE entry affects subsequent market participation. We estimate:

$$Y_{i,t} = \beta \cdot \text{PE Entry}_{i,t} + X'_{i,t}\boldsymbol{\gamma} + \alpha_i + \mu_t + \varepsilon_{i,t} \tag{6}$$

where $Y_{i,t}$ is an indicator for whether region i experiences at least one new bank entry (total, PE-backed, or non-PE-backed) or exit within five years following a bank entry event. Controls include baseline HHI, number of banks, and number of PE-backed banks; standard errors are clustered at the region level.

Table 7 reports the results. PE entry significantly increases subsequent entry by both PE-backed and non-PE-backed banks (Columns 1–3) and significantly reduces exits (Column 4). The results indicate that PE entry crowds in rather than crowds out market participants. The combination of lower concentration, higher entry, and lower exit indicates that PE entry expands effective credit supply and improves market access, though we cannot test the price prediction directly because transaction-level credit prices are not publicly available.[13]

5.4 Ecological Outcomes

Lower concentration and faster credit deployment need not imply improved ecological conditions. Under the Clean Water Act's compensatory mitigation framework, every acre of wetland destroyed must be offset by equivalent restoration within the same service area. Because both development impacts and restoration benefits occur within this regulatory boundary,

[13] Aronoff and Rafey (2025) obtain transaction-level price data for Florida wetland mitigation markets through agreements with private brokers, highlighting both the value and difficulty of obtaining credit price data in decentralized environmental markets.

the no-net-loss mandate implies that service-area ecological conditions should remain stable if the offset mechanism functions correctly. We test this null using the satellite-derived Human Influence Index (HII), a composite of population density, land use, infrastructure, and accessibility that captures landscape-level anthropogenic pressure across the entire service area (see Section 3). Because HII measures the human footprint that threatens wetland and stream integrity rather than ecological outcomes directly, it is best interpreted as capturing the development pressure that compensatory mitigation is designed to offset. HII is measured at the service-area level rather than at the bank site, making it the appropriate outcome for evaluating whether the offset mechanism neutralizes development impacts: a positive PE coefficient indicates that development pressure outpaces restoration in PE service areas.

We implement a stacked DID design analogous to equation (5). Here the unit of observation is the bank rather than the service region. The outcome variable is service-area HII in levels (Columns 1–3) and in logs (Columns 4–6); all specifications include the lagged dependent variable to absorb persistence and isolate within-bank changes. For each PE-backed bank approved from 2005 to 2020, we match each treated bank to the ten closest non-PE banks entering in the same cohort year, using a Mahalanobis distance that combines pre-entry HII level ($HII_{i,g-1}$) and three-year HII growth ($\Delta_3 HII_{i,g-1}$), each variance-normalized.[14] The estimating equation includes service-area, year, and treated-cohort fixed effects, with standard errors clustered at the service-area level. Columns 3 and 6 add interactions of the post-entry indicator with the log of initial wetland and stream credits to test whether project scale mediates the PE effect; these scale variables are discussed further in Section 5.5. We also estimate the corresponding event-study specification with the window $k \in [-5, 10]$ and $\beta_{-1} = 0$.

Table 8 reports baseline stacked-DID estimates. The interaction Post × PE Entry is positive and statistically significant across all specifications, indicating that service-area human

[14] The 2005 start date reflects the earliest cohort year with sufficient PE-backed entrants for matching; results are qualitatively unchanged when extending to 2003. We exclude In-Lieu Fee programs and conservation banks because they operate under distinct regulatory frameworks and credit methodologies (see Section 2.2).

influence rises faster in PE service areas than in matched non-PE service areas. This rejects the no-net-loss null: development pressure in the service areas PE enters outpaces the compensatory mitigation taking place within them.

The attenuation pattern across specifications is economically informative. In the level specification, adding time-varying development controls attenuates the PE coefficient by 25% (from 11.22 to 8.46, Column 1 to Column 2), consistent with PE banks selecting into areas with rising urbanization. Controlling additionally for project scale — the log of initial wetland and stream credits interacted with the post-entry indicator — produces a further 15% attenuation (from 8.46 to 7.21, Column 2 to Column 3), indicating that PE banks' larger project size accounts for a meaningful share of the remaining ecological effect. Relative to the baseline, development selection accounts for 25 percentage points and project scale for 11 percentage points of the total 36% attenuation. In the log specification, the coefficient is essentially unchanged when adding development controls alone (0.008 in both Columns 4 and 5), indicating that the *proportional* HII growth differential is robust to controlling for differential development pressure. Adding scale controls produces modest attenuation (0.008 to 0.007, Column 5 to Column 6), but the PE coefficient remains highly significant. This divergence implies that development density explains absolute HII differences across PE and non-PE service areas—the demand-selection channel—while project scale partially mediates both the absolute and proportional growth gap, a pattern consistent with the structural safeguard dilution documented in Section 5.5, though other scale-related channels may also contribute.

Following Oster (2019), we assess sensitivity to omitted variable bias using the coefficient stability approach. Because our specification includes high-dimensional fixed effects, we apply the Frisch–Waugh–Lovell residualization procedure and compute bounds on the residualized data. For the level specification (Column 3), we obtain $\delta = 1.02$ at $R_{\max} = 0.573$, exceeding the conventional threshold of $\delta = 1$. For the log specification (Column 6), $\delta = 1.01$ at $R_{\max} = 0.571$, again exceeding unity. In both cases, unobservable confounders would need

to be at least as important as the full set of observable controls — development density, bank-type indicators, and project scale — to drive the PE coefficient to zero.[15]

Figure 9 traces the dynamics. The pre-entry coefficients are close to zero, providing no evidence of differential pre-trends. Post-entry, the coefficients turn positive and increase over event time, with economically large increases emerging two to five years after entry. The two-year lag is consistent with the time required for permitted development to physically appear on the landscape. The effect accumulates rather than appearing as a one-time jump, pointing to a sustained widening of the gap in anthropogenic pressure between PE and non-PE service areas.

Appendix D examines HII at two alternative geographic scales. At the bank site—the specific restoration parcel—the PE coefficient is small and insignificant (Table D.1), consistent with restoration proceeding comparably regardless of ownership. At the HUC-8 watershed level, where treatment is defined as the first activation of any PE-backed bank in a given watershed, the coefficient remains positive and significant (Table D.2), confirming that the service-area result is not an artifact of boundary choice.

Decomposing selection and treatment. The founding-time HII result bundles two channels: PE may select into high-development-trajectory service areas (selection), and PE ownership may itself attract or facilitate additional development (treatment). We decompose these channels using the PE buyout design introduced in Section 5.2. Appendix Table D.3 reports the results: banks switching from non-PE to PE ownership show no change in service-area HII, with the Post × PE Acquisition coefficient close to zero and statistically insignificant across all four specifications (levels and logs, with and without development controls). Pre-acquisition coefficients confirm clean parallel trends. The HII divergence documented above is therefore driven overwhelmingly by *where* PE enters—high-development-trajectory

[15] We set $R_{\max}$ equal to the within-R^2 of the fully controlled specification (Column 3: $\tilde{R}^2 = 0.533$; Column 6: $\tilde{R}^2 = 0.516$) plus a margin of four to six percentage points, reflecting the limited scope for additional structured confounders after absorbing service-area, cohort, and year fixed effects. The mechanical $1.3 \times \tilde{R}^2$ rule from Oster (2019) was calibrated for cross-sectional regressions and yields implausibly high $R_{\max}$ values when applied to within-estimators where overall R^2 exceeds 0.99.

markets—rather than by *what* PE does after entry.

This decomposition has two important implications. First, the contrast with the credit release result (Figure 7) is economically informative: credit release timing is under the sponsor's direct operational control (the model's α), so PE's discount-rate advantage accelerates it immediately upon acquisition; ecological conditions, by contrast, reflect the development environment of the service area, which was largely determined by PE's entry decision and cannot be altered by a subsequent ownership change. Second, the null buyout result addresses the "induced demand" concern: if PE-backed credit supply lowered the effective cost of development permits and thereby attracted additional construction, HII would rise after a PE buyout, which it does not. The asymmetry between the two buyout results—credit release responds to PE ownership, HII does not—implies that the ecological divergence is driven by PE's strategic selection into high-development-trajectory markets. The policy-relevant question is therefore whether the regulatory framework adequately safeguards ecological integrity in the markets that PE systematically selects into, where development pressure is greatest and project scale is largest.

5.5 Mechanisms: Financial Assurance and Long-Term Management Requirements

5.5.1 Project Scale as a Mediator

The model predicts that PE's larger project scale is the root cause of safeguard dilution, which in turn weakens long-term stewardship. To test whether scale mediates the PE effect on ecological outcomes, we add the interaction of log initial wetland and stream credits with the post-entry indicator to the stacked DID specification from Table 8. Columns 3 and 6 of Table 8 report the results. In the level specification, controlling for project scale attenuates the PE coefficient by an additional 15% (from 8.46 to 7.21, Columns 2–3), beyond the 25% attenuation from development controls alone. Both scale coefficients are positive and statistically significant: the coefficient on $Post \times Ln(Wetland\ Credits)$ is 1.67 ($p < 0.01$),

and the coefficient on *Post* × *Ln(Stream Credits)* is 1.15 ($p < 0.01$), indicating that larger banks — regardless of PE status — are associated with faster service-area HII growth. In the log specification, scale controls attenuate the PE coefficient by approximately 10% (from 0.008 to 0.007, Columns 5–6), with both scale interactions again positive and highly significant. The PE coefficient remains statistically significant after controlling for scale in both specifications, indicating that scale is a partial mediator: PE's ecological impact flows partly through the scale channel but additional PE-specific factors contribute.

These results establish a link between PE's larger scale and faster-growing anthropogenic pressure in the service areas PE selects into. The next section shows that this larger scale mechanically dilutes per-credit financial assurance, identifying a structural feature of the regulatory framework that is especially consequential for the institutional-scale operators that PE represents.

5.5.2 Financial Assurance and Scale

A regulatory mechanism helps reconcile the pro-competitive and ecological findings. Prediction 3 implies that PE's larger optimal scale dilutes per-credit financial safeguards because the fixed component of assurance does not scale with project size. For mitigation bank i, we estimate:

$$Y_i = \beta\, \textit{PE-backed}_i + \mathbf{X}_i'\boldsymbol{\gamma} + \delta_s + \delta_y + \delta_t + \varepsilon_i, \tag{7}$$

where Y_i is the log of total required financial assurance (Columns 1–3) or total required long-term management funding (Columns 4–6). Controls $\mathbf{X}_i$ include indicators for stream and wetland credit types and, in Columns 3 and 6, the log of initial credits and a DOT indicator. All specifications include district, approval-year, and bank-type fixed effects; standard errors are clustered at the district level.

Table 9 reports the results. The coefficient on *PE-backed* is positive and statistically significant: PE-backed banks post approximately 63% higher total financial assurance (Column 1, $e^{0.487} - 1$) and 40% higher total long-term management funding (Column 4, $e^{0.334} - 1$)

than comparable non-PE banks. However, the elasticity of safeguards with respect to project scale — captured by the coefficient on log initial credits in Columns 3 and 6 — is approximately 0.19–0.21, far below proportionality. Because PE banks operate at systematically larger scale, per-credit financial protection is mechanically diluted: doubling project size increases total safeguards by only 14–16% ($2^{0.19} - 1$ to $2^{0.21} - 1$), implying that per-credit assurance falls by roughly 40%. This structural dilution weakens long-run stewardship incentives even as credit supply expands.

The safeguard dilution documented here helps reconcile the ecological patterns in Section 5.4. The scale attenuation test in Section 5.5.1 shows that controlling for project scale reduces the PE coefficient on service-area HII by 15% in the level specification and 10% in the log specification, and Table 9 shows that financial assurance is sublinear in scale. These findings are consistent with a pathway in which PE's larger operating scale dilutes per-credit safeguards, which in turn weakens the financial backstop against cumulative development pressure. Because the buyout evidence in Section 5.4 demonstrates that the HII divergence is selection-driven, the safeguard dilution channel operates primarily through PE's choice of *which markets to enter*—those with high development trajectories and large-scale projects. The bank-site null (Table D.1) further confirms that PE involvement does not impair on-site restoration.

The combination of front-loaded credit release (Section 5.2), faster-growing anthropogenic pressure in PE service areas (Section 5.4), scale-mediated attenuation (Table 8, Columns 3 and 6), and structurally diluted safeguards points to a regulatory framework whose financial protections were calibrated for smaller, independently operated banks and do not keep pace with institutional-scale deployment.

6 Conclusion

This paper shows that private equity entry into U.S. biodiversity offset markets accelerates credit supply and intensifies competition, but widens the intertemporal gap between

credit monetization and ecological performance. The financial safeguards meant to ensure long-term ecological performance were designed for small, independently operated mitigation banks. They contain large fixed-cost components that do not grow with project size, so per-credit protection falls as banks scale up. The service areas PE selects into, high-growth markets with strong development demand, are precisely where that gap matters most. Quantifying the net welfare effect of PE entry requires transaction-level credit price data, which are not yet publicly available. Extending the market-design frameworks developed for state-level settings (Aronoff and Rafey, 2025) to the national market is a natural next step.

More broadly, our findings speak to the expanding policy effort to mobilize private finance for nature conservation. Ownership structure is a central but largely overlooked margin in environmental market design. The interaction between investor incentives and regulatory architecture determines not only who supplies ecological offsets, but how quickly, at what scale, and with what long-run consequences. The current rules were written for a different kind of market participant, and adapting them is a first-order challenge for any market that seeks to channel private capital toward public environmental goals.

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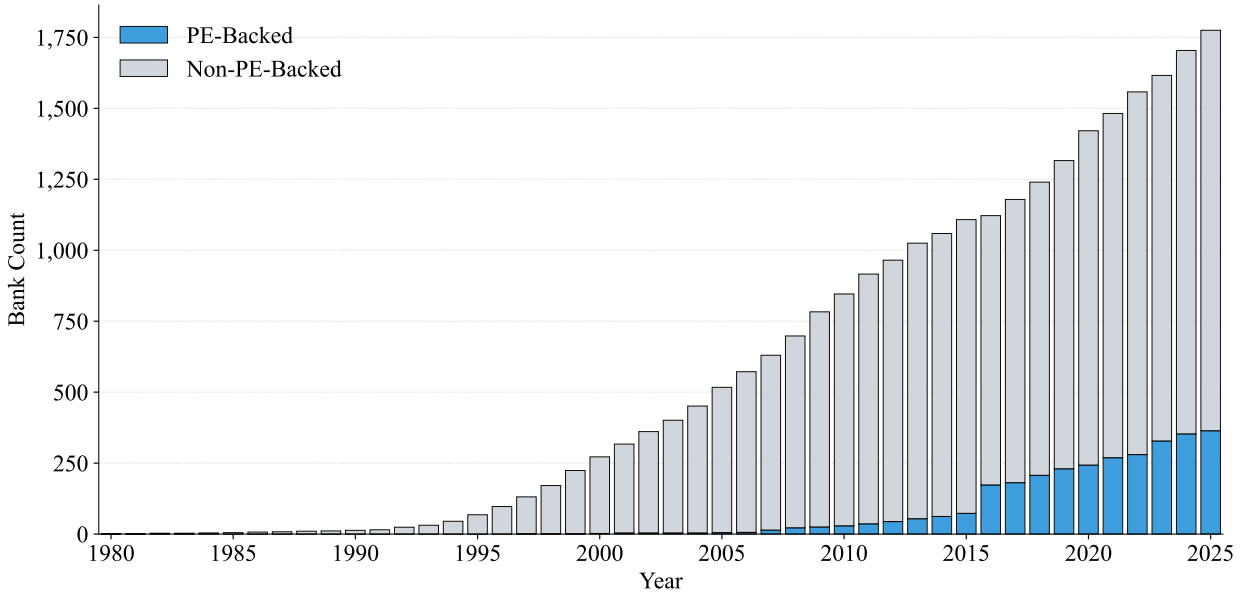
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Figure 1: **Market Overview of U.S. Mitigation Banking.**

This figure presents a market overview of U.S. mitigation banking. Panel (a) plots the annual number of active mitigation banks, separately for private-equity (PE)–backed and non-PE-backed banks. Panel (b) plots the annual number of hydrologic unit code (HUC-8) service areas covered by mitigation banks, classified as service areas covered exclusively by PE-backed banks, exclusively by non-PE-backed banks, or jointly by both.

(a) Active Mitigation Banks: PE vs. Non-PE



(b) Service Area Coverage Across HUC-8 Watersheds

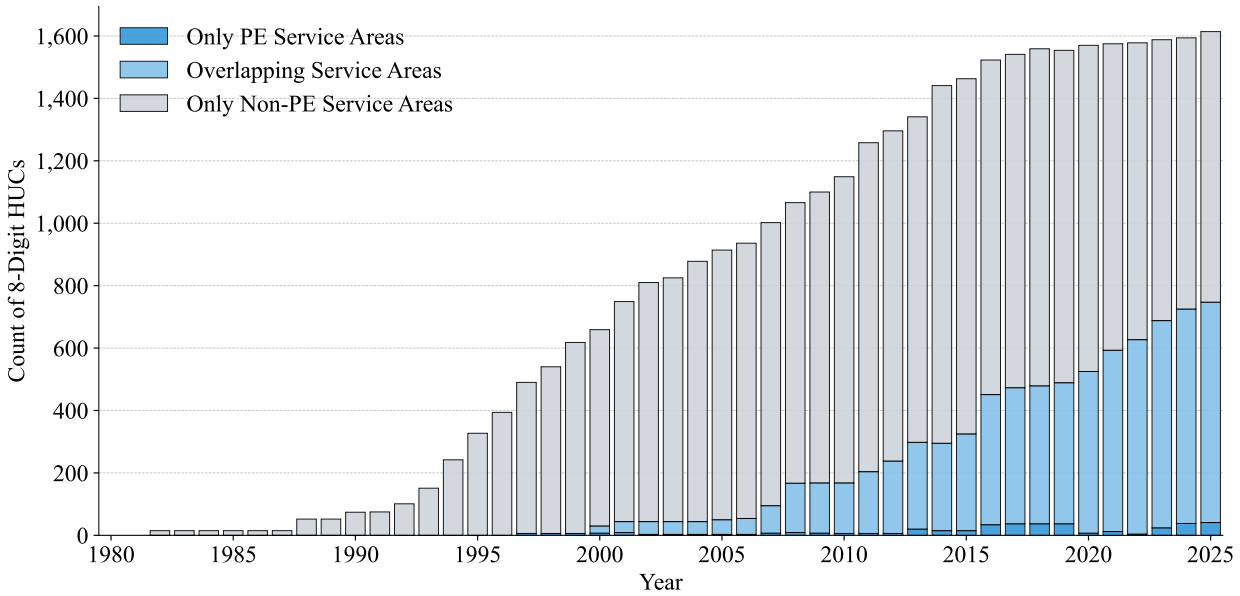
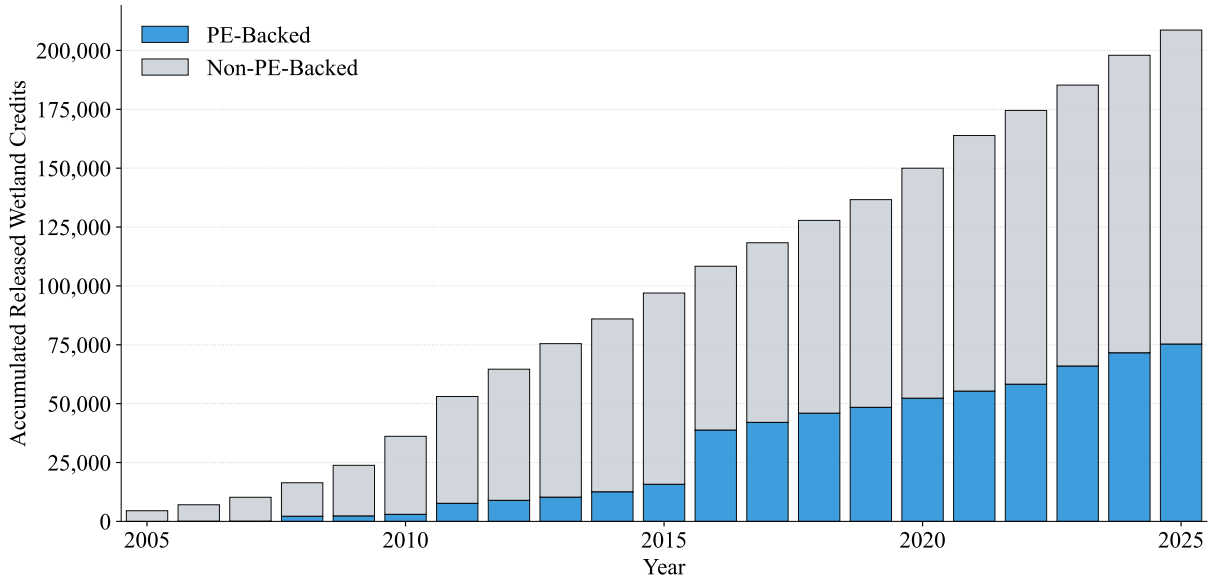


Figure 2: **Accumulated Released Mitigation Credits.**

This figure presents accumulated released mitigation credits from active banks. Panels (a) and (b) plot accumulated released wetland and stream credits, respectively, separately for private-equity (PE)–backed and non-PE-backed banks. Accumulated credits are computed as the cumulative sum of released credits in each year. All credit variables are winsorized at the 1% and 99% percentiles. Species credits are reported separately in Appendix Figure C.1.

(a) Accumulated Wetland Credits: PE vs. Non-PE



(b) Accumulated Stream Credits: PE vs. Non-PE

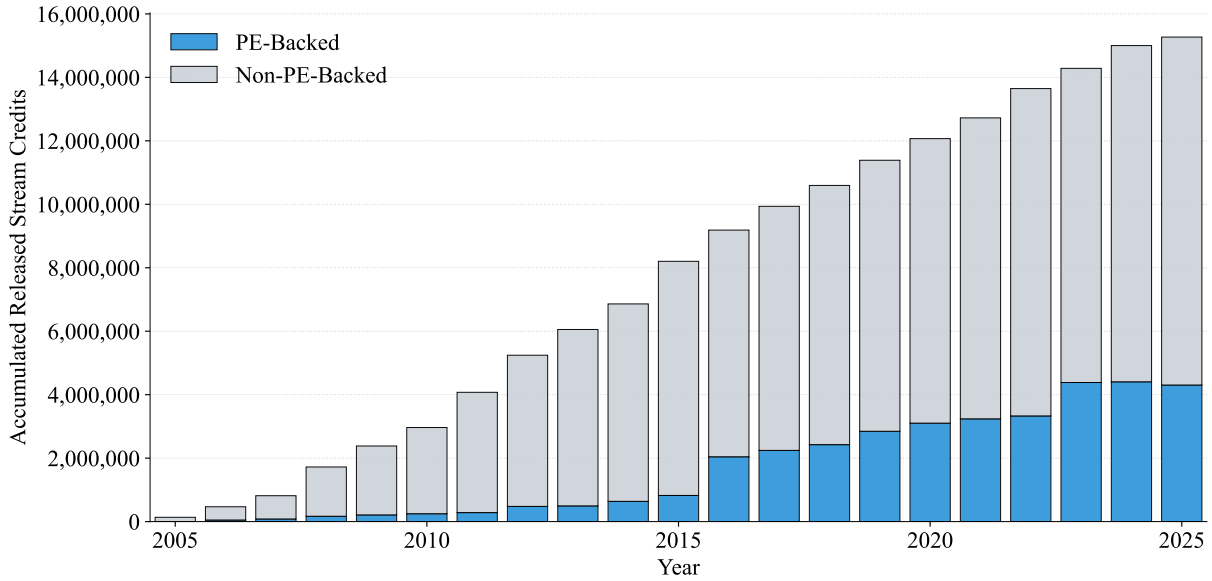


Figure 3: **Geographic Distribution of RES-Affiliated Banks Around the KKR Buyout.**

This figure plots the geographic distribution of mitigation banks affiliated with Resource Environmental Solutions (RES) before and after the KKR leveraged buyout in 2016. Points indicate the locations of RES-affiliated mitigation banks. Light-colored markers denote banks approved in or before 2016, while dark-colored markers denote banks approved after 2016.

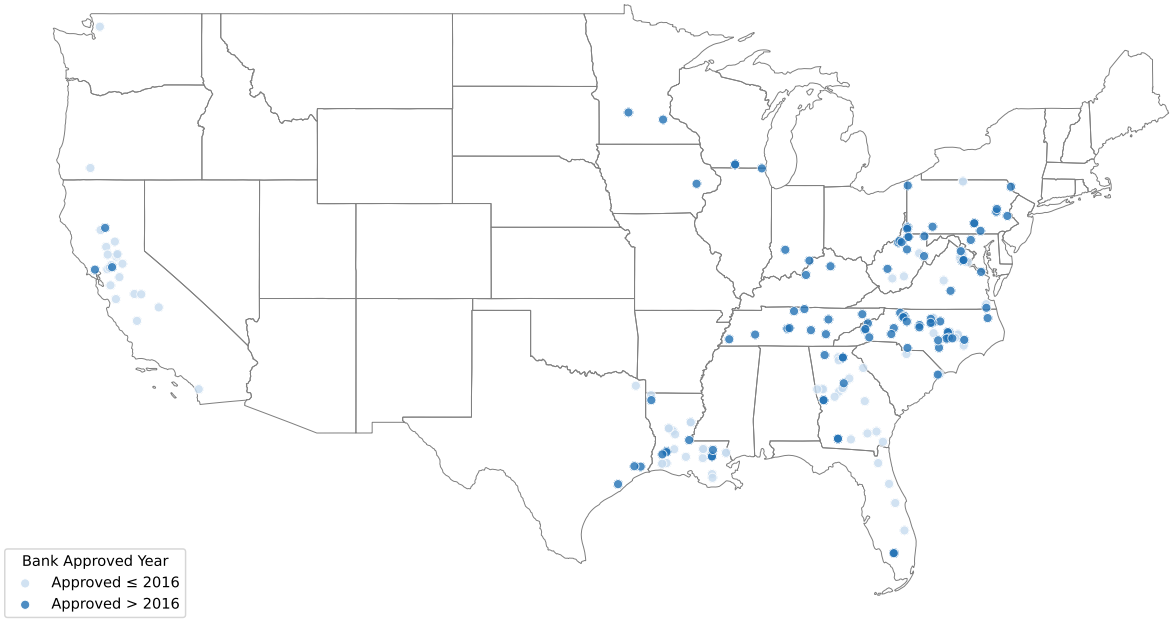
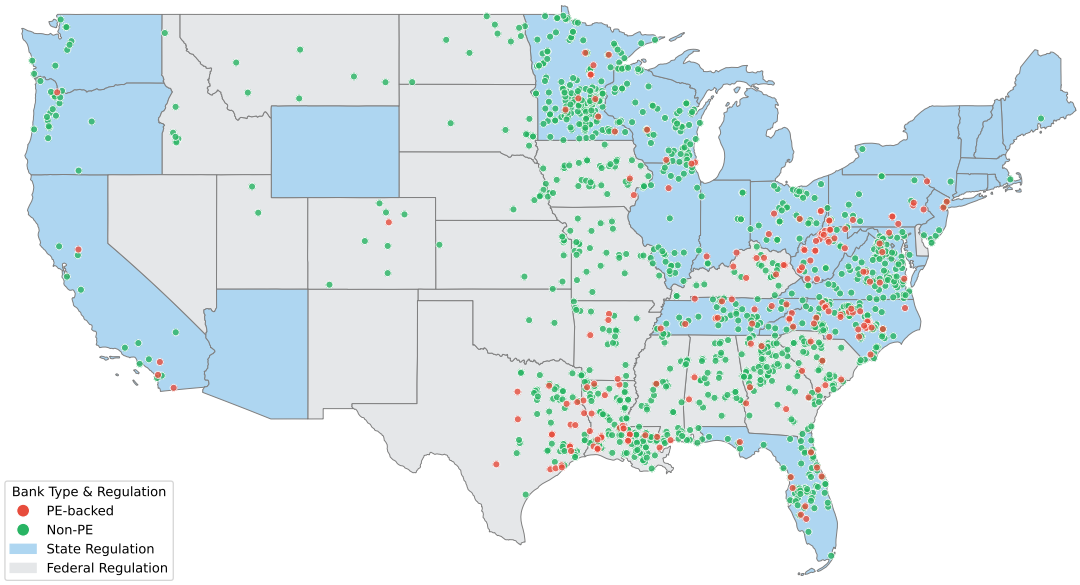


Figure 4: **Spatial Distribution of Mitigation Banks: PE vs. Non-PE**

This figure plots the distribution of PE or non-PE backed banks across the country at different times. Blue shading indicates state-regulation states (state-level programs protecting at least some non-WOTUS wetlands/waters); gray shading indicates federal-only states (no independent state dredge-and-fill permitting coverage for non-WOTUS wetlands/waters). Red points denote PE-backed banks; green points denote non-PE banks. Panel (a) shows banks established after 2005; Panel (b) shows banks established after 2020.

(a) Banks established after 2005



(b) Banks established after 2020

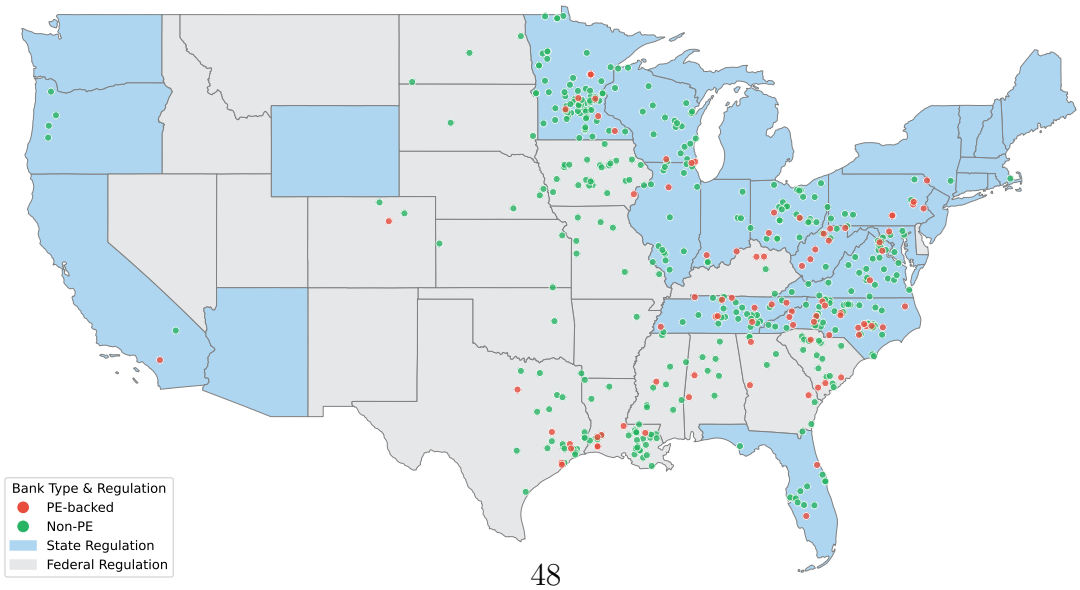


Figure 5: **Growth Trend of Mitigation Banks: State vs. Federal Regulation**

This figure plots the cumulative number of banks in different types of states and bank ownership. Blue series correspond to state-regulation states; red series correspond to federal-only states. Solid lines denote PE-backed banks; dashed lines denote non-PE banks.

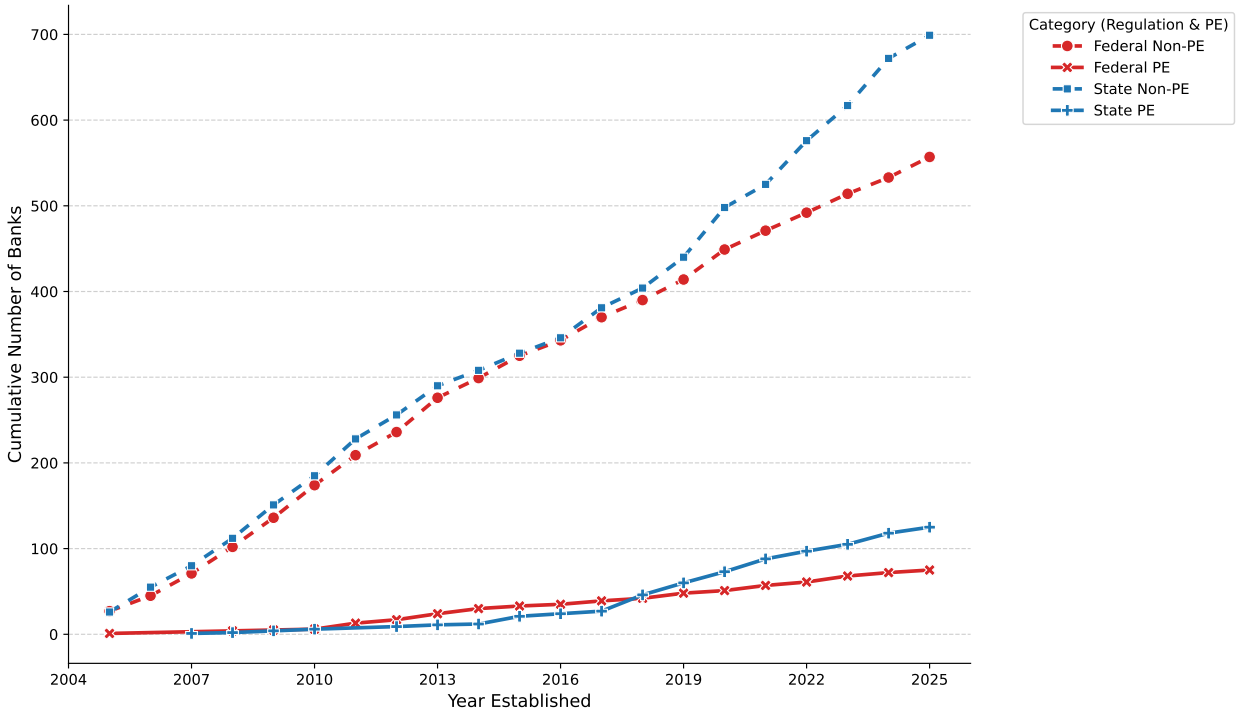
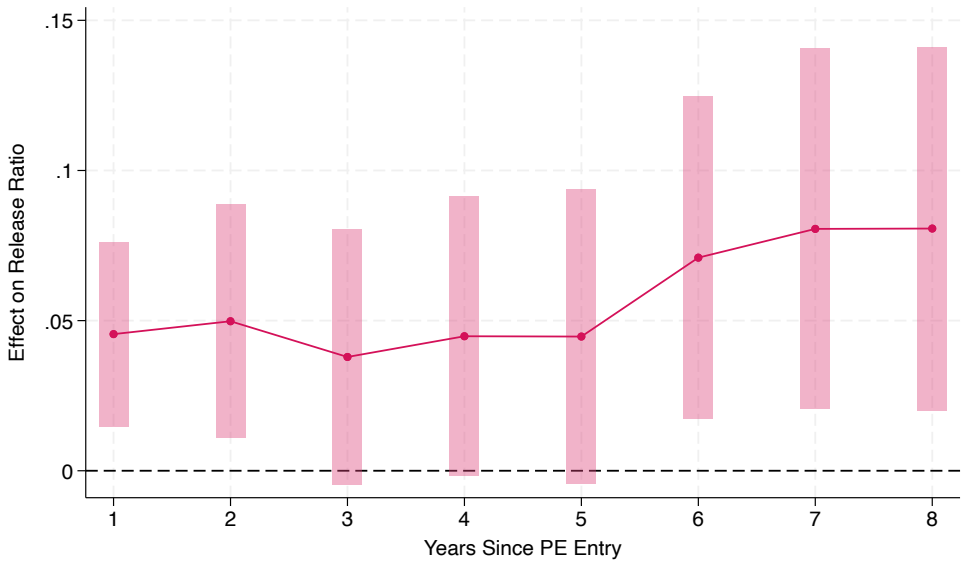


Figure 6: **Differences in Wetland and Stream Credit Release Ratios Following Bank Creation.**

This figure plots yearly differences in wetland and stream credit release ratios between private-equity (PE)–backed and non-PE-backed mitigation banks following bank creation. Panels (a) and (b) report differences in wetland credits and stream credits cumulative release ratios, respectively. The horizontal axis measures years since bank creation. Each point represents the estimated difference between PE-backed and non-PE-backed banks in a given year. Error bars represent 95% confidence intervals based on standard errors clustered at the bank level.

(a) Differences in Wetland Release Ratios



(b) Differences in Stream Release Ratios

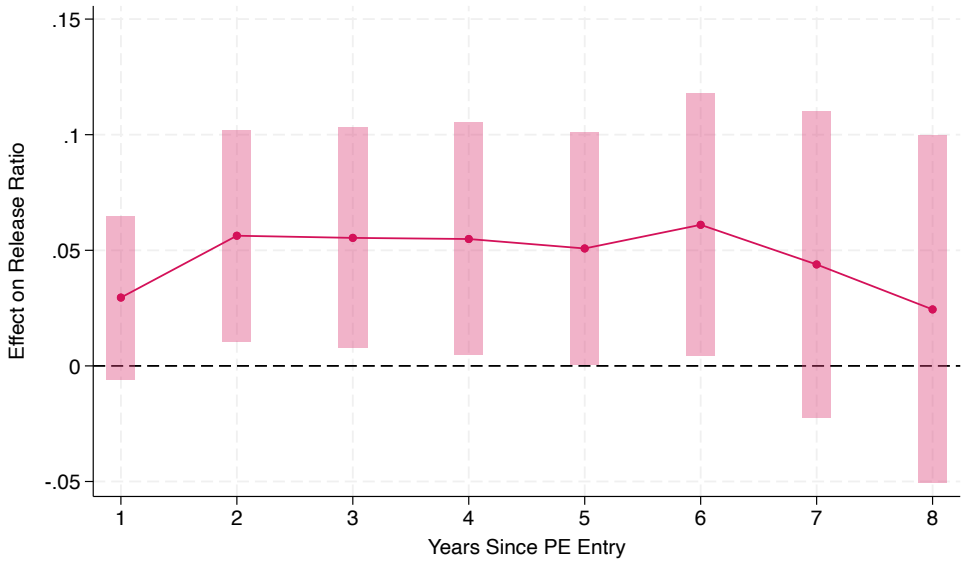


Figure 7: **Credit Release Ratio After PE Acquisition: Event Study**

This figure plots event-study estimates of the effect of PE buyout on the wetland credit release ratio using the Callaway and Sant'Anna (2021) doubly-robust difference-in-differences estimator (DRIMP with inverse probability tilting). The sample consists of 48 PE buyout banks and never-PE controls, restricted to banks with wetland credits, acquired at ages one through six, and approved from 2005 onward. Event time k is measured relative to the acquisition year, with $k = -1$ as the reference period. Covariates include the log of released wetland credits, lagged bank stock of wetland credits, the log of maximum wetland credit, and the lagged release ratio. Error bars represent 95% confidence intervals based on robust standard errors clustered at the bank level. The pre-treatment average is 0.012 (insignificant), and the post-treatment average is 0.096 ($p = 0.002$).

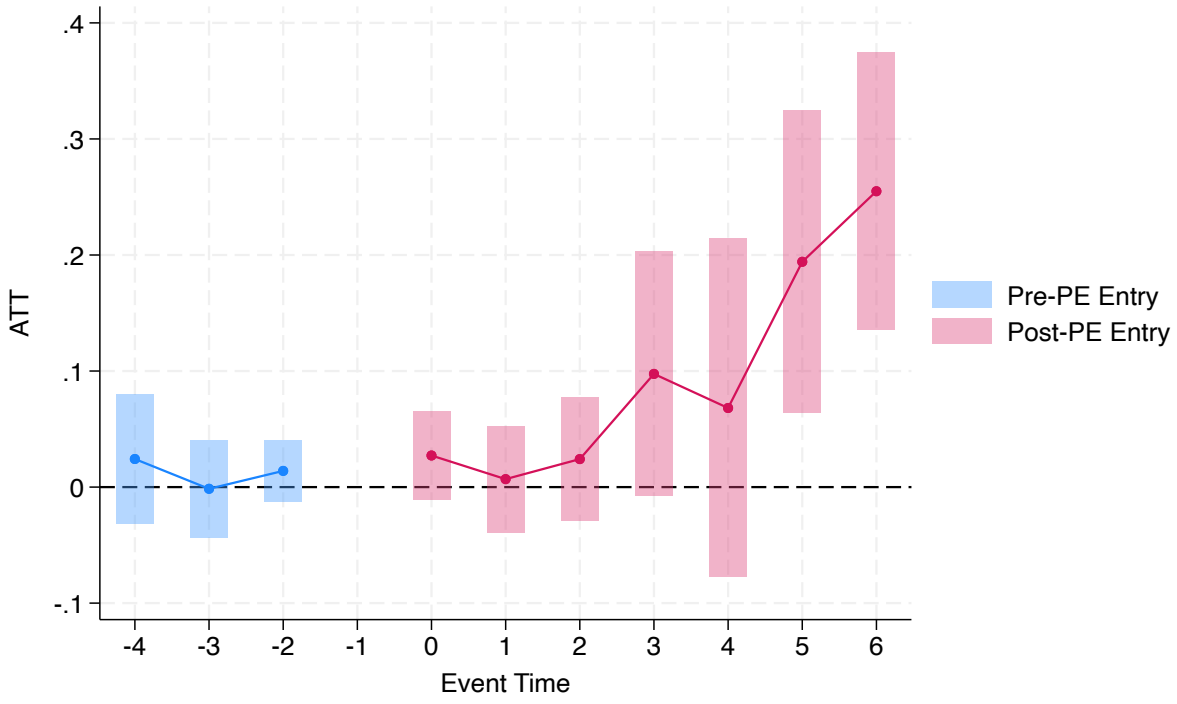
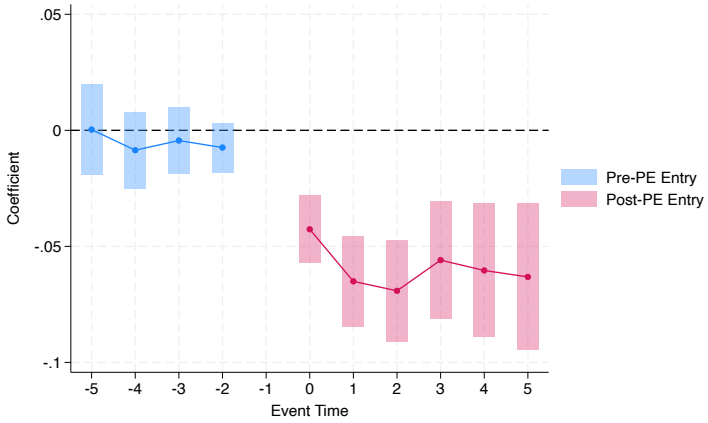


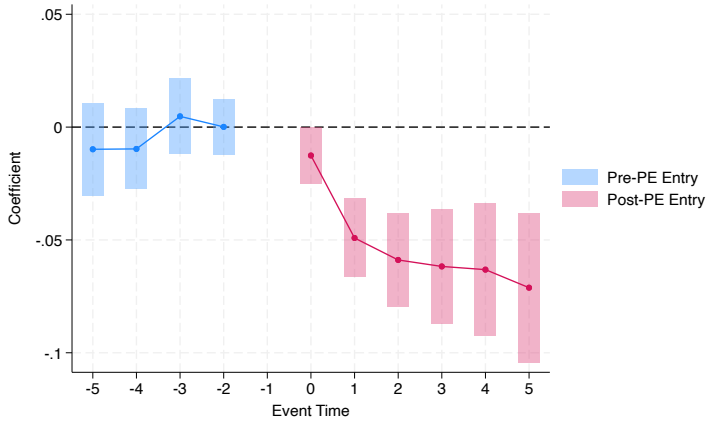
Figure 8: **Dynamic Effects of Private Equity Entry on Market Concentration**

This figure plots event-study estimates of the effects of private equity (PE) entry on market concentration, measured by the Herfindahl–Hirschman Index (HHI). Panels (a) and (b) report results for wetland mitigation banking, while Panels (c) and (d) report results for stream mitigation banking. Panels labeled "Withdrawn" construct HHIs using withdrawn credits, while panels labeled "Released" construct HHIs using released credits, respectively. Event time is defined relative to the first year of PE entry, with coefficients normalized to zero in the year immediately preceding entry ($t = -1$). Estimates are obtained from a stacked difference-in-differences design with HUC-8 fixed effects, year fixed effects, and treated-HUC fixed effects. Error bars represent 95% confidence intervals based on standard errors clustered at the HUC-8 level.

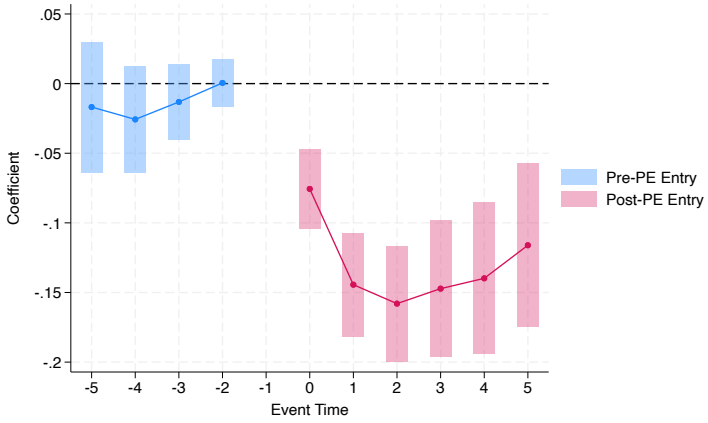
(a) Wetland Released Credit HHI



(b) Wetland Withdrawn Credit HHI



(c) Stream Released Credit HHI



(d) Stream Withdrawn Credit HHI

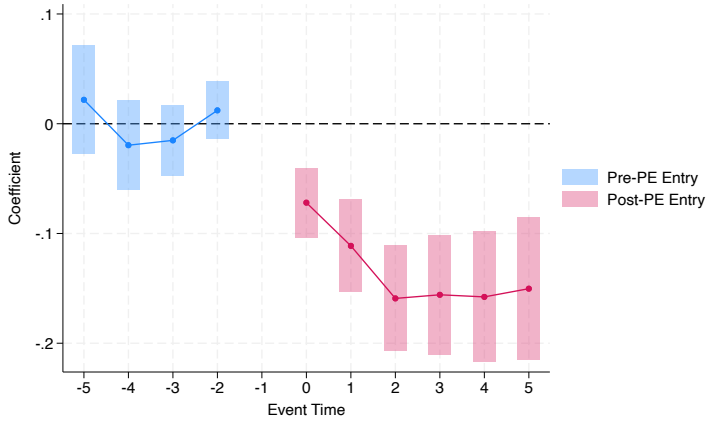
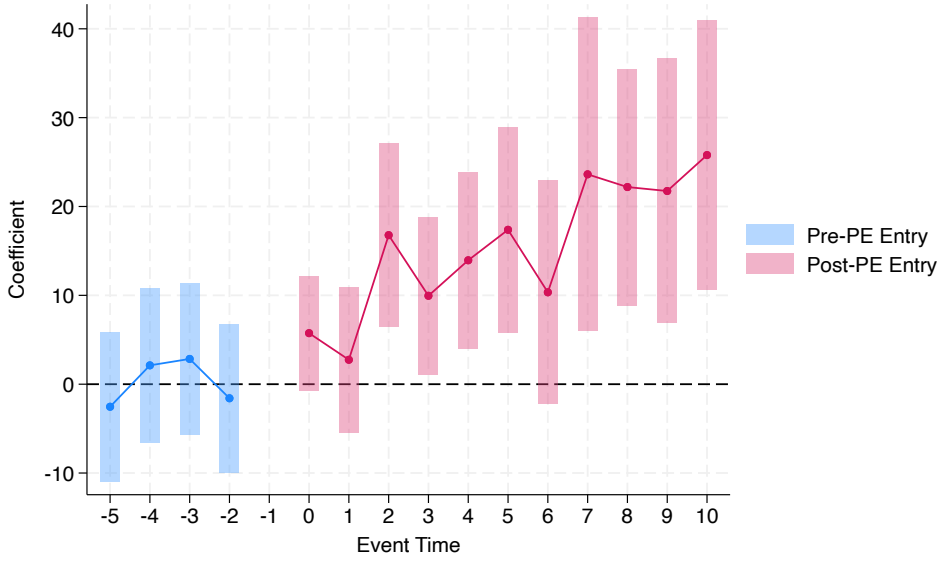


Figure 9: **Dynamic Effects of Private Equity Entry on Local Environmental Quality.**

This figure plots event-study estimates of the dynamic effects of private equity (PE) entry on local environmental quality, measured by the Human Influence Index (HII) and ln value of HII (LnHII). Event time is defined relative to the first year of PE entry, with coefficients normalized to zero in the year immediately preceding entry ($t = -1$). Estimates are obtained from a stacked difference-in-differences design with bank service area fixed effects, year fixed effects, and treated-cohort fixed effects. Error bars represent 95% confidence intervals based on standard errors clustered at the bank level.

(a) Service-Area HII (Levels)



(b) Service-Area LnHII (Logs)

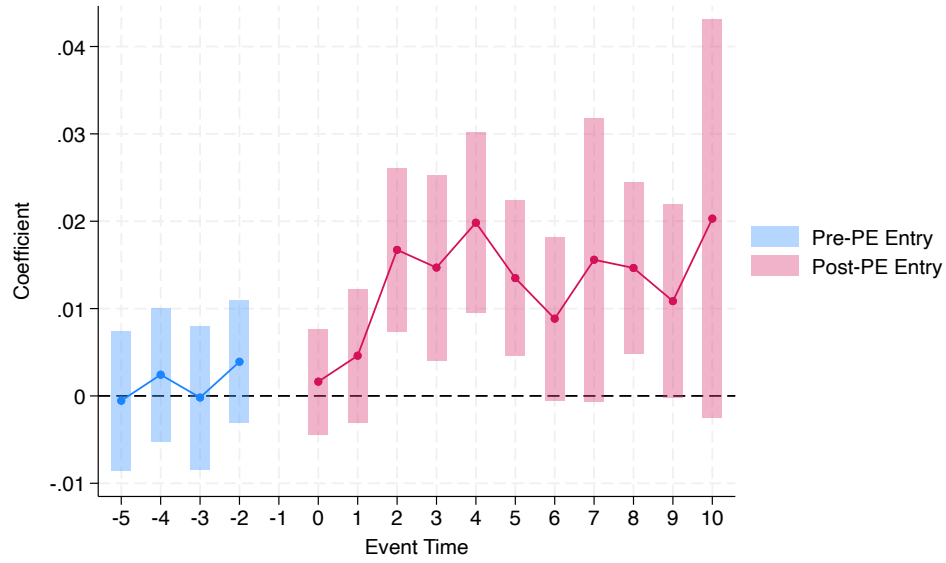


Table 1: **Descriptive Statistics**

This table reports descriptive statistics for credit quantities, bank stock measures, and market concentration. Panel A reports cumulative initial credits, released tradable credits, and withdrawn (traded) credits by ecosystem type as of 2025. Panel B reports bank stock and market concentration at the HUC-8 level, measured in the last observed year of the sample. Panel C reports HUC-PE-Year level variables used in Table 2. Panel D reports banks' time to first credit release, financial assurance, long-term management fund, and the first difference service-area Human Influence Index (HII) at bank approval. All variables in Panel A are winsorized at the 1st and 99th percentiles.

Variable	N	Mean	SD	p25	p50	p75
Panel A: Credit variables (by 2025)						
Wetland						
Initial	2,322	245.86	665.54	9.33	39.32	159.17
Released	2,322	176.11	497.88	4.48	22.39	101.08
Withdrawn	2,322	95.81	262.17	0.86	10.19	53.29
Stream						
Initial	1,158	28,152.51	53,215.89	2,836.16	7,328.37	25,877.65
Released	1,158	18,671.18	39,034.66	1,180.78	4,377.48	15,160.42
Withdrawn	1,158	11,866.92	26,807.19	0.00	1,895.05	8,834.12
Panel B: Bank stock and market concentration (HUC-8 level)						
Number of wetland banks	1,359	6.10	9.90	1.00	3.00	7.00
Number of stream banks	1,359	1.88	3.22	0.00	1.00	3.00
HHI (Released wetland)	19,366	0.57	0.34	0.26	0.50	1.00
HHI (Withdrawn wetland)	19,184	0.58	0.33	0.30	0.51	1.00
HHI (Released stream)	9,436	0.72	0.32	0.43	0.99	1.00
HHI (Withdrawn stream)	8,291	0.73	0.32	0.44	1.00	1.00
NewBank5	6,923	0.73	0.44	0.00	1.00	1.00
PENewBank5	6,923	0.16	0.37	0.00	0.00	0.00
NonPENewBank5	6,923	0.71	0.45	0.00	1.00	1.00
ExitBank5	6,923	0.21	0.41	0.00	0.00	0.00
Panel C: HUC-PE-Year Level						
PEbuildNewBank(10^{-2})	1,481,760	0.16	4.02	0.00	0.00	0.00
PE Business Involve	1,481,760	0.11	0.31	0.00	0.00	0.00
No Credit	1,481,760	0.18	0.38	0.00	0.00	0.00
Panel D: Bank variables						
InitReleaseCost	1,417	70.45	115.22	0.00	9.00	90.00
LnFA	430	12.46	1.40	11.51	12.44	13.29
LnLMF	426	11.72	1.06	11.08	11.74	12.42
HII	13,432	1,481.00	543.32	1,111.85	1,375.35	1,813.31
LnHII	13,432	7.23	0.37	7.01	7.23	7.50
Panel E: HUC–Year Level Variables						
Urban Density	42,420	0.04	0.07	0.01	0.02	0.04
Agricultural Density	42,420	0.16	0.23	0.00	0.04	0.25
Wetland Density	42,420	0.07	0.11	0.01	0.02	0.07
Δ Urban Density	40,299	0.01	0.02	0.00	0.01	0.01
Δ Wetland Density (10^{-2})	40,299	-0.01	4.20	-0.24	-0.02	0.21

Table 2: **Local PE Presence and the Probability of Mitigation Bank Entry**

This table reports the estimation of mitigation bank entry at the HUC8–year level. The dependent variable is an indicator equal to one if a private-equity-backed mitigation bank enters a given HUC-8 watershed in year t, and zero otherwise. PE Business Involve equals one if the sponsoring private equity investor had other related active business operations in the same state in year t–1. L.Number of Banks is the lagged number of existing mitigation banks in the HUC-8 area. No Credit is an indicator equal to one if no mitigation bank credit has been released in the HUC-8 area. L.HHI is the lagged Herfindahl–Hirschman Index of banks' cumulated released credit at the HUC-8 level. All specifications include private equity investor fixed effects, HUC-8 area fixed effects, and year fixed effects. The sample covers the period 2005–2025. Standard errors are clustered at the private equity investor level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) PEbuildNewBank	(2) PEbuildNewBank	(3) PEbuildNewBank
PE Business Involve	0.002***	0.002***	0.002***
	(0.001)	(0.001)	(0.001)
L.Number of Banks		-0.000	-0.000
		(0.000)	(0.000)
No Credit			0.000
			(0.001)
L.HHI			-0.000
			(0.001)
PE FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
HUC8 FE	Yes	Yes	Yes
Observations	1,481,760	1,481,760	1,481,760
Adj. R^2	0.02	0.02	0.02

Table 3: **Effect of State Regulation on PE Entry**

This table reports random-effects panel logit estimates of the effect of state-level wetland regulation on PE-backed mitigation bank entry at the HUC-8 service-area-by-year level. The dependent variable, *PE Entry*, equals one if a PE-backed mitigation bank is established in HUC-8 service area i in year t, and zero otherwise. The key regressor is *State*, an indicator equal to one if the HUC-8 service area is located in a state-regulation jurisdiction (i.e., a state with independent wetland protections extending beyond federal WOTUS coverage) and zero otherwise. We interact *State* with indicators for three federal policy periods: *Obama Era* (2016–2019), *Trump Era* (2020–2022), and *Post-2023* (2023–2025). Control variables include HUC-8 level land-cover data from MRLC/NLCD: *Urban Density* (developed land share), *Agricultural Density* (agricultural land share), and *Wetland Density* (wetland land share). Δ Developed/Wetland Area represents the annual changes in developed and wetland area shares, constructed as log yearly differences. Standard errors are clustered at the HUC-8 service-area level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) PE Entry	(2) PE Entry	(3) PE Entry
State × Obama Era	1.799***	1.801***	1.761***
	(0.208)	(0.209)	(0.211)
State × Trump Era	1.586***	1.586***	1.538***
	(0.213)	(0.214)	(0.216)
State × Post-2023	2.322***	2.325***	2.279***
	(0.257)	(0.257)	(0.260)
Urban Density		5.050***	5.104***
		(0.598)	(0.602)
Agricultural Density		-0.363*	-0.367*
		(0.212)	(0.215)
Wetland Density		2.438***	2.248***
		(0.436)	(0.453)
Δ Developed Area			3.847**
			(1.739)
Δ Wetland Area			-1.938***
			(0.581)
Observations	42,420	42,420	40,299
Service Areas	2,121	2,121	2,121

Table 4: **Time to Initial Credit Release and Private Equity Ownership**

This table reports OLS estimates of the number of days between a mitigation bank's approval date and the release of its initial-stage credits. The dependent variable is the weighted average number of days since approval. PE-backed is an indicator equal to one if the bank is affiliated with a private equity investor. Wetland and Stream are two dummy variables equal to one if this bank has wetland/stream credits. InitCredits is the natural logarithm of the value of initial mitigation credits. DOT indicates whether the project is sponsored by a Department of Transportation. Umbrella indicates whether the project belongs to the Umbrella program. All specifications include approval-year, bank-type, and USACE district fixed effects. Standard errors are clustered at the district level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) InitReleaseCost	(2) InitReleaseCost	(3) InitReleaseCost
PE-backed	-20.530**	-21.914***	-17.838**
	(8.089)	(7.942)	(8.218)
Wetland	6.177	6.901	6.934
	(8.503)	(8.585)	(8.615)
Stream	-5.428	-17.080	-15.560
	(10.856)	(18.383)	(17.968)
InitCredits		2.749	2.463
		(2.500)	(2.483)
Umbrella			-36.606***
			(13.420)
DOT			-12.186
			(24.584)
Approval Year FE	Yes	Yes	Yes
Bank Type FE	Yes	Yes	Yes
District FE	Yes	Yes	Yes
Observations	1,417	1,417	1,417
Adj. R^2	0.08	0.08	0.08

Table 5: **Effect of PE Entry on Market Concentration (Wetland)**

This table reports stacked difference-in-differences estimates of the effect of private equity (PE) entry on market concentration in wetland mitigation banking. The dependent variable is the Herfindahl–Hirschman Index (HHI) at the HUC-8 level. Columns (1)–(3) measure concentration using released credits, defined as the cumulative volume of credits authorized for sale by regulators, while Columns (4)–(6) measure concentration using withdrawn credits, defined as credits that have been sold or otherwise allocated to a permitted impact. $Post \times PEEntry$ equals one for treated HUC-8 regions in years following the first entry of a PE-backed mitigation bank. L.HHI denotes the one-year lagged Herfindahl–Hirschman Index. All specifications include HUC-8 fixed effects, year fixed effects, and treated-HUC (experiment) fixed effects. Controls in Columns 3 and 6 include: L.Urban Density (lagged percentage of developed area in the HUC-8 area), New Bank (indicator equal to one if the HUC-8 area has a new bank entry in that year), ILF (indicator for participation in an In-Lieu Fee program), and Umbrella (indicator for banks belonging to the Umbrella program). Standard errors are clustered at the HUC-8 level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	Released			Withdrawn		
	(1)	(2)	(3)	(4)	(5)	(6)
	HHI	HHI	HHI	HHI	HHI	HHI
Post × PE Entry	-0.055***	-0.036***	-0.030***	-0.045***	-0.026***	-0.030***
	(0.012)	(0.010)	(0.010)	(0.012)	(0.010)	(0.010)
Post	0.005	-0.004	-0.000	0.003	-0.010**	-0.011**
	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)	(0.004)
PE Entry	-0.018	-0.018**	-0.007	-0.018	-0.018	-0.008
	(0.012)	(0.009)	(0.008)	(0.015)	(0.012)	(0.013)
L.HHI		0.266***	0.270***		0.246***	0.241***
		(0.023)	(0.024)		(0.024)	(0.023)
Controls	No	No	Yes	No	No	Yes
HUC8 FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Treated-HUC FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,366	19,270	19,270	19,184	19,084	19,084
Adj. R^2	0.91	0.93	0.93	0.91	0.92	0.93

Table 6: **Effect of PE Entry on Market Concentration (Stream)**

This table reports stacked difference-in-differences estimates of the effect of private equity (PE) entry on market concentration in stream mitigation banking. The dependent variable is the Herfindahl–Hirschman Index (HHI) at the HUC-8 level. Columns (1)–(3) measure concentration using released credits, defined as the cumulative volume of credits authorized for sale by regulators, while Columns (4)–(6) measure concentration using withdrawn credits, defined as credits that have been sold or otherwise allocated to a permitted impact. $Post \times PEEntry$ equals one for treated HUC-8 regions in years following the first entry of a PE-backed mitigation bank. L.HHI denotes the one-year lagged Herfindahl–Hirschman Index. All specifications include HUC-8 fixed effects, year fixed effects, and treated-HUC (experiment) fixed effects. Controls in Columns 3 and 6 include: L.Urban Density (lagged percentage of developed area in the HUC-8 area), New Bank (indicator equal to one if the HUC-8 area has a new bank entry in that year), ILF (indicator for participation in an In-Lieu Fee program), and Umbrella (indicator for banks belonging to the Umbrella program). Standard errors are clustered at the HUC-8 level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	Released			Withdrawn		
	(1)	(2)	(3)	(4)	(5)	(6)
	HHI	HHI	HHI	HHI	HHI	HHI
Post × PE Entry	-0.117***	-0.109***	-0.105***	-0.125***	-0.112***	-0.116***
	(0.025)	(0.023)	(0.023)	(0.026)	(0.024)	(0.024)
Post	-0.012	-0.025***	-0.025***	-0.001	-0.019*	-0.022**
	(0.009)	(0.010)	(0.009)	(0.010)	(0.010)	(0.010)
PE Entry	0.025*	0.027**	0.027*	-0.005	0.003	0.010
	(0.015)	(0.013)	(0.014)	(0.024)	(0.021)	(0.023)
L.HHI		0.183***	0.175***		0.178***	0.179***
		(0.020)	(0.020)		(0.019)	(0.018)
Controls	No	No	Yes	No	No	Yes
HUC8 FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Treated-HUC FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9,436	9,393	9,393	8,291	8,232	8,232
Adj. R^2	0.85	0.87	0.87	0.85	0.86	0.86

Table 7: **Effect of PE Entry/Exit on Future Bank Involvement**

This table reports estimates of the effect of private-equity-backed mitigation bank entry on subsequent bank entry and exit at the HUC-8 level. The sample consists of HUC-8 watersheds experiencing the first entry of a PE-backed mitigation bank, and outcomes are measured over the subsequent five years. The dependent variable in column (1), $NewBank5$, is an indicator equal to one if any new mitigation bank enters the HUC-8 watershed within five years following PE entry. $PENewBank5$ in column (2) equals one if a new PE-backed mitigation bank enters within five years, while $NonPENewBank5$ in column (3) equals one if a non–PE-backed mitigation bank enters over the same horizon. The dependent variable in column (4), $ExitBank5$, is an indicator equal to one if a bank exits the HUC-8 watershed within five years, including withdrawal, termination, or complete sell-out. PE Entry equals one in the year a PE-backed mitigation bank first enters a HUC-8 watershed. Number of Banks is the number of mitigation banks in the HUC-8 area at PE entry time. Number of PE Banks is the number of PE-backed mitigation banks in the HUC-8 area at PE entry time. HHI denotes the Herfindahl–Hirschman Index of cumulated released credit at the time of PE entry. ILF and Umbrella are indicators for participation in an In-Lieu Fee program and an umbrella mitigation arrangement, respectively. Standard errors are clustered at the HUC-8 level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) NewBank5	(2) PENewBank5	(3) NonPENewBank5	(4) ExitBank5
PE Entry	0.054***	0.047**	0.088***	-0.047***
	(0.018)	(0.019)	(0.017)	(0.015)
Number of Banks	-0.005***	0.001	-0.004***	0.017***
	(0.001)	(0.001)	(0.001)	(0.002)
Number of PE Banks	0.013**	-0.100***	0.019**	-0.010
	(0.006)	(0.013)	(0.008)	(0.011)
HHI	0.116***	-0.079***	0.137***	-0.072***
	(0.022)	(0.020)	(0.021)	(0.018)
ILF	-0.017	-0.058**	0.016	0.016
	(0.024)	(0.027)	(0.026)	(0.030)
Umbrella	0.052*	-0.023	0.049*	0.043
	(0.029)	(0.029)	(0.029)	(0.035)
HUC8 FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	6,923	6,923	6,923	6,923
Adj. R^2	0.33	0.33	0.34	0.40

Table 8: **Environmental Impact of PE-Backed Bank Entry**

This table reports stacked difference-in-differences estimates of the effect of private-equity (PE)-backed mitigation bank entry on the Human Influence Index (HII) of a bank's service area. The sample consists of matched stacks constructed around the entry (approval) year of PE-backed banks, with each treated bank matched to the ten closest non-PE banks entering in the same year based on a Mahalanobis distance combining pre-entry HII level and three-year HII level change, each variance-normalized so that level and trajectory contribute equally to the matching distance. The dependent variable is HII in levels (Columns 1–3) and the natural logarithm of HII (Columns 4–6). *Post* × *PE Entry* captures the differential change in service-area HII for PE-backed entrants relative to matched non-PE entrants. L.HII and L.LnHII are the lagged one-year HII and its log, respectively. Controls in Columns 2–3 and 5–6 include: Developed Area Density (percentage of developed area in the service area), Post × Umbrella (interaction of the post-entry indicator with an indicator for banks belonging to the Umbrella program), and Post × DOT (interaction with an indicator for Department of Transportation-sponsored banks). *Post* × *Ln(Wetland Credits)* and *Post* × *Ln(Stream Credits)* interact the post-entry indicator with the log of initial wetland and stream mitigation credits, respectively, to capture whether project scale mediates the PE effect on ecological outcomes; these variables are included in Columns 3 and 6. All specifications include service-area fixed effects, year fixed effects, and treated-cohort fixed effects. Standard errors are clustered at the service-area level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) HII	(2) HII	(3) HII	(4) LnHII	(5) LnHII	(6) LnHII
Post × PE Entry	11.217***	8.463***	7.213**	0.008***	0.008***	0.007***
	(2.950)	(3.007)	(3.066)	(0.003)	(0.003)	(0.003)
Post	-2.298	-1.343	-11.683***	0.001	0.003	-0.007**
	(1.941)	(2.113)	(3.325)	(0.002)	(0.002)	(0.003)
L.HII	0.715***	0.648***	0.638***			
	(0.016)	(0.014)	(0.014)			
L.Ln(HII)				0.700***	0.680***	0.672***
				(0.014)	(0.013)	(0.014)
Post × Ln(Wetland Credits)			1.673***			0.002***
			(0.494)			(0.001)
Post × Ln(Stream Credits)			1.145***			0.001***
			(0.241)			(0.000)
Controls	No	Yes	Yes	No	Yes	Yes
Service-Area FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,432	13,320	13,320	13,432	13,320	13,320
Within R^2	0.532	0.529	0.532	0.523	0.513	0.516

Table 9: **Financial Assurance and Long-Term Management Fund Requirements**

This table reports cross-sectional estimates of financial assurance and long-term management fund (LMF) requirements for PE-backed and non–PE-backed mitigation banks, as specified in mitigation banking instruments (MBIs). The dependent variable in Columns (1)–(3) is the natural logarithm of total required financial assurance, and in Columns (4)–(6) is the natural logarithm of total required LMF. PE-backed is an indicator equal to one if the mitigation bank is backed by private equity investors. Stream and Wetland indicate whether this bank provides stream or wetland credits, respectively. Ln.initCredit is the natural logarithm of total initial mitigation credits, included in Columns (3) and (6) to estimate the scale elasticity of safeguards. DOT indicates whether the project is sponsored by a Department of Transportation. All specifications include district, approval-year, and bank-type fixed effects. Standard errors are clustered at the district level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Financial assurance and LMF amounts are winsorized at the 1st and 99th percentiles before taking logs.

	(1) LnFA	(2) LnFA	(3) LnFA	(4) LnLMF	(5) LnLMF	(6) LnLMF
PE-backed	0.487**	0.488**	0.387*	0.334*	0.361**	0.320*
	(0.219)	(0.207)	(0.200)	(0.178)	(0.175)	(0.164)
Stream		0.648***	-0.148		0.400**	-0.512*
		(0.213)	(0.290)		(0.153)	(0.263)
Wetland		0.130	0.406**		0.398***	0.624***
		(0.143)	(0.186)		(0.106)	(0.164)
Ln.initCredit			0.191**			0.211***
			(0.074)			(0.057)
DOT			-0.515			1.310***
			(0.498)			(0.176)
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	430	430	428	426	426	426
Adj. R^2	0.41	0.43	0.46	0.25	0.26	0.32

Table A: **Variable definitions**

Variable name	**Definition**	**Source**
Credit related variables		
InitCredits	Total number of mitigation credits that a bank is authorized to generate and eventually sell when the mitigation bank is established.	RIBITS
ReleCredits	Number of credits that have been officially "released" into the market by regulatory agencies. Only released credits are available for sale or transfer to developers needing mitigation.	RIBITS
WdrCredits	Number of credits that have been taken off the bank's available balance because they were sold, transferred, or otherwise allocated to a permitted impact project.	RIBITS
Credit Release ratio	Proportion of a mitigation bank's initial credits that have been formally released by regulators and thereby made available for sale or transfer. *Formula:* $\text{Release Ratio}_{i,t} = \min\left(\frac{\sum_{k=0}^{t} \text{ReleaseCredit}_{i,k}}{\sum_{k=0}^{T} \text{ReleaseCredit}_{i,k}}, \frac{\sum_{k=0}^{t} \text{ReleaseCredit}_{i,k}}{\sum_{k=0}^{T} \text{InitialCredit}_{i,k}}\right)$	RIBITS
Credit type	The specific category of ecological resource or habitat function that a mitigation credit represents. Credit types are classified into three categories: wetland, stream, and species. Wetland credits offset impacts to wetland ecosystems, stream credits offset impacts to flowing water systems such as rivers and streams, and species credits offset impacts to the habitat of particular species.	RIBITS
Transaction Date	The calendar date on which a specific credit activity (initialization, release, withdrawn) occurred and was recorded in the ledger as part of a credit transaction.	RIBITS
Bank-level variables		
Bank Initiation Date	The earliest recorded date associated with substantive mitigation bank activity, capturing when the bank effectively began operations. It is calculated as the minimum of the first credit-related transaction date recorded in the RIBITS ledger and the official Bank Approved Date. *Formula:* $\text{Bank Initiation Date}_i = \min\big(\min_{t \in \text{T}_i}(\text{Transaction Date}_t), \text{Bank Approved Date}_i\big)$	RIBITS

Continued on next page

Table A: **Variable definitions** (Continued)

Variable name	Definition	Source
Service HUC-8 code	The geographic region within which regulators authorize the bank to provide compensatory mitigation credits for permitted wetland or aquatic resource impacts, typically delineated by an 8-digit Hydrologic Unit Code (HUC8) watershed. A single bank may have multiple service HUC8 areas defined in its service area.	RIBITS
PE-backed	Equal to 1 if the bank is backed by private equity (PE), either because the bank was established with direct investment from PE investors or because a PE fund invested in a private company that subsequently founded the bank.	RIBITS; PitchBook
Credit-Based Bank Type	The classification of a mitigation bank according to the primary type(s) of ecological credits it generates and offers in the market. Banks are categorized based on the main resource categories of their released credits, such as Wetland banks, Stream banks, and Species-credit banks. One bank can have more than one type.	RIBITS
ILF	Equal to 1 if the mitigation bank is associated with an In-Lieu Fee (ILF) program, and 0 otherwise.	RIBITS
Umbrella	Equal to 1 if the mitigation bank is part of an Umbrella Mitigation Bank Instrument (UMBI) program, and 0 otherwise.	RIBITS
DOT	Equal to 1 if the mitigation bank is sponsored by federal or state Departments of Transportation, and 0 otherwise.	RIBITS
Conservation	Equal to 1 if the mitigation bank is a conservation bank, and 0 otherwise.	RIBITS
State	A list of the U.S. states (standard two-letter state codes) associated with a mitigation bank's service area.	RIBITS
LnFA	Natural logarithm of the value of the dollar amount of financial assurance recorded in MBI document.	RIBITS
LnLMF	Natural logarithm of the value of the dollar amount of long-term management fund recorded in MBI document.	RIBITS
LnHII	The ln value of *Human Influence Index* (HII) for a bank's primary service area, HII is a high-resolution satellite-derived measure of cumulative anthropogenic pressure on terrestrial ecosystems, developed by Venter et al. (2016).	Venter et al. (2016)

Continued on next page

Table A: **Variable definitions** (Continued)

Variable name	Definition	Source
HII	The value of *Human Influence Index* (HII) for a bank's primary service area, HII is a high-resolution satellite-derived measure of cumulative anthropogenic pressure on terrestrial ecosystems, developed by Venter et al. (2016).	Venter et al. (2016)
InitReleaseCost	The time elapsed between bank Bank initiation date and the first release of credits.	RIBITS
Region and PE investor level variables		
Bank Entry	Equal to 1 if this region has a bank entry in certian year.	RIBITS
Regional Credit HHI	The Regional Credit (release/withdrawn) Herfindahl–Hirschman Index (HHI). *Formula:* $\text{HHI}_{h,t} = \sum_{i=1}^{N} \left(\frac{\text{Credit}_{h,i,t}}{\sum_{i=1}^{N} \text{Credit}_{h,i,t}} \right)^2$	RIBITS
PE Entry	Equal to 1 if this service region has at least one PE-backed bank at certain year.	RIBITS; PitchBook
PE Business Involve	Equal to 1 if at least one private equity firm active in the HUC-8 service area has investments in construction- or real-estate-related businesses.	RIBITS; PitchBook
PEbuildNewBank	Equal to 1 if the private equity investor establishes a new bank in a certain area and in a given year.	RIBITS; PitchBook
No Credit	Equal to 1 if the HUC-8 service area has no released credits in a given year.	RIBITS
NewBank5	Equal to 1 if the HUC-8 service area records at least one new bank entry within the five-year window following the entry of a bank into the area.	RIBITS
PENewBank5	Equal to 1 if the HUC-8 service area records at least one PE-backed bank entry within the five-year window following the entry of a bank into the area.	RIBITS
NonPENewBank5	Equal to 1 if the HUC-8 service area records at least one non-PE-backed bank entry within the five-year window following the entry of a bank into the area.	RIBITS
ExitBank5	Equal to 1 if the HUC-8 service area records at least one bank exit within the five-year window following the entry of a bank into the area.	RIBITS
Number of Wetland bank	Number of banks that provide wetland offset credits in this region.	RIBITS

Continued on next page

Table A: **Variable definitions** (Continued)

Variable name	**Definition**	**Source**
Number of Stream bank	Number of banks that provide stream offset credits in this region.	RIBITS
Urban Density	Share of developed land (NLCD Classification Codes 21–24) in total HUC-8 area	MRLC/NLCD
Agricultural Density	Share of agricultural land (NLCD Classification Codes 81–82) in total HUC-8 area	MRLC/NLCD
Wetland Density	Share of wetland area (NLCD Classification Codes 90–95) in total HUC-8 area	MRLC/NLCD
Δ Urban Density	Annual log change in developed land share of the HUC-8 area, computed as $\ln(x_{it}) - \ln(x_{i,t-1})$	MRLC/NLCD
Δ Wetland Density	Annual log change in wetland land share of the HUC-8 area, computed as $\ln(x_{it}) - \ln(x_{i,t-1})$	MRLC/NLCD

Online Appendix

Private Equity and Biodiversity Offset Markets

April 28, 2026

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A Additional Institutional Background

This appendix supplements the institutional overview in Section 2 with additional detail on the legal evolution, governance structure, and crediting methodologies of the U.S. mitigation banking system. These details clarify how regulatory design transforms ecological obligations into verifiable and financeable assets.

A.1 Historical Evolution and Legal Foundation

The institutional architecture of the U.S. wetlands mitigation system developed incrementally through two landmark environmental statutes: the Clean Water Act of 1972 (CWA) and the Endangered Species Act of 1973 (ESA). Together they function as substitutes for a comprehensive biodiversity law. Under Section 404 of the CWA, the U.S. Army Corps of Engineers (USACE), in coordination with the Environmental Protection Agency (EPA), regulates the discharge of dredged or fill material into jurisdictional waters. Developers whose projects unavoidably affect wetlands or streams must compensate for these impacts by restoring or preserving equivalent habitat. A parallel offset requirement under Sections 7 and 10 of the ESA mandates mitigation for the incidental take of listed species. Although both statutes were originally designed as command-and-control regulation, they evolved into the foundation of a market-based offset system once the concept of "no net loss" of wetlands was formally adopted in 1990.

The regulatory framework was consolidated by the 2008 Compensatory Mitigation Rule, which transformed ecological mitigation into an investable asset class. The Rule established three principles that define the modern offset market. First, it created a mitigation hierarchy that prioritizes advance credits from approved mitigation banks over in-lieu fee (ILF) programs and permittee-responsible mitigation (PRM). Second, it imposed uniform ecological and procedural standards across all mitigation mechanisms, ensuring comparability and consistency across regions. Third, it codified the transfer of long-term liability from the permittee to the offset provider once credits are purchased. These elements introduced legal

clarity and verifiable performance obligations, allowing the emergence of professional mitigation bank sponsors and external investors capable of bearing long-horizon ecological and financial risks.

A.2 Governance Standards and Liability Design

Governance standards under the 2008 Rule link ecological performance to contractual accountability. Mitigation banks operate under formal instruments approved by Interagency Review Teams comprising federal and state agencies. Credits are released in stages as ecological milestones such as hydrologic restoration, vegetative establishment, and habitat functionality are verified through field inspections. This milestone-based schedule aligns revenue recognition with ecological progress and minimizes the risk of temporal loss.

The Rule enforces equivalent performance standards across private, public, and non-profit sponsors, creating a level regulatory playing field. Each sponsor must post financial assurances, secure perpetual real-estate protection (typically through conservation easements), and establish endowments for long-term management. Crucially, Section 332.3(l) codifies the transfer of liability: once credits are sold, the sponsor assumes full responsibility for the site's long-term ecological success. This provision converts environmental obligations into contractual assets and underpins the credibility of mitigation banking as a financeable system of ecological restoration.

A.3 Credit Methodologies

Credit methodologies define how ecological improvements are measured and standardized into tradable units. Each credit represents a quantified gain in ecosystem function, typically expressed in acres for wetlands or linear feet for streams, though many jurisdictions now use multi-attribute functional assessment tools to account for hydrology, vegetation, and habitat quality. The number of credits generated depends on the baseline condition, the type of ecological action (restoration, establishment, enhancement, or preservation), and the magnitude of expected functional uplift.

Service areas are delineated by hydrologic boundaries such as eight-digit Hydrologic Unit Codes (HUCs), which determine where credits can be used to offset permitted impacts. This geographic constraint ensures ecological equivalence and prevents sponsors from supplying credits that are functionally unrelated to the impacted resource. Because credit supply and demand are localized, price variation across regions reflects both ecological scarcity and regulatory enforcement intensity.

Mitigation banking instruments specify performance standards, monitoring requirements, and credit-release schedules. A small initial tranche (often 10 to 20 percent) may be released once key legal and administrative steps—such as securing site protection, posting financial assurances, and executing the mitigation instrument—are complete. Subsequent tranches are released only after independent verification of ecological milestones by the USACE and participating agencies. This staged-release mechanism aligns revenue timing with ecological achievement and reduces the risk that projects monetize unverified outcomes.

A.4 Verification Framework

Performance standards are defined ex ante and verified ex post through multi-year monitoring. Each milestone requires approval by the USACE and participating agencies, and all transactions are recorded in the publicly accessible RIBITS registry, which tracks approved, released, sold, and remaining credits in real time. These mechanisms ensure that ecological uplift precedes or closely follows permitted losses, mitigating concerns about adverse selection and unverifiable offsets.

The standardized crediting and verification framework introduced by the 2008 Rule, coupled with transparent registries and enforceable liability transfer, established the institutional credibility necessary for private finance to enter biodiversity markets. The system's strength lies in its ability to translate regulatory compliance into verifiable performance contracts, aligning ecological outcomes with financial accountability.

B A Model of Sponsor Heterogeneity in Mitigation Banking

This appendix develops a stylized model of mitigation bank entry, credit release timing, and financial safeguard adequacy. The model derives joint predictions about these outcomes from a small set of primitives: heterogeneous discount rates, differential information about local demand, and operational cost advantages. The institutional features motivating the model are documented in Section 2; the testable predictions summarized in Section 4.4 are stated here with full formalism and proved below.

B.1 Setup

Markets. There is a set of geographically segmented service areas. Each market is characterized by credit demand intensity $d > 0$, driven by local development and permitting activity; regulatory persistence $\sigma \in (0, 1]$, the probability that the regulatory framework supporting credit demand remains intact through the project's life; and supply-side regulatory maturity $\tau \in (0, 1]$, capturing how streamlined the state's permitting and milestone-verification process is for mitigation banks. There are two periods, Early ($t = 1$) and Late ($t = 2$).

Sponsors. Two types of risk-neutral sponsors, $j \in \{P, N\}$, discount period-2 cash flows by $\delta_j \in (0, 1)$ with $\delta_P < \delta_N$. PE-backed sponsors (type P) discount more steeply, a reduced-form for IRR-focused compensation: fund managers maximize carried interest above a hurdle rate within a finite fund life, so that distant cash flows contribute less to the performance metric that determines compensation (Kaplan and Strömberg, 2009). PE investors also observe local demand more precisely through portfolio companies in permitting-intensive sectors (information precision $\xi_P > \xi_N$), and have lower per-credit operational costs $c_P < c_N$, reflecting platform economies (Bernstein and Sheen, 2016).

Technology. A sponsor entering a market invests fixed cost $I > 0$, then chooses project scale $Q \geqslant 0$ and the fraction $\alpha \in [\underline{\alpha}, \bar{\alpha}]$ of credits to release early. Early-stage milestones (site protection, financial instruments, initial construction) are under the sponsor's administrative control, while later milestones depend on ecological performance verified through multi-year monitoring. In period 1, a fraction α of credits is released and sold at price d. Accelerating early milestones is costly: per-credit effort cost is $\phi_0(\alpha)/\tau$, where ϕ_0 is convex ($\phi_0' > 0$, $\phi_0'' > 0$) and higher τ reduces the administrative friction of acceleration. In period 2, the remaining $(1-\alpha)Q$ credits are released and sold at price d with probability σ, conditional on ecological performance and regulatory continuity. Scale diseconomies are captured by $\frac{\kappa}{2}Q^2$.

Safeguards. The regulator requires financial assurance $A(Q) = \bar{A} + aQ$ with fixed minimum $\bar{A} > 0$ and marginal component $a \geqslant 0$, so per-credit assurance $s(Q) = \bar{A}/Q + a$ is strictly decreasing in project scale. Larger projects therefore carry lower per-credit financial protection, a structural feature that becomes consequential when sponsors differ in optimal scale.[1]

We maintain throughout the regularity assumption that $d(1 - \delta_j\sigma) \in \big(\phi_0'(\underline{\alpha})/\tau,\, \phi_0'(\bar{\alpha})/\tau\big)$ for both types, ensuring interior solutions for α_j^*.

B.2 Sponsor's Problem

A type-j sponsor maximizes

$$V_j = -I + Q\,\Pi_j(\alpha) - \tfrac{\kappa}{2}Q^2, \qquad \Pi_j(\alpha) \equiv d\,\alpha + \delta_j\,\sigma\,d\,(1-\alpha) - c_j - \phi_0(\alpha)/\tau, \tag{B.1}$$

where Π_j is per-credit profit. Since (B.1) is separable in α and Q, the problem decomposes: the sponsor first chooses timing $\alpha_j^* = \arg\max_\alpha \Pi_j(\alpha)$, then sets scale $Q_j^* = \Pi_j^*/\kappa$, and enters if and only if $(\Pi_j^*)^2/(2\kappa) \geqslant I$. The separability means that the timing decision (how

[1] Under 33 C.F.R. §332.3(n)(2), assurance amounts must cover legal fees, mobilization, and planning costs that are largely invariant to bank scale. Lump-sum items account for roughly 42% of a representative assurance estimate (Knauer et al., 2022). See Section 2.5 for details.

aggressively to front-load credit release) is independent of project scale, and vice versa. The entry threshold links both margins to market selection: a sponsor enters only when per-credit profit at optimal timing exceeds the hurdle set by fixed costs, concentrating entry in markets with favorable demand and regulatory conditions.

B.3 Propositions

Proposition 1 (Front-loading of credit release)**.** $\alpha_P^* > \alpha_N^*$ *in every market.*

Proof. Differentiating per-credit profit $\Pi_j(\alpha)$ from (B.1) with respect to α:

$$\frac{\partial \Pi_j}{\partial \alpha} = d - \delta_j \, \sigma \, d - \frac{\phi_0'(\alpha)}{\tau} = d(1 - \delta_j \, \sigma) - \frac{\phi_0'(\alpha)}{\tau}.$$

Setting this to zero yields the first-order condition

$$d(1 - \delta_j \, \sigma) = \frac{\phi_0'(\alpha_j^*)}{\tau}. \tag{B.2}$$

The second-order condition is $\partial^2 \Pi_j / \partial \alpha^2 = -\phi_0''(\alpha)/\tau < 0$, which holds globally since $\phi_0'' > 0$ and $\tau > 0$, so the FOC characterizes a unique maximum. The regularity assumption in the setup ensures interior solutions.

Since $\delta_P < \delta_N$ and $\sigma \in (0, 1]$:

$$d(1 - \delta_P \, \sigma) \;>\; d(1 - \delta_N \, \sigma) \;>\; 0.$$

By (B.2), $\phi_0'(\alpha_P^*)/\tau > \phi_0'(\alpha_N^*)/\tau$, hence $\phi_0'(\alpha_P^*) > \phi_0'(\alpha_N^*)$. Since $\phi_0'' > 0$ implies ϕ_0' is strictly increasing, $\alpha_P^* > \alpha_N^*$. □

Proposition 2 (Strategic market selection)**.** *(a) Both types' optimal per-credit profit is increasing in demand intensity, regulatory persistence, and supply-side regulatory maturity:* $\partial \Pi_j^* / \partial d > 0$, $\partial \Pi_j^* / \partial \sigma > 0$, *and* $\partial \Pi_j^* / \partial \tau > 0$.

(b) Higher signal precision ($\xi_P > \xi_N$) *implies PE entry is more strongly correlated with*

realized d, conditional on public observables.

(c) If PE faces higher platform-level fixed costs $I_P > I_N$, its entry region is a strict subset of non-PE's, concentrated in markets with high (d, σ, τ).

(d) PE's profit is more responsive to supply-side regulatory maturity: $\partial\Pi_P^*/\partial\tau > \partial\Pi_N^*/\partial\tau$.

Proof.

Part (a). By the envelope theorem, the derivatives of $\Pi_j^* \equiv \Pi_j(\alpha_j^*)$ with respect to market parameters are evaluated holding α_j^* fixed:

$$\frac{\partial\Pi_j^*}{\partial d} = \alpha_j^* + \delta_j\,\sigma(1-\alpha_j^*) > 0, \qquad \frac{\partial\Pi_j^*}{\partial\sigma} = \delta_j\,d\,(1-\alpha_j^*) > 0, \qquad \frac{\partial\Pi_j^*}{\partial\tau} = \frac{\phi_0(\alpha_j^*)}{\tau^2} > 0.$$

All three are strictly positive given interior $\alpha_j^* \in (\underline{\alpha}, \bar{\alpha}) \subset (0,1)$ and $\delta_j, \sigma, d, \tau > 0$. Since entry requires $\Pi_j^* \geqslant \sqrt{2\kappa I}$ and $Q_j^* = \Pi_j^*/\kappa$, both the probability of entry and optimal scale are increasing in (d, σ, τ).

Part (b). Suppose type j receives signal $s_j = d + \varepsilon_j$ with $\mathrm{Var}(\varepsilon_j) = 1/\xi_j$ and ε_j independent of d. Entry requires $\mathbb{E}[d \mid s_j] \geqslant \bar{d}_j$, where $\bar{d}_j$ satisfies $\Pi_j^*(\bar{d}_j) = \sqrt{2\kappa I}$. Under normal priors, $\mathbb{E}[d \mid s_j]$ is a linear combination of the prior mean and the signal with weight $\xi_j/(\xi_j + \xi_0)$ on the signal, where ξ_0 is prior precision. Higher ξ_P makes the posterior track realized d more tightly. The conditional distribution of d given entry under precision ξ_P therefore first-order stochastically dominates the corresponding distribution under $\xi_N < \xi_P$, so PE entry is more strongly correlated with realized demand.

Part (c). Define $\mathcal{E}_j \equiv \{(d, \sigma, \tau) : \Pi_j^*(d, \sigma, \tau) \geqslant \sqrt{2\kappa I_j}\}$. With $I_P > I_N$, the threshold $\sqrt{2\kappa I_P} > \sqrt{2\kappa I_N}$. Since Π_j^* is increasing in (d, σ, τ) by part (a), each $\mathcal{E}_j$ is an upper contour set. Raising the entry threshold shrinks the entry region toward markets with high (d, σ, τ). For $I_P - I_N$ large enough to offset any level difference between Π_P^* and Π_N^*, we have $\mathcal{E}_P \subset \mathcal{E}_N$.

Part (d). From the envelope theorem, $\partial\Pi_j^*/\partial\tau = \phi_0(\alpha_j^*)/\tau^2$. By Proposition 1, $\alpha_P^* > \alpha_N^*$. Since $\phi_0' > 0$, the function ϕ_0 is strictly increasing, so $\phi_0(\alpha_P^*) > \phi_0(\alpha_N^*)$ and therefore $\partial\Pi_P^*/\partial\tau = \phi_0(\alpha_P^*)/\tau^2 > \phi_0(\alpha_N^*)/\tau^2 = \partial\Pi_N^*/\partial\tau$. □

Part (d) links supply-side selection to the discount-rate primitive without any additional assumption: PE front-loads more (Proposition 1), incurs higher acceleration costs at the optimum, and therefore benefits disproportionately when regulatory maturity reduces those costs.

Proposition 3 (Financial safeguard dilution)**.** *If the PE cost advantage satisfies*

$$c_N - c_P \;>\; d\,\sigma\,(\delta_N - \delta_P)(1-\alpha_N^*) + \big[\phi_0(\alpha_P^*) - \phi_0(\alpha_N^*)\big]/\tau, \tag{B.3}$$

then $Q_P^* > Q_N^*$ *and* $s(Q_P^*) < s(Q_N^*)$.

Proof. Expanding Π_j^* at the respective optima and subtracting:

$$\begin{aligned}\Pi_P^* - \Pi_N^* &= \big[d\,\alpha_P^* + \delta_P\,\sigma\,d\,(1-\alpha_P^*) - c_P - \phi_0(\alpha_P^*)/\tau\big] \\ &\quad - \big[d\,\alpha_N^* + \delta_N\,\sigma\,d\,(1-\alpha_N^*) - c_N - \phi_0(\alpha_N^*)/\tau\big] \\ &= (c_N - c_P) + d(\alpha_P^* - \alpha_N^*) + \sigma\,d\big[\delta_P(1-\alpha_P^*) - \delta_N(1-\alpha_N^*)\big] - \frac{\phi_0(\alpha_P^*) - \phi_0(\alpha_N^*)}{\tau}.\end{aligned} \tag{B.4}$$

To sign the period-2 revenue bracket in (B.4), add and subtract $\delta_P(1-\alpha_N^*)$:

$$\delta_P(1-\alpha_P^*) - \delta_N(1-\alpha_N^*) = -\delta_P(\alpha_P^* - \alpha_N^*) - (\delta_N - \delta_P)(1-\alpha_N^*).$$

Substituting and collecting terms:

$$\begin{aligned}\Pi_P^* - \Pi_N^* = (c_N - c_P) + \underbrace{d(\alpha_P^* - \alpha_N^*)(1-\sigma\delta_P)}_{>\,0\ \text{(front-loading gain)}} - \underbrace{d\,\sigma(\delta_N - \delta_P)(1-\alpha_N^*)}_{>\,0\ \text{(discount-rate penalty)}} \\ - \underbrace{\frac{\phi_0(\alpha_P^*) - \phi_0(\alpha_N^*)}{\tau}}_{>\,0\ \text{(acceleration cost premium)}}.\end{aligned} \tag{B.5}$$

The front-loading gain is positive because $\alpha_P^* > \alpha_N^*$ (Proposition 1) and $1 - \sigma\delta_P > 0$; it

reflects PE selling a larger share at the undiscounted period-1 price. The discount-rate penalty is positive because $\delta_N > \delta_P$; it captures PE's steeper discounting of period-2 revenue on credits that even non-PE would retain. The acceleration cost premium is positive because ϕ_0 is increasing and $\alpha_P^* > \alpha_N^*$.

Dropping the positive front-loading gain from (B.5), condition (B.3) is sufficient for $\Pi_P^* - \Pi_N^* > 0$. Since optimal scale is $Q_j^* = \Pi_j^*/\kappa$, we obtain $Q_P^* > Q_N^*$. Per-credit financial assurance is $s(Q) = \bar{A}/Q + a$, with $s'(Q) = -\bar{A}/Q^2 < 0$ since $\bar{A} > 0$, so $Q_P^* > Q_N^*$ implies $s(Q_P^*) < s(Q_N^*)$. □

The dilution is mechanical: it arises from a safeguard structure with a fixed component $\bar{A} > 0$ combined with PE's larger scale, not from PE-specific regulatory treatment. If assurance were fully proportional ($\bar{A} = 0$), $s(Q) = a$ is constant and the dilution vanishes regardless of scale.

B.4 Summary

All three propositions trace to two primitives: discount-rate heterogeneity ($\delta_P < \delta_N$) and PE's information/cost advantage ($\xi_P > \xi_N$, $c_P < c_N$). Selection and treatment are complementary manifestations of the same PE characteristics. Table B.1 maps each prediction to the corresponding empirical test.

Table B.1: Model Predictions and Empirical Tests

Proposition	**Prediction**	**Test**
1: Front-loading	$\alpha_P^* > \alpha_N^*$	Credit release event study (Section 5.2); days to initial milestone (Table 4)
2(a–c): Demand selection	PE entry ↑ in (d, σ)	Portfolio exposure predicts entry (Table 2)
2(d): Supply selection	$\partial\Pi_P^*/\partial\tau > \partial\Pi_N^*/\partial\tau$	State regulation predicts PE entry (Table 3)
3: Dilution	$s(Q_P^*) < s(Q_N^*)$	FA/credit and LMF/credit lower for PE (Table 9)

C Additional Details on Sample Construction

This appendix provides additional detail on the ownership classification procedure, the MBI financial-obligation extraction, and ecological measures described in Section 3.

C.1 Ownership Classification: Matching and Validation

The Regulatory In-lieu Fee and Bank Information Tracking System (RIBITS), maintained by the U.S. Army Corps of Engineers, serves as the central registry for the compensatory mitigation banking program. RIBITS records bank-level information on sponsor identity, service area delineation, credit generation, credit releases and withdrawals, and regulatory status, and hosts key regulatory documents including Mitigation Banking Instruments (MBIs).

Domain-based matching. For each bank in RIBITS, we extract the email domain associated with the listed sponsor or point of contact and match it to company and investor records in PitchBook through the WRDS extract. This domain-based procedure links 1,656 banks to PitchBook entities, covering approximately 34% of the full sample. We classify a bank as PE-backed if any of its matched PitchBook fields (PrimaryInvestorType, CompanyFinancingStatus, OwnershipStatus, Universe) contains terms indicating private equity involvement (e.g., "Private Equity," "PE," "PE-Backed," "Fund of Funds," or related variants), using case-insensitive matching after trimming whitespace. Sponsors with only venture capital (VC) backing and no PE involvement are excluded from the PE-backed classification, as the economic mechanisms in our framework (discount-rate heterogeneity, platform economies, IRR-driven incentives) are specific to PE ownership structures. Banks matched to PitchBook entities without PE indicators are classified as non-PE-backed.

Supplemental validation. For sponsors that cannot be matched directly through the WRDS extract, we apply a two-step supplemental procedure. First, when a sponsor email domain is available, we query the domain directly through PitchBook's web interface to

identify entities not covered in the WRDS snapshot. If the matched entity is a PE-backed firm or investor, we classify the sponsor accordingly.

Second, for remaining unmatched cases, we assess sponsor background using a large language model (LLM). The model is instructed to act as a corporate-structure analyst and to evaluate, based on publicly available information, whether the sponsoring entity is funded, controlled, or otherwise affiliated with PE investors. It adopts a conservative classification rule and defaults to a negative assessment when evidence is ambiguous. For each sponsor, the model produces a structured summary of the sponsor's role and reports dated, citable source URLs. The full prompt is reproduced below.

We then cross-check each sponsor's background using PitchBook and open-source web research. We classify PE relationships into two categories: (i) PE-controlled (control at the sponsor or parent level) and (ii) PE cooperation (co-investment, joint ventures, or strategic partnerships without control or lending). Both categories are treated as PE-backed in the empirical analysis. Sponsors identified as VC-backed only (without PE involvement) are excluded, as their ownership incentives and fund structures differ from those of PE sponsors.

By manually checking banks without email directly matched with PitchBook data, we expand our sample to 4,750 banks. Table C.1 reports the counts and percentages of PE-backed institutions by bank type. Sponsors with PE backgrounds constitute 11.24% of the sample.

After excluding banks belonging to the ILF program (which operate differently from standard mitigation banks), Table C.2 reports the distribution in the non-ILF sample. PE-backed banks constitute 17.25% of this sample. Tables C.3 and C.4 report the distribution by bank status as of 2025, with and without ILF banks.

C.2 LLM Prompt for Ownership Classification

We use ChatGPT 5 web query with the following prompt.

GPT inquiry

Subject: Mitigation bank funder — PE/VC due diligence Items: Company/Domain: XXXX — Company/Address: XXXX —Linked mitigation bank: XXXX

For each item, please:

1. Identify the company that funds/sponsors/develops or finances the mitigation bank (confirm the actual funder if different from the name provided).
2. Determine whether that company is PE/VC-controlled or owned by a PE/VC-backed platform.
3. Check for PE/VC "management links" (e.g., externally managed by a private investment adviser) and any private credit/debt involvement (loan facilities, UCC liens, credit funds).
4. Summarize the company's role with the mitigation bank (sponsor/owner/developer/creditor) and provide dated, citable sources.

Please include a 'Sources — raw URLs' section immediately after each item's results.

The prompt queries for both PE and VC involvement to cast a wide initial net. In the classification step, we retain only sponsors with PE involvement; VC-only sponsors are excluded from the PE-backed sample.

C.3 Distribution of PE-Backed Banks

C.4 MBI Financial-Obligation Extraction

To extract financial assurance and long-term management fund (LMF) requirements from MBI documents, we use GPT-5.1. Each MBI is provided to the model in its entirety, and the model is instructed to identify and return: (i) the total required financial assurance amount, (ii) the total required long-term management fund amount, (iii) the unit of measurement

Table C.1: PE-backed Banks: Matched Sample

This table reports the distribution of mitigation banks by bank type and private equity involvement. The variable *PE-backed* equals one if a bank is affiliated with a private equity investor, and zero otherwise. The final column reports the share of PE-backed banks within each bank type.

	PE-backed		=1 (%)
Bank Type	0	1	
Combination Public/Private	375	9	2.34
Private Commercial	1981	495	19.99
Private Nonprofit	484	9	1.83
Public Commercial	982	12	1.21
Single-Client	394	9	2.23
Total	4216	534	11.24

Table C.2: PE-backed Banks: Matched Sample (Excluding ILF Banks)

This table reports the distribution of mitigation banks by bank type and private equity involvement after excluding sites in the In-Lieu Fee (ILF) program. The variable *PE-backed* equals one if a bank is affiliated with a private equity investor, and zero otherwise. The final column reports the share of PE-backed banks within each bank type.

	PE-backed		=1 (%)
Bank Type	0	1	
Combination Public/Private	30	5	14.29
Private Commercial	1903	495	20.64
Private Nonprofit	46	4	8.00
Public Commercial	137	8	5.52
Single-Client	383	9	2.30
Total	2499	521	17.25

Table C.3: PE-backed Banks by Bank Status (Matched Sample)

This table reports the distribution of mitigation banks by bank status and private equity involvement. The variable *PE-backed* equals one if a bank is affiliated with a private equity investor, and zero otherwise. The final column reports the share of PE-backed banks within each bank status category.

	PE-backed		=1 (%)
Bank Status	0	1	
Approved	2337	380	13.99
Pending	514	79	13.32
Sold-Out	790	27	3.30
Suspended	33	3	8.33
Terminated	167	6	3.47
Withdrawn	375	39	9.42
Total	4216	534	11.24

Table C.4: PE-backed Banks by Bank Status (Excluding ILF Banks)

This table reports the distribution of mitigation banks by bank status and private equity involvement after excluding sites in the In-Lieu Fee (ILF) program. The variable *PE-backed* equals one if a bank is affiliated with a private equity investor, and zero otherwise. The final column reports the share of PE-backed banks within each bank status category.

	PE-backed		=1 (%)
Bank Status	0	1	
Approved	1424	371	20.67
Pending	329	78	19.16
Sold-Out	327	26	7.37
Suspended	33	3	8.33
Terminated	115	6	4.96
Withdrawn	271	37	12.01
Total	2499	521	17.25

(e.g., nominal dollars, per-acre, per-credit), and (iv) any phasing or tranche structure. The prompt is structured as follows:

GPT inquiry: MBI extraction

You are a regulatory-document analyst. Read the attached Mitigation Banking Instrument (MBI) and extract the following information:

1. Total required Financial Assurance amount (in US dollars). If multiple tranches or phases are specified, list each and report the aggregate total. 2. Total required Long-Term Management Fund amount (in US dollars). If endowment or annuity structures are described, report the capitalized amount. 3. Any qualifying language regarding conditions, triggers, or reductions tied to milestone completion.

Report "Not specified" if the document does not contain the relevant information. Do not infer amounts from other sections of the document.

When amounts are reported in nominal dollar terms, we record the stated values. If multiple tranches or phased requirements are described, we aggregate them to construct total amounts at the bank level. Documents that do not specify financial assurance or LMF amounts in extractable form are coded as missing.

Validation. We validate the extraction by independently hand-coding a random subsample of 150 MBIs drawn proportionally from PE-backed and non-PE-backed banks across all USACE districts. Two research assistants each code the financial assurance and LMF amounts from the original PDF documents. We compare the LLM-extracted values to the manually coded values at the bank level. The overall agreement rate is 94%, defined as the share of banks for which the LLM-extracted and manually verified amounts differ by less than 5% of the manually coded value. Disagreements arise primarily from documents with ambiguous phasing language or amounts embedded in tabular formats that the model occasionally misparses. All disagreements are resolved by manual review of the original document.

C.5 Land-Cover and Land-Use Data

This subsection provides additional detail on the NLCD land-cover variables introduced in Section 3. The NLCD, produced by the Multi-Resolution Land Characteristics (MRLC) Consortium, provides gridded land-cover data for the United States at a 30-meter spatial resolution. Historically, the NLCD was released at approximately two- to three-year intervals. In 2024, in collaboration with the U.S. Geological Survey (USGS), the MRLC Consortium released the first version of the Annual NLCD as part of a broader modernization effort. Leveraging advances in remote sensing, cloud computing, and machine learning, the program transitioned from periodic releases to annual land-cover products. The Annual NLCD is derived primarily from Landsat imagery, supplemented by additional satellite sources, and processed using time-series change detection algorithms and classification models to generate consistent yearly land-cover maps. The dataset adopts a modified Anderson Level II classification scheme comprising 16 land-cover classes.

We access the NLCD through Google Earth Engine and construct HUC-8-level measures by intersecting the NLCD raster data with HUC-8 watershed shapefiles and summing the corresponding land-cover areas within each polygon. The three land-cover composition variables are defined as follows:

- *Urban Density*: share of developed land (codes 21–24: Developed Open Space, Low Intensity, Medium Intensity, and High Intensity) in total HUC-8 area;
- *Agricultural Density*: share of agricultural land (codes 81–82: Pasture/Hay and Cultivated Crops) in total HUC-8 area;
- *Wetland Density*: share of wetland area (codes 90 and 95: Woody Wetlands and Emergent Herbaceous Wetlands) in total HUC-8 area.

To capture dynamic changes in land cover, we also construct two annual change variables:

- Δ *Urban Density*: annual log change in developed land share, computed as $\ln(x_{it}) - \ln(x_{i,t-1})$;
- Δ *Wetland Density*: annual log change in wetland land share, computed as $\ln(x_{it}) - \ln(x_{i,t-1})$.

These variables serve as time-varying controls in the state-regulation analysis of PE entry determinants (Section 5.1.2). The level variables control for baseline differences in land composition across watersheds, while the change variables absorb contemporaneous development pressure and wetland conversion dynamics that might otherwise confound the estimated effect of state regulatory regimes on PE entry.

C.6 Discussion of Alternative Ecological Measures

In this subsection, we provide additional detail on the three spatial-ecological indices used in our analysis: the Human Influence Index (HII), the Biodiversity Habitat Index (BHI), and the Bioclimatic Ecosystem Resilience Index (BERI). While the main text presents the HII as our primary ecological metric, here we discuss the BHI and BERI in greater depth, contrast their conceptual underpinnings and spatial-temporal characteristics, and highlight their complementarity and limitations.

Conceptual framework. The BHI focuses on habitat structural quality (intactness, fragmentation, connectivity) and serves as a closer proxy to biodiversity outcomes compared to footprint measures. The BERI assesses an ecosystem's capacity to maintain functioning under varying climatic and anthropogenic stress, capturing resilience rather than current condition. Both metrics extend the ecological lens beyond anthropogenic pressure, which is the focus of HII.

Spatial and temporal coverage. The HII is available at approximately 1 km spatial resolution on an annual or bi-annual basis for the period 2000–2020. The BHI is typically available at finer spatial resolution (e.g., 300 m to 1 km) but updated less frequently (multi-year intervals). The BERI likewise uses approximately 1 km resolution but is updated

decennially or in multi-year steps. We align all indices by resampling to a 1 km grid and, where necessary, apply linear interpolation between measurement years to generate annual values.

Operationalization. For each mitigation-bank service area and calendar year, we overlay the service-area polygon on each raster index and compute the area-weighted mean value. We standardize each index (z-score transformation) across the full sample of bank-year observations, allowing coefficient sizes in regression models to be directly compared. To minimize outlier influence, we winsorize values at the 1st and 99th percentiles. Service areas overlapping fewer than ten raster cells are excluded from robustness checks to mitigate edge-cell effects.

Complementarity and trade-offs. By adopting all three indices, our framework allows for nuanced interpretation: a decline in HII signifies reduced anthropogenic pressure; an increase in BHI signals improved habitat suitability; an increase in BERI reflects enhanced ecosystem resilience. In practice, banks might succeed in lowering human footprint (HII) without immediate gains in habitat structure (BHI) or resilience (BERI). Such divergence aligns with prior findings and informs our empirical interpretation.

Limitations. All three indices are derived from large-scale raster datasets rather than detailed field surveys; consequently, they do not capture species-level responses, wetland hydrology specifics, or fine habitat heterogeneity. Linear interpolation of coarsely updated indices (e.g., BERI) may misestimate actual dynamics. Small service areas overlapping few cells may yield less reliable index values. Most critically, these metrics are proxies for ecological change, not direct measures of biodiversity, and findings should be interpreted accordingly.

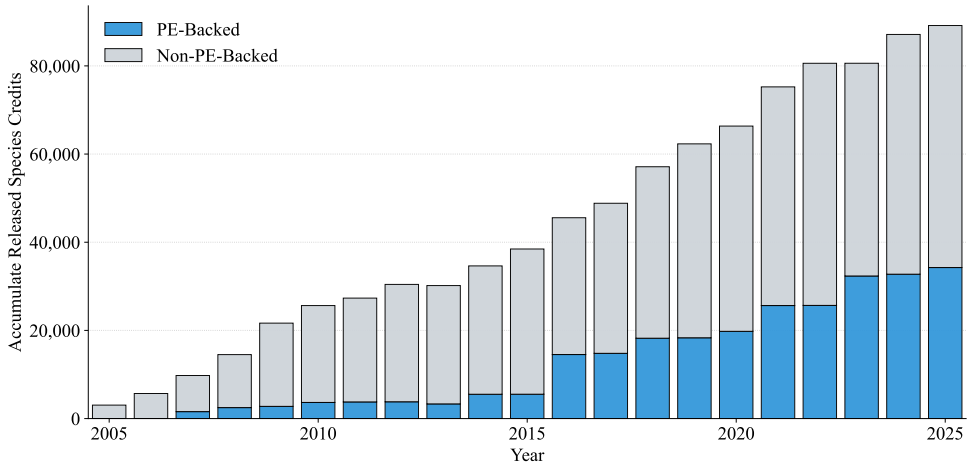
C.7 Species Credits

Our main empirical analysis focuses on wetland and stream credits issued under the Clean Water Act, excluding conservation banks that generate species habitat credits under the

Endangered Species Act (see Section 2.2). Conservation banks operate under a distinct regulatory regime with different crediting methodologies, approval processes, and ecological performance standards, and they represent fewer than 4% of all mitigation banks. We nevertheless document the distribution of species credit activity across PE-backed and non-PE-backed conservation banks for descriptive completeness. Figure C.1 plots accumulated released species credits over time, separately by ownership type. The figure shows that PE-backed conservation banks account for a non-trivial share of total species credit supply, suggesting that PE involvement in biodiversity offset markets extends beyond the CWA-regulated wetland and stream segments that form the basis of our analysis.

Figure C.1: **Accumulated Released Species Credits: PE vs. Non-PE.**

This figure plots accumulated released species credits from active conservation banks, separately for PE-backed and non-PE-backed banks. Conservation banks generate credits for impacts to endangered or threatened species habitat under the Endangered Species Act and are excluded from the main empirical analysis because they operate under a distinct regulatory regime (see Section 2.2). The figure is included for descriptive completeness. Accumulated credits are computed as the cumulative sum of released credits in each year. All credit variables are winsorized at the 1% and 99% percentiles.



D Robustness Checks

As a robustness check, we re-estimate the dynamic effects of PE entry using the multi-period difference-in-differences estimator of Callaway and Sant'Anna (2021), implemented via the Stata package *csdid2*. This approach estimates group–time average treatment ef-

fects (ATTs) for the outcome variables examined in Section 5, including market concentration (HHI) and human impact intensity (HII). Estimation is conducted using the improved doubly robust procedure (method(drimp)), which combines outcome regression and inverse-probability weighting and remains consistent if either the outcome model or the treatment model is correctly specified.

In the analysis of PE's effect on HHI, we control for the lagged log value of HHI and the lagged number of banks in the service area. These variables are also used in the inverse-probability weighting step to reweight control service areas toward those with similar pre-treatment characteristics. Standard errors are clustered at the service-area level to account for serial correlation within markets.

In the analysis of PE's effect on HII, we include the lagged value of HII as a control variable and as the covariate used in the inverse-probability weighting procedure, thereby assigning greater weight to control service areas with comparable pre-treatment levels of human activity. Standard errors are clustered at the bank level to account for within-bank serial correlation.

The resulting event-study estimates are presented in Figures D.1 and D.2. Figure D.1 reports the dynamic ATT estimates for wetland and stream credit HHI. The results closely mirror the baseline event-study estimates in Figure 8, confirming that PE entry is associated with a decline in local market concentration. Figure D.2 presents the corresponding ATT estimates for HII in banks' service areas. The dynamic pattern is broadly consistent with the baseline results in Figure 9, with effects becoming particularly large beyond event-time +5, broadly consistent with the stacked DiD baseline in Table 8. In quantitative terms, over a $(-5, +10)$ event window the aggregated pre-treatment average ATT is 4.33 (SE = 3.78, $p = 0.252$), consistent with parallel pre-trends, while the post-treatment average ATT is 38.98 (SE = 9.41, $p < 0.001$), confirming a statistically and economically significant increase in service-area human influence following PE entry.

We also report two supplementary analyses of ecological outcomes. Table D.1 estimates

the effect of PE entry on HII measured at the bank site itself rather than the service area. In contrast to the robust service-area results in Table 8, the bank-site coefficient is small and statistically insignificant across all specifications. This informative null is consistent with the hypothesis that PE involvement affects the spatial distribution of development pressure across the service area without differentially altering conditions at the bank site, where restoration activities occur regardless of ownership structure.

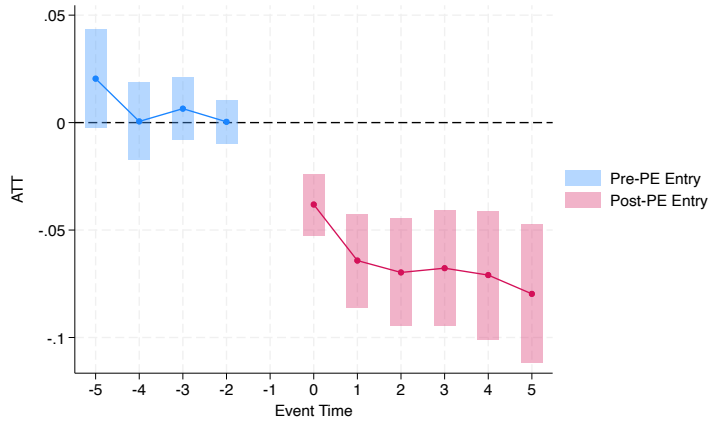
Table D.2 reports stacked difference-in-differences estimates at the HUC-8 watershed level, where the treatment is the first activation of any PE-backed bank in a given HUC-8. This specification exploits geographic variation at a broader spatial scale than the bank-level analysis. The Post × PE Entry coefficient is positive and statistically significant across all four specifications. In levels, PE involvement raises HUC-level HII by 8.8 points with the lagged dependent variable only (Column 1) and by 6.8 points with the full control set (Column 2). In logs, the proportional effect is 0.4–0.5% (Columns 3–4). These results corroborate the main service-area-level findings and confirm that PE involvement in wetland mitigation is associated with rising anthropogenic pressure at the watershed level.

Table D.3 reports a complementary test that decomposes the founding-time HII result into selection and treatment components. We exploit banks that switched from non-PE to PE ownership after founding (124 PE buyouts in the HII panel) and match each to never-PE controls using Mahalanobis distance on pre-acquisition HII level and three-year HII growth, with exact match on bank age and USACE district. The estimating equation includes bank, cohort, and year fixed effects; standard errors are clustered at the bank level. The coefficient on Post × PE Acquisition is close to zero and statistically insignificant across all four specifications: -1.54 ($p = 0.476$) and -0.82 ($p = 0.708$) in levels, and -0.000 ($p = 0.843$) and -0.001 ($p = 0.766$) in logs. The null treatment effect implies that the service-area HII divergence documented in Table 8 is driven entirely by selection (PE entering high-development-trajectory areas) rather than by PE ownership itself causing additional development.

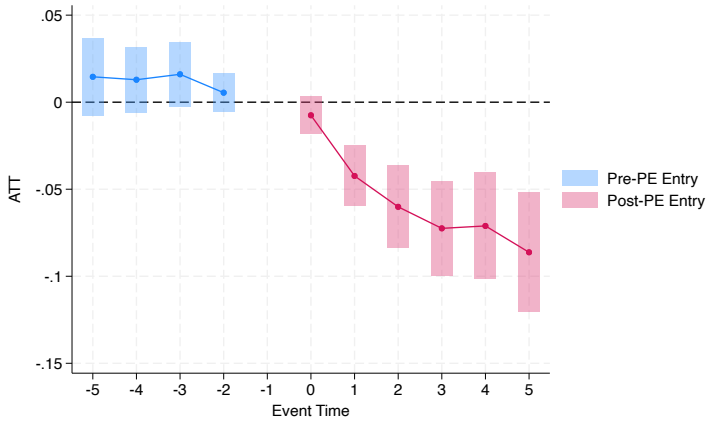
Figure D.1: **Dynamic Effects of Private Equity Entry on Market Concentration (CSDID method)**

This figure plots event-study estimates of the effects of private equity (PE) entry on market concentration, measured by the Herfindahl–Hirschman Index (HHI), using the Callaway–Sant'Anna multi-period DID estimator (CSDID). Panels (a) and (b) report results for wetland mitigation banking, while Panels (c) and (d) report results for stream mitigation banking. Panels labeled "Withdrawn" construct HHIs using withdrawn credits, while panels labeled "Released" construct HHIs using released credits, respectively. Event time is defined relative to the first year of PE entry, with coefficients normalized to zero in the year immediately preceding entry ($t = -1$). Estimates are group-time average treatment effects aggregated by event time using the doubly robust implementation (*method(drimp)*). Error bars represent 95% confidence intervals based on standard errors clustered at the HUC-8 level.

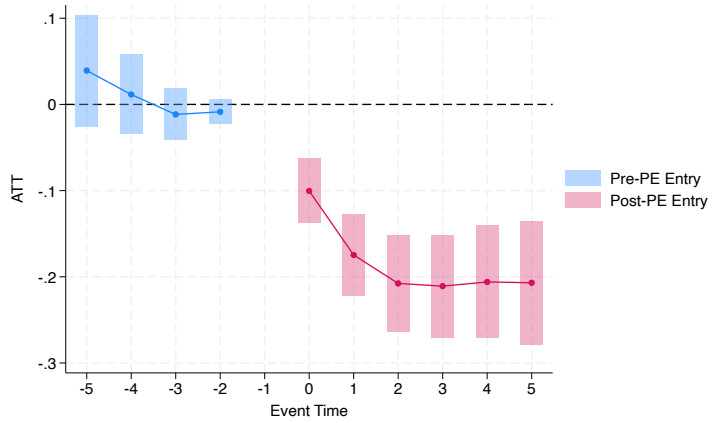
(a) Wetland Released Credit HHI



(b) Wetland Withdrawn Credit HHI



(c) Stream Released Credit HHI



(d) Stream Withdrawn Credit HHI

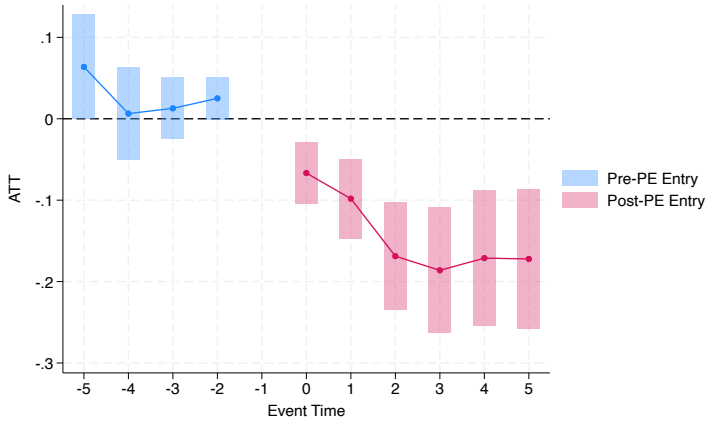


Table D.1: **Bank-Site HII: Informative Null Results**

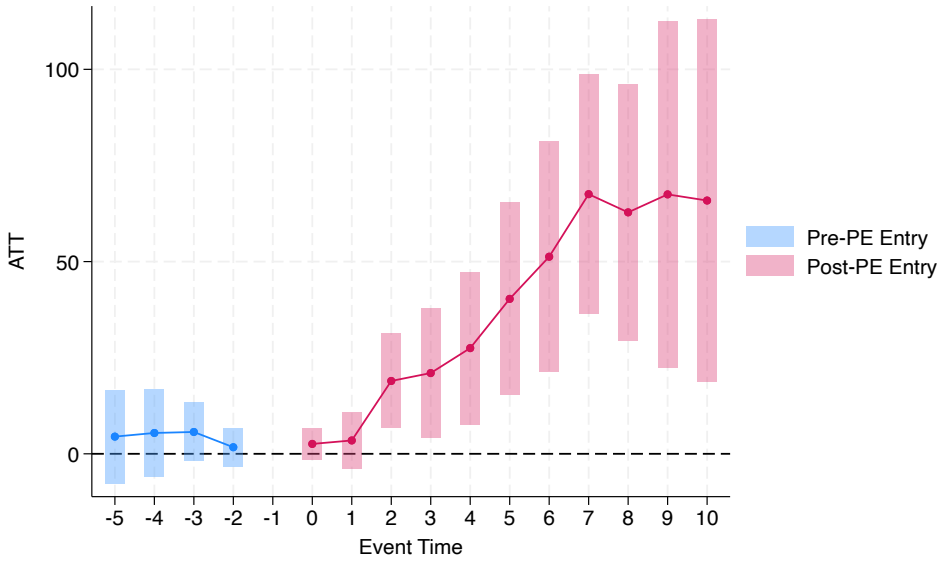
This table reports stacked difference-in-differences estimates of the effect of private-equity (PE)-backed mitigation bank entry on the Human Influence Index (HII) measured at the bank site rather than at the service-area level. The sample consists of matched stacks constructed around the entry (approval) year of PE-backed banks, with each treated bank matched to the five closest non-PE banks entering in the same year based on absolute difference in pre-entry bank-site HII. The dependent variable in Columns (1)–(2) is bank-site HII in levels; in Columns (3)–(4) it is the natural logarithm of bank-site HII. *Post* × *PE Entry* captures the differential change in bank-site HII for PE-backed entrants relative to matched non-PE entrants. All columns include the lagged dependent variable. Controls in Columns (2) and (4) include: Urban Density (percentage of developed area in the service area), Umbrella (indicator for banks belonging to the Umbrella program), and DOT (indicator for Department of Transportation-sponsored banks). All specifications include service-area fixed effects, year fixed effects, and treated-cohort fixed effects. Standard errors are clustered at the service-area level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) Bank HII	(2) Bank HII	(3) Ln(Bank HII)	(4) Ln(Bank HII)
Post × PE Entry	-0.777	-4.583	0.008	0.008
	(14.550)	(15.400)	(0.025)	(0.025)
Post	9.742	4.006	0.009	0.008
	(11.363)	(11.127)	(0.016)	(0.016)
L.Bank HII	0.666***	0.664***		
	(0.030)	(0.029)		
L.Ln(Bank HII)			0.625***	0.625***
			(0.032)	(0.032)
Controls	No	Yes	No	Yes
Service-Area FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Treated-Cohort FE	Yes	Yes	Yes	Yes
Observations	4,470	4,428	4,470	4,428
Within R^2	0.45	0.45	0.44	0.44

Figure D.2: **Dynamic Effects of Private Equity Entry on Local Environmental Quality (CSDID method).**

This figure plots event-study estimates of the dynamic effects of private equity (PE) entry on local environmental quality, measured by the Human Influence Index (HII) and ln value of HII (LnHII), using the Callaway–Sant'Anna multi-period DID estimator (CSDID). Event time is defined relative to the first year of PE entry, with coefficients normalized to zero in the year immediately preceding entry ($t = -1$). Estimates are group-time average treatment effects aggregated by event time using the doubly robust implementation (*method(drimp)*). Error bars represent 95% confidence intervals based on standard errors clustered at the bank level.

(a) Yearly Change of HII



(b) Yearly Change of LnHII

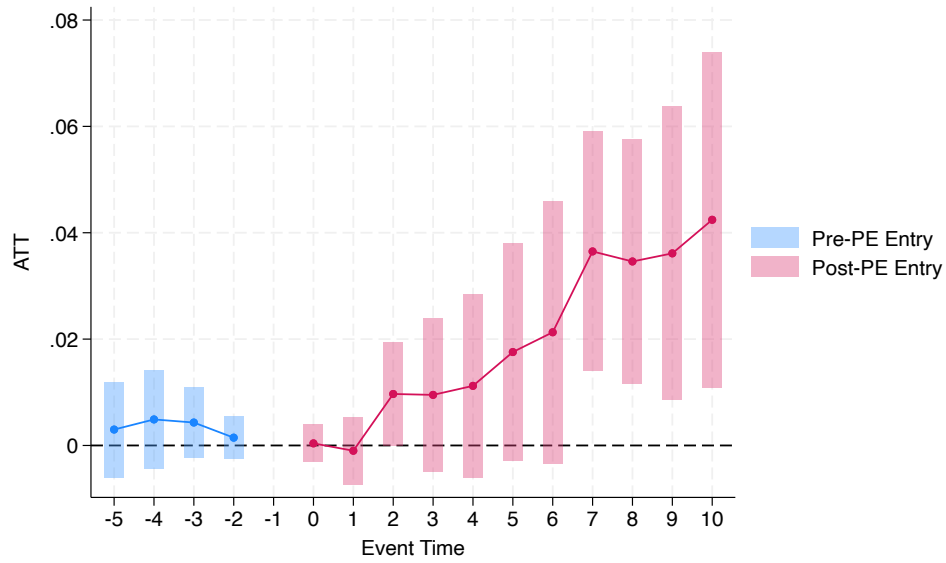


Table D.2: **HUC-Level Stacked Difference-in-Differences: Service-Area HII**

This table reports stacked difference-in-differences estimates of the effect of PE involvement on the Human Influence Index (HII) at the HUC-8 watershed level. Each treated HUC-8 (defined as the first year any PE-backed bank becomes active in the watershed) is matched to the five closest never-treated HUC-8 watersheds based on absolute difference in pre-treatment HII level. The dependent variable in Columns (1)–(2) is HII in levels; in Columns (3)–(4) it is the natural logarithm of HII. *Post* × *PE Entry* captures the differential change in HUC-level HII following PE involvement relative to matched control HUC-8s. L.HII and L.LnHII are the lagged one-year HII and its log. Columns (1) and (3) include the lagged dependent variable only. Controls in Columns (2) and (4) include: L.Urban Density (lagged percentage of developed area in the HUC-8 watershed), Bank Active (indicator equal to one if any mitigation bank is operating in the HUC-8), ILF (indicator for participation in an In-Lieu Fee program), and Umbrella (indicator for banks belonging to the Umbrella program). All specifications include HUC-8 fixed effects, year fixed effects, and treated-cohort fixed effects. Standard errors are clustered at the HUC-8 level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)
	HII	HII	LnHII	LnHII
Post × PE Entry	8.812***	6.837***	0.004**	0.005**
	(2.016)	(1.917)	(0.002)	(0.002)
Post	-0.095	0.415	0.005***	0.005***
	(1.200)	(1.211)	(0.001)	(0.001)
PE Entry	1.341	0.895	0.000	0.001
	(2.943)	(3.058)	(0.002)	(0.002)
L.HII	0.756***	0.733***		
	(.010)	(0.010)		
L.LnHII			0.785***	0.782***
			(0.005)	(0.006)
Controls	No	Yes	No	Yes
HUC8 FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Treated-Cohort FE	Yes	Yes	Yes	Yes
Observations	23,424	23,424	23,424	23,424
Within. R^2	0.56	0.57	0.61	0.62

Table D.3: **PE Buyout and Service-Area HII**

This table reports difference-in-differences estimates of the effect of PE buyout on the Human Influence Index (HII) of a bank's service area. The sample consists of banks that switched from non-PE to PE ownership after founding ("PE buyouts"), matched to never-PE control banks using Mahalanobis distance on pre-acquisition HII level and three-year HII growth, each variance-normalized, with exact match on bank age and USACE district. The dependent variable in Columns (1)–(2) is service-area HII in levels; in Columns (3)–(4) it is the natural logarithm of service-area HII. *Post* × *PE Acquisition* captures the differential change in service-area HII for PE-acquired banks relative to matched controls after the acquisition year. L.HII and L.LnHII are lagged one-year HII and its log. Controls in Columns (2) and (4) include: Urban Density (percentage of developed area in the service area). All specifications include bank fixed effects, year fixed effects, and cohort fixed effects. Standard errors are clustered at the bank level and reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) HII	(2) HII	(3) LnHII	(4) LnHII
Post × PE Acquisition	-1.538	-0.821	-0.000	-0.001
	(2.156)	(2.190)	(0.002)	(0.002)
Post	-11.312***	-11.530***	-0.009***	-0.009***
	(3.251)	(2.874)	(0.002)	(0.002)
L.HII	0.727***	0.658***		
	(0.017)	(0.020)		
L.LnHII			0.657***	0.647***
			(0.014)	(0.015)
Controls	No	Yes	No	Yes
Bank FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes
Observations	5,050	5,050	5,050	5,050
Within R^2	0.57	0.60	0.49	0.49

References Appendix

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