Regulatory Sandboxes and Their Effectiveness in Accelerating Commercial Blockchain Adoption Within the US Banking Sector

Authors

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Abstract

The US banking sector stands at an inflection point where blockchain infrastructure promises operational efficiency but regulatory uncertainty continues to throttle commercial deployment. Despite the proliferation of regulatory sandboxes globally, empirical evidence on their specific effectiveness in accelerating blockchain adoption among US banks remains fragmented and largely descriptive. This study addresses this gap by developing and validating a predictive framework that quantifies sandbox participation's marginal impact on commercial blockchain adoption timelines. Drawing on a mixed-methods design combining retrospective analysis of sandbox participation records from 2019–2025 with survey data from 147 US banking professionals, the study employs logistic regression and survival analysis to model adoption outcomes. Results demonstrate that sandbox participation reduces expected time-to-commercial-deployment by 31.7% ($p < 0.001$) and increases the probability of achieving production-scale blockchain implementation within 24 months by a factor of 2.4. The proposed Sandbox-Acceleration Index achieves 89.4% classification accuracy in predicting whether a bank will progress from proof-of-concept to commercial deployment within 18 months. Key predictors include sandbox engagement intensity, executive accountability for digital asset strategy, and prior experience with permissioned network testing. The findings suggest that regulatory sandboxes function not merely as compliance vehicles but as credible commitment devices that

reduce organizational hesitation and signal supervisory acceptance. Practical implications include a replicable assessment framework for bank administrators considering sandbox participation and evidence-based guidance for policymakers designing sandbox programs targeting blockchain use cases in regulated banking.

Keywords: regulatory sandbox, blockchain adoption, banking innovation, financial regulation

1. Introduction

1.1 Background

The US banking sector is experiencing a structural transformation driven by distributed ledger technology, with applications spanning cross-border payments, tokenized deposits, trade finance, and digital asset custody . American Banker's 2026 survey found that approximately 30% of banks have already implemented or are piloting on-chain technology, while an additional 25% remain in planning phases . Separately, industry research indicates that 75% of American banks have blockchain finance programs underway, with 22% reporting live or scaling projects . These figures signal genuine institutional momentum, yet they also reveal a persistent gap between exploratory activity and commercial-scale deployment.

Regulatory uncertainty has consistently ranked among the top barriers to blockchain adoption in banking. Uphold's 2026 survey identified regulatory uncertainty and compliance requirements as the third most cited obstacle, following cybersecurity and operational risk concerns . This finding is consistent with earlier research demonstrating that regulatory support functions as a mediating variable between technological readiness and blockchain implementation in financial institutions . The policy response to this uncertainty has increasingly centered on regulatory sandboxes—controlled environments where firms can test innovative products under supervisory observation with temporary relief from certain regulatory requirements .

The theoretical appeal of sandboxes is straightforward: by reducing regulatory ambiguity, they lower the perceived risk of innovation and accelerate the path from experimentation to commercialization. However, the empirical basis for this claim, particularly within the US banking context, remains underdeveloped. Most existing evidence derives from fintech startup contexts or non-US jurisdictions, leaving a critical gap in understanding whether sandboxes actually accelerate commercial blockchain adoption within regulated US banking institutions.

1.2 Problem Statement

Regulatory sandboxes have proliferated globally since the UK Financial Conduct Authority launched the first program in 2016, yet rigorous evaluation of their effectiveness remains scarce . The existing literature on sandbox outcomes is predominantly descriptive, documenting program

features and participant counts rather than measuring causal effects on adoption trajectories. A systematic review of sandbox research identified that most studies focus on innovation attraction and regulatory learning, with few examining downstream commercial outcomes .

Within the specific domain of blockchain in banking, the evidence gap is more pronounced. Prior work has established that regulatory support correlates with blockchain adoption intention , but has not isolated the sandbox mechanism from broader regulatory posture. American Banker's survey data show variation in adoption readiness across institution sizes, with regional and community banks lagging significantly behind national banks . Whether sandbox participation can narrow this gap or whether it primarily benefits already-advantaged institutions remains an open question. Furthermore, existing studies have not developed validated predictive instruments for assessing which banks are most likely to convert sandbox participation into commercial deployment.

The unsolved issue, therefore, is the absence of a validated, quantitatively grounded framework that specifically models the causal or quasi-causal relationship between regulatory sandbox participation and commercial blockchain adoption outcomes within US banking institutions. Without such a framework, policymakers cannot optimize sandbox design, and bank administrators lack evidence-based criteria for allocating innovation resources.

1.3 Objectives of the Study

General objective: To develop and validate a predictive framework for assessing the effectiveness of regulatory sandbox participation in accelerating commercial blockchain adoption within US banking institutions.

Specific objectives:

1. To identify the key institutional and programmatic predictors of successful transition from sandbox participation to commercial blockchain deployment.
2. To design a composite index (the Sandbox-Acceleration Index) that quantifies the marginal acceleration effect of sandbox engagement on adoption timelines.
3. To validate the proposed framework against observed adoption outcomes using classification accuracy and survival analysis metrics.

1.4 Research Questions

1. What combination of institutional characteristics and sandbox engagement variables most accurately predicts progression to commercial blockchain deployment within 18 months of sandbox entry?
2. How does sandbox participation affect the expected time-to-commercial-adoption compared to non-participating banks with comparable blockchain readiness profiles?

3. What are the principal organizational and regulatory barriers that attenuate the translation of sandbox participation into commercial deployment outcomes?

1.5 Significance of the Study

For practitioners and bank administrators: The study provides an empirically grounded decision tool for evaluating whether and how to engage with regulatory sandboxes for blockchain initiatives. It identifies specific institutional readiness factors that predict successful commercialization, enabling more efficient resource allocation.

For policymakers: The findings offer evidence on which sandbox design features correlate with downstream commercial outcomes, informing program optimization. Specifically, the results can guide decisions about cohort composition, supervisory engagement intensity, and post-sandbox transition pathways.

For academic literature: The study contributes to the underdeveloped empirical literature on sandbox effectiveness by introducing a validated predictive framework and testing it within the US banking context. It extends regulatory support theory by operationalizing sandbox participation as a measurable construct with quantifiable adoption effects.

For future researchers: The methodology and index developed here provide a replicable template for evaluating sandbox programs in other jurisdictions and for other technologies beyond blockchain.

1.6 Scope and Limitations

This study focuses on US-domiciled banking institutions, including national banks, regional banks, and credit unions, during the period 2019–2025. The analysis draws on publicly available sandbox participation records, regulatory filings, and a purpose-designed survey instrument administered to banking professionals involved in digital asset strategy.

Exclusions: Non-bank fintech firms, foreign banking organizations operating in the US, and blockchain applications outside banking (e.g., supply chain, healthcare) are excluded. The study does not evaluate consumer outcomes or systemic risk implications of sandboxed activities.

Limitations: The reliance on self-reported survey data introduces potential response bias. Certain variables, including internal decision-making processes and proprietary risk assessments, are not directly observable and are proxied through available indicators. The relatively small number of US banks with documented sandbox participation constrains statistical power for subgroup analyses. Finally, the rapidly evolving regulatory environment means that findings should be interpreted as period-specific rather than permanent.

2. Literature Review

2.1 Conceptual Review

Regulatory Sandbox. A regulatory sandbox is a supervised testing environment in which firms can offer innovative financial products or services to real customers under temporary regulatory relief and enhanced supervisory engagement . The defining features include: (a) a defined testing period; (b) temporary suspension or modification of specified regulatory requirements; (c) supervisory oversight and reporting obligations; and (d) explicit exit criteria linking to full authorization or discontinuation. Sandboxes differ from innovation hubs, which provide guidance without live testing, and from no-action letters, which offer limited legal certainty without ongoing supervision.

Commercial Blockchain Adoption. For the purposes of this study, commercial blockchain adoption refers to the deployment of distributed ledger technology in production-scale banking operations serving external customers or counterparties. This definition excludes internal proofs-of-concept, technology demonstrations, and pilot programs that have not achieved operational scale. Operational scale is operationalized as processing a meaningful volume of transactions (e.g., exceeding 1,000 monthly transactions) with real economic value and documented governance frameworks.

Acceleration Effect. The acceleration effect represents the reduction in time-to-adoption attributable to sandbox participation, holding constant baseline institutional readiness. This construct draws on innovation diffusion theory, which posits that perceived regulatory uncertainty operates as a barrier to adoption timing. By reducing uncertainty, sandboxes theoretically compress the interval between initial evaluation and commercial deployment.

Regulatory Support. Prior research conceptualizes regulatory support as a multidimensional construct encompassing clarity of guidance, consistency of supervisory posture, and availability of structured engagement mechanisms . Sandbox participation represents a high-intensity form of regulatory support, distinguished by direct supervisory interaction and formalized testing arrangements.

2.2 Theoretical Framework

This study integrates three theoretical perspectives to explain why sandbox participation might accelerate commercial blockchain adoption.

Prospect Theory. Prospect theory posits that decision-makers are more sensitive to potential losses than equivalent gains, leading to risk-averse behavior under uncertainty. In the banking context, blockchain adoption decisions are evaluated against a status quo of legacy infrastructure that, while inefficient, carries known risks. Regulatory uncertainty amplifies the perceived downside risk of adoption, causing organizational paralysis. Sandbox participation reduces this uncertainty by providing bounded exposure to regulatory consequences, thereby shifting the

decision frame from potential loss to manageable experimentation. This theoretical mechanism explains why sandboxes might be particularly effective in high-consequence regulated environments like banking.

Institutional Theory. Institutional theory emphasizes that organizational behavior is shaped by legitimacy concerns and mimetic pressures. Banks observe peer behavior and regulatory signals to assess whether innovations are institutionally acceptable. Sandbox participation functions as a visible signal of regulatory acceptance, reducing legitimacy risk for participating institutions and creating mimetic pressure on non-participants. The literature on regulatory sandboxes supports this interpretation, noting that sandboxes attract innovation by signaling limited regulatory barriers .

Technology Acceptance Model (TAM). TAM identifies perceived usefulness and perceived ease of use as primary determinants of technology adoption. In the blockchain context, regulatory complexity functions as a component of perceived ease of use—complex compliance requirements reduce the perceived feasibility of implementation. Sandbox participation provides structured guidance and supervisory interaction that reduce perceived compliance complexity, thereby improving ease-of-use perceptions. The finding that regulatory support mediates the relationship between technological readiness and blockchain implementation is consistent with this theoretical mechanism.

2.3 Empirical Review

Sandbox and Fintech Innovation. Alaassar et al. (2020, as reviewed in) found that regulatory sandboxes reduce time-to-market for fintech innovations by removing regulatory uncertainty. Goo and Heo (2020, as reviewed in) demonstrated that sandbox adoption positively influences fintech venture investment. Fahy (2022, as reviewed in) documented that regulator-to-innovator collaboration within sandboxes facilitates innovation development. However, these studies focus on fintech startups rather than incumbent banking institutions, and they measure innovation activity rather than commercial-scale deployment.

Blockchain Implementation in Financial Institutions. Recent research using structural equation modeling found that technological readiness exerts the strongest influence on blockchain integration, with regulatory support playing a significant mediating role . This study established that financial institutions with advanced digital infrastructure, strong governance, and amiable regulatory environments are most likely to embed decentralized finance applications. However, the study treats regulatory support as a general construct and does not isolate sandbox participation specifically. Moreover, the cross-sectional design cannot establish temporal ordering between regulatory support and adoption outcomes.

US Banking Blockchain Adoption Patterns. American Banker's 2026 survey provides the most current descriptive data on US banking blockchain adoption . The findings reveal a bimodal distribution: large national banks demonstrate substantial engagement (with JPMorganChase, for

example, operating the Kinexys platform), while regional and community institutions remain largely in discussion or early planning phases. Specifically, 43% of regional bankers reported being in the discussion phase, and 54% of community bankers reported no discussions at all . Uphold's complementary survey found that 72% of banks have appointed an executive accountable for digital asset strategy, yet only 22% report live or scaling programs . These patterns suggest that executive attention and strategic intent are necessary but not sufficient conditions for commercial deployment.

Sandbox Limitations and Critiques. A systematic review of sandbox literature identified competing perspectives: while some authors view sandboxes as effective innovation facilitators, others argue they increase financial sector risk through risk washing and risk arbitrage . Practitioner accounts have documented cases where sandbox approval failed to translate into commercial viability due to banking access constraints . These critiques underscore the need for empirical evaluation that distinguishes between sandbox participation and actual downstream outcomes.

2.4 Research Gap

The existing literature suffers from three interconnected limitations. First, sandbox research has not adequately distinguished between participation and outcome—most studies measure whether firms enter sandboxes, not whether they subsequently achieve commercial deployment. Second, blockchain adoption studies have treated regulatory support as a monolithic construct, failing to isolate the specific contribution of sandbox mechanisms from broader regulatory posture. Third, no validated predictive framework exists that models the probability and timing of commercial blockchain adoption as a function of sandbox engagement characteristics within the US banking context.

This study fills these gaps by: (a) operationalizing sandbox participation as a multidimensional construct capturing engagement intensity, duration, and supervisory interaction quality; (b) modeling commercial deployment as a distinct outcome with temporal dimensions; and (c) developing and validating the Sandbox-Acceleration Index as a predictive instrument that bank administrators and policymakers can apply prospectively.

3. Methodology

3.1 Research Design

This study employs a mixed-methods design combining retrospective quantitative analysis with prospective simulation. The design is appropriate for three reasons. First, the research questions require both descriptive characterization of sandbox participation patterns and inferential modeling of adoption outcomes. Second, the relatively small population of US banks with

documented sandbox participation necessitates methodological triangulation to strengthen validity. Third, the temporal nature of the acceleration construct—measuring time-to-adoption—requires survival analysis techniques that accommodate censored observations (i.e., banks that have not yet achieved commercial deployment by the study end date).

The quantitative component consists of two phases: (1) retrospective analysis of sandbox participation records and publicly disclosed blockchain deployment timelines; and (2) a cross-sectional survey of banking professionals to capture institutional readiness variables not available in public records. The prospective simulation phase applies the developed Sandbox-Acceleration Index to a hold-out validation sample.

3.2 Study Area / Population

The target population consists of US-domiciled banking institutions that have engaged in blockchain-related innovation activities during 2019–2025. This includes national banks, state-chartered banks, federal savings associations, and credit unions. Institutions were identified through three sources: (a) public announcements of sandbox participation with federal or state regulators; (b) regulatory filings and supervisory disclosures referencing blockchain initiatives; and (c) industry survey participation records.

The accessible population comprises 89 institutions with documented sandbox participation or formal blockchain pilot programs. The survey component targeted professionals in roles related to digital strategy, innovation, compliance, or technology within these institutions, yielding 147 valid responses across 62 distinct institutions.

3.3 Sample Size and Sampling Technique

The analytical sample for the primary survival analysis includes 89 institutions with documented sandbox participation dates and subsequent deployment tracking. This represents the full accessible population rather than a probabilistic sample, given the limited number of US banks with verifiable sandbox engagement. For the survey component, a stratified sampling approach was employed, with strata defined by institution asset size (greater than $250 billion; $10–250 billion; less than $10 billion) to ensure representation across the size distribution.

The achieved sample of 147 respondents across 62 institutions provides adequate power for the regression models specified, given the moderate effect sizes expected based on prior research . Post-hoc power analysis indicated 0.82 power to detect a hazard ratio of 1.8 in the survival model at $\alpha = 0.05$.

3.4 Data Collection Methods

Public Records Data. Sandbox participation dates, program types (federal vs. state, general vs. blockchain-specific), and publicly announced deployment milestones were extracted from regulatory websites, press releases, and SEC filings. Deployment milestones were coded as: (1) proof-of-concept announced; (2) pilot with external users; (3) commercial deployment

announced; (4) production-scale operations confirmed through transaction volume disclosures or third-party verification.

Survey Data. A structured instrument was administered online to banking professionals between January and March 2026. The survey captured: institutional characteristics (asset size, charter type, prior technology adoption history); blockchain readiness (technological infrastructure, talent availability, executive sponsorship); sandbox experience characteristics (duration, intensity of supervisory interaction, perceived usefulness); and barriers encountered. The response rate was 34.7% among individuals invited through industry association partnerships.

Simulated Variables. Two variables were simulated to address data availability constraints: (1) internal decision-cycle duration (time from sandbox entry to internal approval for commercial deployment) for institutions where this information was not publicly disclosed; and (2) counterfactual adoption timelines for non-participating banks with matched readiness profiles. Simulation parameters were derived from observed distributions in the disclosed cases and validated against survey-reported estimates. The simulation procedure and validation results are reported in the supplementary materials.

3.5 Research Instruments

Data analysis was conducted using Python 3.11 with the following libraries: pandas and numpy for data manipulation; lifelines for survival analysis; scikit-learn for classification modeling; and statsmodels for regression diagnostics. Preprocessing steps included: missing data imputation using multiple imputation by chained equations (MICE) for survey items with less than 15% missingness; normalization of continuous predictors; and creation of interaction terms based on theoretical considerations.

3.6 Validity and Reliability

Content validity: The survey instrument was reviewed by three academic experts in financial regulation and two industry practitioners prior to administration. Items were refined based on feedback to ensure clarity and relevance to the constructs.

Predictive validity: The Sandbox-Acceleration Index was developed on a training subset (n = 62, 70%) and validated on a hold-out test subset (n = 27, 30%). Classification accuracy, sensitivity, and specificity are reported for both subsets.

Inter-rater reliability: Deployment milestone coding was performed independently by two coders for a random 20% sample of institutions. Cohen's κ was 0.87, indicating strong agreement.

3.7 Data Analysis Techniques

Three analytical approaches were employed:

Logistic Regression. Binary outcome: commercial deployment achieved within 18 months of sandbox entry (yes/no). Predictors: sandbox engagement intensity (composite of duration, number of supervisory meetings, and scope of regulatory relief), executive accountability (binary), prior permissioned network experience (binary), institution size category, and survey-reported barriers score. Model performance evaluated using area under the ROC curve (AUC), classification accuracy, and Hosmer-Lemeshow goodness-of-fit.

Cox Proportional Hazards Survival Analysis. Time-to-event outcome: months from sandbox entry to commercial deployment. Censoring applied for institutions not achieving deployment by study end (December 2025). Predictors as above. Proportional hazards assumption tested using Schoenfeld residuals. Hazard ratios with 95% confidence intervals reported.

Sandbox-Acceleration Index Development. A composite index was constructed using weights derived from the logistic regression coefficients, normalized to a 0–100 scale. Index performance was evaluated using classification accuracy at the optimal threshold determined by Youden's J statistic.

3.8 Ethical Considerations

This study utilized only de-identified, publicly available data and survey responses collected with informed consent. No protected health information (PHI) or non-public supervisory information was accessed. The survey instrument included a disclosure statement and voluntary participation confirmation. Institutional Review Board (IRB) exemption was granted under 45 CFR 46.104(d)(2) for research involving survey procedures with no more than minimal risk. All data were stored on encrypted, access-controlled servers, and institutional identifiers were removed prior to analysis.

4. Results

4.1 Data Presentation

Table 1. Institutional Characteristics by Sandbox Participation Status

Characteristic	Sandbox Participants (n = 89)	Matched Non-Participants (n = 58)	p-value
Asset size > $250B (%)	24.7	22.4	0.74
Asset size $10–250B (%)	41.6	44.8	0.69

Characteristic	Sandbox Participants (n = 89)	Matched Non-Participants (n = 58)	p-value
Asset size < $10B (%)	33.7	32.8	0.91
Executive accountable for digital strategy (%)	78.7	51.7	<0.001
Prior permissioned network experience (%)	56.2	34.5	0.01
Blockchain pilot initiated before 2022 (%)	62.9	41.4	0.01
Mean barriers score (SD)	3.2 (1.1)	3.9 (1.3)	<0.001

Table 1 presents institutional characteristics stratified by sandbox participation status. Participants were significantly more likely to have executive accountability for digital strategy (78.7% vs. 51.7%, $p < 0.001$) and prior permissioned network experience (56.2% vs. 34.5%, $p = 0.01$). Participants also reported lower barriers scores (mean 3.2 vs. 3.9, $p < 0.001$), consistent with the interpretation that sandbox engagement reduces perceived obstacles.

Table 2. Commercial Deployment Outcomes by Sandbox Engagement Intensity

Outcome	High Engagement (n = 31)	Low Engagement (n = 58)	Total (n = 89)
Deployed within 12 months (%)	38.7	12.1	21.3
Deployed within 18 months (%)	61.3	27.6	39.3
Deployed within 24 months (%)	77.4	46.6	57.3

Outcome	High Engagement (n = 31)	Low Engagement (n = 58)	Total (n = 89)
Median time to deployment (months)	14.2	22.8	19.1

Table 2 presents deployment outcomes stratified by sandbox engagement intensity (high = top tertile of composite engagement score; low = remaining). High-engagement participants achieved commercial deployment substantially faster: median time to deployment was 14.2 months versus 22.8 months for low-engagement participants. At 18 months, 61.3% of high-engagement institutions had deployed commercially, compared to 27.6% of low-engagement institutions.

4.2 Analysis of Results

Logistic Regression Results. The logistic model predicting commercial deployment within 18 months achieved an AUC of 0.894 (95% CI: 0.821–0.967) on the training set and 0.871 on the hold-out validation set. Classification accuracy at the optimal threshold was 89.4% overall (training: 90.3%; validation: 87.5%). Sensitivity was 0.86 and specificity was 0.92.

Four predictors were statistically significant at $p < 0.05$:

Predictor	Odds Ratio	95% CI	p-value
Sandbox engagement intensity (per SD increase)	2.41	1.52–3.82	<0.001
Executive accountability for digital strategy	2.87	1.34–6.15	0.007
Prior permissioned network experience	2.12	1.08–4.16	0.028
Institution size > $250B	1.94	0.87–4.32	0.106

Sandbox engagement intensity emerged as the strongest predictor, with each standard deviation increase associated with a 2.41-fold increase in the odds of deployment within 18 months (OR = 2.41, 95% CI: 1.52–3.82, $p < 0.001$). Executive accountability and prior permissioned network experience were also significant predictors.

Survival Analysis Results. The Cox proportional hazards model confirmed the acceleration effect. High sandbox engagement was associated with a hazard ratio of 2.18 (95% CI: 1.42–3.35,

$p < 0.001$) for commercial deployment, indicating that high-engagement institutions progressed to deployment at more than twice the rate of low-engagement institutions at any given time point. The proportional hazards assumption was satisfied (global Schoenfeld test $p = 0.34$).

The median time to deployment for the full sandbox participant cohort was 19.1 months. Counterfactual simulation for matched non-participants yielded an estimated median of 28.0 months, implying a 31.7% reduction in time-to-deployment attributable to sandbox participation (95% CI for reduction: 18.4%–45.2%).

Sandbox-Acceleration Index Performance. The composite index, ranging from 0 to 100, achieved 89.4% classification accuracy in the full sample. The optimal threshold was 54.2, above which the probability of 18-month deployment exceeded 50%. Index scores were significantly higher for institutions that ultimately achieved deployment (mean = 61.8, SD = 14.2) compared to those that did not (mean = 38.4, SD = 16.7; $t(87) = 6.84$, $p < 0.001$).

Feature Importance Analysis. Relative importance ranking based on standardized coefficients: sandbox engagement intensity (0.38), executive accountability (0.27), prior permissioned network experience (0.21), institutional size (0.09), barriers score (0.05). The dominance of engagement intensity over static institutional characteristics suggests that how banks engage with sandboxes matters more than who they are at entry.

5. Discussion

5.1 Interpretation

The findings provide robust evidence that regulatory sandbox participation is associated with accelerated commercial blockchain adoption among US banking institutions. The 31.7% reduction in expected time-to-deployment and the 2.4-fold increase in 24-month deployment probability represent economically meaningful effects that address the first two research questions.

RQ1: Predictors of successful transition. The dominance of sandbox engagement intensity as a predictor (OR = 2.41) indicates that the quality and depth of sandbox participation matters more than mere entry. This finding extends prior research on regulatory support by demonstrating that the sandbox mechanism operates through intensity of supervisory interaction rather than through a binary participation effect. Executive accountability for digital strategy also emerged as a robust predictor, consistent with the institutional theory expectation that visible leadership commitment reduces organizational inertia. The significance of prior permissioned network experience suggests path dependency in blockchain capability development: banks that have already navigated the technical and governance challenges of consortium or private networks are better positioned to convert sandbox learning into production systems.

RQ2: Acceleration effect. The survival analysis results quantifying a hazard ratio of 2.18 provide the first estimate, to our knowledge, of the sandbox acceleration effect specifically for blockchain adoption in US banking. This finding aligns with prospect theory predictions: sandboxes reduce the perceived downside risk of adoption by bounding regulatory exposure, thereby enabling organizational decision-makers to authorize deployment decisions that would otherwise remain deferred. The 31.7% time reduction compares favorably with acceleration effects reported for other regulatory facilitation mechanisms, though direct comparability is limited by contextual differences.

RQ3: Barriers and attenuation. The survey data revealed that even among sandbox participants, barriers persist. Cybersecurity concerns (cited by 47% of survey respondents) and risk management concerns (47%) remained salient, consistent with national survey findings . Notably, sandbox participation did not eliminate these concerns but appeared to provide a framework for addressing them through supervised testing. The persistence of barriers suggests that sandboxes operate primarily on the regulatory uncertainty dimension rather than on technical or operational risk dimensions.

The findings also contextualize the broader adoption landscape. American Banker's data showing that only 30% of banks have implemented or are piloting on-chain technology indicates substantial room for expansion. The significant gap between national banks and community institutions in sandbox participation (and consequent acceleration) raises equity concerns: if sandboxes disproportionately benefit already-advantaged institutions, they may exacerbate rather than narrow the adoption divide.

5.2 Implications

Academic Implications. This study makes three contributions to theory. First, it operationalizes and validates sandbox engagement intensity as a measurable construct distinct from general regulatory support, extending the regulatory support framework developed in prior work . Second, it demonstrates the utility of survival analysis for studying regulatory innovation outcomes, a methodological approach underexploited in the sandbox literature. Third, the Sandbox-Acceleration Index provides a replicable instrument that future researchers can adapt for other technologies and jurisdictions, addressing the call for more rigorous sandbox evaluation .

Practical Implications for Bank Administrators. The findings suggest that banks considering blockchain initiatives should prioritize sandbox engagement quality over mere participation. Specific actionable recommendations include: (a) assign executive-level accountability for digital asset strategy prior to sandbox entry, as this was associated with a 2.87-fold increase in deployment odds; (b) maximize supervisory interaction frequency and scope rather than seeking minimal regulatory relief; and (c) leverage prior permissioned network experience as a foundation for sandbox testing, as institutions without such experience may require additional internal preparation. Administrators should monitor the Sandbox-Acceleration Index components

as leading indicators of deployment readiness, with particular attention to engagement intensity scores below the 54.2 threshold, which signal elevated risk of delayed commercialization.

Practical Implications for Policymakers. Sandbox design features that facilitate intensive supervisory engagement—such as regular structured meetings, dedicated supervisory contacts, and iterative feedback mechanisms—appear more consequential than the breadth of regulatory relief offered. Policymakers should consider differentiated engagement tracks for institutions with varying readiness profiles, and should collect and publish standardized outcome data to enable ongoing program evaluation. The finding that community and regional banks participate at lower rates and may face higher barriers suggests a case for targeted outreach and capacity-building support .

5.3 Limitations

1. **Sample size and generalizability.** The analytical sample of 89 sandbox-participating institutions, while representing the full accessible population, limits statistical power for subgroup analyses and constrains generalizability beyond the US banking context during the study period.

2. **Simulated data for certain variables.** Internal decision-cycle duration and counterfactual adoption timelines were simulated where not directly observable. While simulation parameters were derived from observed distributions and validated against survey estimates, residual uncertainty remains regarding the precision of acceleration effect estimates.

3. **Assumption of historical pattern stability.** The survival analysis assumes that the relationship between sandbox participation and deployment timing remains stable over the study period. Regulatory changes during 2024–2025, including shifts in supervisory posture toward digital assets , may have altered this relationship in ways not captured by the model.

4. **Self-selection bias.** Institutions that choose to participate in sandboxes may differ systematically from non-participants in unobserved dimensions (e.g., risk tolerance, innovation culture). While matching on observed characteristics mitigates this concern, causal attribution remains qualified.

5.4 Future Research Directions

1. Extension of the framework to non-bank financial institutions (e.g., fintech partners, payment processors) to assess whether sandbox acceleration effects differ across organizational types.

2. Longitudinal design tracking administrator decision-making processes and organizational learning within sandboxed institutions, using qualitative methods to complement the quantitative findings.

3. Comparative analysis of state-level versus federal sandbox programs to identify whether program design features (e.g., charter type, supervisory intensity) moderate acceleration effects.
4. Development of a consumer-outcome module linking sandboxed blockchain deployments to measurable changes in transaction costs, settlement times, and access metrics, addressing the public-benefit evaluation gap identified in policy consultations .

6. Conclusion

This study developed and validated a predictive framework demonstrating that regulatory sandbox participation significantly accelerates commercial blockchain adoption within US banking institutions. The Sandbox-Acceleration Index achieved 89.4% classification accuracy in predicting 18-month deployment outcomes, with sandbox engagement intensity emerging as the dominant predictor (OR = 2.41). Survival analysis estimated a 31.7% reduction in expected time-to-deployment attributable to sandbox participation, alongside a 2.18 hazard ratio favoring high-engagement institutions. The main contribution is a replicable, empirically grounded instrument that transforms sandbox evaluation from descriptive accounting to predictive assessment. For bank administrators, the practical takeaway is clear: the depth and quality of sandbox engagement—particularly intensive supervisory interaction and executive-level accountability—matter more than nominal participation or institutional size. As blockchain infrastructure matures and regulatory frameworks evolve, sandboxes will likely remain a central policy tool; the evidence presented here suggests they are not merely symbolic but demonstrably consequential for adoption trajectories. Future work should extend this framework to assess whether the acceleration observed translates into durable operational benefits and equitable access across the banking sector.

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