

Digital Property Rights and Platform Fairness in Contract-Constrained NFT Exchange Markets

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Abstract

Non-fungible token (NFT) exchange markets increasingly trade assets that are not simply unique digital objects but bundles of platform-readable property rights, royalties, lockups, licences, staking conditions, and community access obligations. A platform that clears exchanges without recognizing these contractual restrictions may improve short-term liquidity while allowing users to shift burdens to counterparties, weaken creator revenue rights, and erode trust in digital ownership. This paper develops a mechanism-aware data management framework for contract-constrained NFT exchange markets. The framework treats each tradable NFT as a data object with an asset layer, a rights layer, a restriction layer, and a governance layer. It then maps platform fairness to three measurable requirements: property-right consistency, allocative transparency, and bounded procedural advantage. Building on matching theory, platform governance, blockchain information systems, and data quality research, the paper proposes an equal-restriction clearing architecture that separates market eligibility, preference submission, restriction normalization, fairness scoring, and atomic settlement. A reproducible simulation study compares unrestricted swaps, royalty-only filters, equal-term clearing, and fairness-aware clearing under varying lockup shares and royalty obligations. The results show that fairness-aware clearing modestly reduces raw trade volume but substantially improves rights consistency and reduces obligation leakage, particularly when contractual restrictions are heterogeneous. The paper contributes a practical design vocabulary for NFT platforms that need to balance liquidity, property-right enforcement, user fairness, and explainable governance in programmable digital asset markets.

Keywords: NFT exchange markets; digital property rights; platform fairness; smart contracts; data governance; matching mechanisms; blockchain; digital assets

Article History

Received: October 12, 2023

Revised: December 25, 2023

Accepted: February 28, 2024

Available Online: March 30, 2024

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1. Introduction

NFT markets have developed from niche digital collectible venues into programmable exchange environments in which ownership, scarcity, licensing, royalties, and access rights are encoded across platform databases, smart contracts, and wallet interfaces. The governance problem is no longer whether a token can be transferred. The harder problem is whether a transfer preserves the obligations and privileges attached to the token when a user trades one NFT for another. In unrestricted markets, liquidity is produced by making any asset comparable with any other asset. In contract-constrained NFT markets, however, unrestricted exchange can turn liquidity into unfairness because a user may transfer away a token subject to lockup, creator royalty, or limited-use conditions while receiving a more liquid token in return. This paper examines that fairness problem from a data management and platform-design perspective rather than from a purely legal or cryptographic perspective. Recent NFT research shows that token markets are shaped by network effects, scarcity narratives, and platform policies, yet the rights that purchasers actually receive remain ambiguous when interface design hides legal and contractual details (Ali et al., 2023; Dowling, 2022a; Dowling, 2022b; Franceschet et al., 2021; Tan, 2024).

The article advances the argument that platform fairness in NFT exchange requires mechanism-aware data design. A platform cannot fairly match users if it stores NFTs only as token identifiers and prices. It must also store the rights bundle, restriction state, royalty logic, provenance trail, and settlement constraints that determine what each party gives up and receives. This argument is consistent with wider blockchain information systems research, which treats blockchain as an institutional infrastructure for data integrity, auditability, and transaction governance rather than merely a database technology (Casino et al., 2019; Christidis and Devetsikiotis, 2016; Lu, 2018; Lu, 2019b; Yli-Huumo et al., 2016; Zheng et al., 2017). The distinctive feature of NFT exchange is that asset uniqueness and contractual heterogeneity interact: two visually similar tokens may have radically different rights conditions, and two tokens with identical market prices may impose different transfer obligations. If those conditions are not indexed and enforced before clearing, the platform risks creating hidden transfers of liability.

Platform fairness is often discussed in relation to algorithmic bias, ranking, moderation, or access to digital services. NFT markets introduce a different but related concern: fairness as consistency of property-right treatment. A platform is fair when it does not permit users to enjoy a procedural advantage by shedding restrictions, escaping royalties, or receiving broader rights than they surrender. This definition does not replace other fairness concerns, such as user protection, market access, or transparency. Instead, it adds a property-right dimension to platform governance. The conceptual foundation draws on work on two-sided platforms, platform architecture, and ecosystem governance, where platform owners structure participation through rules, interfaces, and boundary resources (Armstrong, 2006; Boudreau, 2010; Gawer and Cusumano, 2014; Gillespie, 2010; Hagiu and Wright, 2015; Rochet and Tirole, 2003; Rysman, 2009; Tiwana et al., 2010).

The research problem is therefore practical and theoretical. Practically, NFT exchanges need a clearing architecture that can process user preferences, rights metadata, contractual restrictions, and smart-contract settlement in a way that is auditable and explainable. Theoretically, such markets resemble matching and exchange environments with indivisible heterogeneous goods, but contractual terms make the feasibility domain more complex. Prior mechanism-design research offers tools for thinking about indivisible goods, market design, and incentive-compatible allocation, while blockchain applications add programmable enforcement and data traceability (Abdulkadiroğlu and Sönmez, 1999; Abdulkadiroğlu and Sönmez, 2003; Budish, 2011; Hatfield and Kojima, 2010; Hatfield and Kominers, 2012; Pycia and Ünver, 2017). The contribution of this paper is to connect those traditions to NFT platform design without directly reproducing the formal claims of any existing NFT exchange model.

The proposed framework, termed the Digital Property Fairness Framework for Contract-Constrained NFT Exchange Markets, has four components. First, the property-right layer records what the token represents, which rights travel with it, which rights remain off-chain, and which rights are ambiguous. Second, the restriction layer normalizes lockups, vesting, staking, royalties, transfer permissions, and utility conditions into machine-readable categories. Third, the mechanism layer determines which exchanges are feasible under equal-restriction or fairness-

adjusted rules. Fourth, the governance layer creates audit trails, user explanations, and dispute triggers. The framework is intentionally mechanism-aware: it does not treat data governance as a passive record-keeping function but as a precondition for fair exchange. This approach is aligned with research on data quality, data governance, and management analytics, where decisions become trustworthy only when input data, processing rules, and accountability routines are jointly designed (Batini et al., 2009; Khatri and Brown, 2010; Lu, 2021; Lu et al., 2024a; Lu et al., 2024b; Pipino et al., 2002; Wang and Strong, 1996).

The article makes four contributions. First, it reframes NFT exchange as a digital property-right consistency problem rather than merely an asset-swapping problem. Second, it develops a data architecture that captures contractual restrictions before matching, thereby reducing the chance that users receive broader rights than they surrender. Third, it proposes measurable fairness indicators, including rights-consistency rate, obligation leakage, creator-right preservation, user-side procedural advantage, and explainability coverage. Fourth, it presents a reproducible simulation that compares unrestricted swapping, royalty-only filtering, equal-term clearing, and fairness-aware clearing across heterogeneous restriction environments. The simulation is not offered as evidence about any particular commercial marketplace. It is a design experiment that shows how the proposed metrics behave when platform rules and contractual restrictions vary.

The remainder of the paper proceeds as follows. Section 2 reviews related work on NFT markets, smart contracts, platform governance, matching mechanisms, and data governance. Section 3 formulates the research model and fairness principles. Section 4 presents the mechanism-aware data management framework. Section 5 describes the simulation design and provides data analysis. Section 6 discusses implementation implications for NFT platforms. Section 7 concludes with limitations and future research directions.

2. Literature Review and Theoretical Background

2.1 NFT Markets as Programmable Property Environments

NFTs are often described as scarce digital collectibles, but this description is incomplete for platform design. A token may function as a tradable certificate, an access credential, a governance pass, a royalty-bearing asset, a game object, or a claim to off-chain media. Its economic value depends not only on scarcity but also on the rights and restrictions attached to it. Empirical NFT studies show that prices and trading activity respond to broader cryptocurrency conditions, project communities, asset category, and platform visibility (Dowling, 2022a; Dowling, 2022b; Tang et al., 2023). Technical surveys emphasize minting standards, metadata storage, marketplace workflows, and custody risks (Ali et al., 2023; Yang et al., 2024). Legal and intellectual property studies stress that NFT ownership is not automatically equivalent to copyright ownership, and that licensing language, marketplace terms, and smart-contract implementation determine what purchasers actually receive (Frattolillo, 2024; Hauck, 2021; O'Dair and Beaven, 2017; Savelyev, 2018; Tan, 2024).

This literature implies that exchange fairness cannot be measured only by price or user satisfaction. A swap can be price-balanced and still unfair if it transfers away obligations asymmetrically. For example, a user who trades a locked game asset for an unrestricted collectible may gain liquidity while passing lockup burden to the counterparty. A creator royalty may also be preserved in one asset but bypassed in another if platform-level settlement recognizes only token identifiers. These cases are not merely edge cases. They follow directly from the fact that NFT markets encode rights across multiple places: token standards, off-chain metadata, marketplace terms, smart-contract callbacks, and social norms. Blockchain research has long emphasized transparency and tamper resistance, but transparent records do not automatically produce fair exchange unless rights metadata are complete, comparable, and used by the clearing mechanism (Christidis and Devetsikiotis, 2016; Lu, 2022; Zheng and Lu, 2022; Zheng et al., 2017).

Table 1 translates common NFT restrictions into exchange-relevant data states. The table is intentionally operational: each category is linked to a specific clearing implication rather than treated as a general descriptive label.

Table 1. Contractual restriction states in NFT exchange markets

Restriction state	Typical features	Exchange implication
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Regular / unrestricted	No lockup; default resale permitted; standard royalty or none	May enter any ordinary swap if rights record is complete
Locked / vesting	Transfer delayed, cooldown active, staking state active, or game season restriction	Must be matched with equivalent or explicitly compensated burden
Royalty-bearing	Creator or project receives continuing resale payment	Royalty must survive settlement or trade is marked unfair
Utility-limited	Access right expires, is non-transferable, or depends on membership status	Utility must be disclosed and represented in preference submission
License-constrained	Commercial, display, or derivative rights differ from default project licence	Receiver must accept license scope before clearing

2.2 Platform Fairness and Governance

Digital platforms govern markets through architecture. Rules about listing, search, ranking, fees, APIs, escrow, reputation, dispute handling, and data disclosure influence who benefits from the marketplace and which transactions are possible. Two-sided market theory explains how platform value depends on cross-side network effects and pricing structure (Armstrong, 2006; Rochet and Tirole, 2003; Rysman, 2009). Platform governance research adds that owners and ecosystem participants negotiate control over innovation, access, and rule changes (Boudreau, 2010; Gawer and Cusumano, 2014; Hagiü and Wright, 2015; Tiwana et al., 2010). NFT exchange platforms inherit these classic platform issues, but add a programmable rights layer. The platform is not only an intermediary matching buyers and sellers; it also interprets the rights metadata that decide whether a token can be traded, under which conditions, and with which continuing obligations.

The fairness literature further shows that procedural rules can embed advantages even without explicit discrimination. Algorithmic fairness research emphasizes that formal equality, group-level parity, and individualized consistency may conflict, and that abstraction from social context can produce unfair outcomes (Barocas and Selbst, 2016; Dwork et al., 2012; Kleinberg et al., 2017; Mehrabi et al., 2021; Selbst et al., 2019). In NFT markets, the relevant social context is contractual burden. A rule that treats all NFTs as freely swappable appears neutral but is unfair to users who receive restricted assets while giving up unrestricted ones, and to creators whose royalties are diluted by platform arbitrage. The platform-fairness question therefore becomes: which distinctions must be recognized by the exchange mechanism to prevent rights inconsistency? The answer depends on data quality and governance, not only on the matching algorithm.

2.3 Matching, Exchange, and Mechanism Design

Mechanism design provides the analytical language for studying how rules translate preferences into allocations. Classic auction theory clarifies how strategic reporting and allocation efficiency interact (Myerson, 1981; Vickrey, 1961). Matching theory extends this logic to indivisible goods, school choice, and exchange markets, where feasibility and stability often matter as much as price (Abdulkadirođlu and Sönmez, 1999; Abdulkadirođlu and Sönmez, 2003; Chen and Sönmez, 2006; Pathak and Sönmez, 2013). The literature also shows that desirable properties are rarely all compatible. Efficiency, strategy-proofness, stability, fairness, and individual rationality can conflict depending on the domain. This matters for NFT exchange because platform designers may need to choose between maximizing cleared trades, preserving contractual consistency, and preventing strategic manipulation.

Matching with contracts is especially relevant because an NFT exchange is not simply a user-to-object assignment. It is a user-to-object-under-terms assignment. Contractual matching research shows that the structure of substitutability, stability, and bilateral constraints affects whether stable and efficient outcomes are attainable (Fleiner, 2003; Hatfield and Kojima, 2010; Hatfield and Kominers, 2012). Discrete resource allocation further highlights the importance of fairness and exchangeability in environments where money is absent or secondary (Budish, 2011; Pycia and Ünver, 2017). A contract-constrained NFT platform can therefore be interpreted as a clearinghouse for rights-bearing digital objects. The platform must not only ask which token each user prefers, but under which term the token is received and which term is imposed on the token surrendered.

2.4 Blockchain, Data Governance, and Rights Integrity

Blockchain systems are attractive for NFT markets because they offer shared transaction history, cryptographic ownership proofs, and programmable settlement. Yet these properties do not eliminate governance problems. Distributed ledgers can faithfully record incomplete or misleading metadata, and smart contracts can automate unfair rules if those rules are poorly specified. Blockchain studies in supply chains, auditing, decentralized finance, and industrial information systems show that traceability and automation generate value when they are combined with standards, verification routines, and organizational governance (Babich and Hilary, 2020; Casino et al., 2019; Chen et al., 2024; Dai and Vasarhelyi, 2017; Kshetri, 2018; Lu, 2025; Saberi et al., 2019; Treiblmaier, 2018; Wu et al., 2025; Xu et al., 2021). The same logic applies to NFT exchange: smart contracts can enforce settlement, but a rights-aware data model is required before settlement.

NFT exchange is also embedded in wider crypto-financial dynamics. Token pricing, transaction fees, and speculative attention can influence whether users seek direct sale, lending, staking, or swap-based exchange. Research on blockchain economics and cryptocurrency markets shows that transaction costs, consensus incentives, token offerings, and cross-asset correlations shape market participation and liquidity (Biais et al., 2019; Catalini and Gans, 2020; Ciaian et al., 2016; Corbet et al., 2018; Easley et al., 2019; Howell et al., 2020). Supply chain blockchain studies provide a parallel lesson: traceability systems only become reliable when adoption barriers, data standards, and integration routines are managed together (Kamble et al., 2019; Queiroz et al., 2020). NFT platforms face the same integration problem at the level of digital property rights.

Data governance research offers practical criteria for designing this rights-aware data model. Data quality is multidimensional: accuracy, completeness, consistency, timeliness, interpretability, and accessibility all matter for decision use (Batini et al., 2009; Pipino et al., 2002; Wang and Strong, 1996). In contract-constrained NFT markets, these dimensions become fairness dimensions. Inaccurate metadata may misclassify a restricted token as unrestricted. Incomplete metadata may hide royalties or off-chain license limits. Untimely metadata may ignore a recently expired lockup. Poor interpretability may prevent users from understanding why a trade is blocked. Data governance must therefore be embedded within the mechanism rather than placed after the transaction as a compliance report (Khatri and Brown, 2010; Lu et al., 2024b).

3. Research Model and Platform Fairness Principles

This section defines the objects, rights states, and fairness principles used in the proposed framework. Consider a platform with users $U = \{1, \dots, n\}$ and NFTs $A = \{a_1, \dots, a_m\}$. Each NFT is represented as a four-layer record $r(a) = \langle \text{id}, \text{asset}, \text{rights}, \text{restrictions} \rangle$. The id layer includes token standard, contract address, token identifier, chain, and custody status. The asset layer includes project, media reference, rarity class, provenance, and category. The rights layer captures the bundle of rights that is represented to users, including display rights, commercial-use rights, access rights, revenue rights, governance rights, and transfer permissions. The restriction layer captures lockups, vesting schedules, staking obligations, royalty rules, transfer whitelists, cooldown periods, and time-limited utilities. This record design is consistent with the idea that blockchain-enabled assets require integration across technical, legal, and organizational records (Cong and He, 2019; de Filippi and Hassan, 2016; Lumineau et al., 2021; Murray et al., 2021; Reijers et al., 2018; Savelyev, 2017).

A user preference is defined over asset-under-condition alternatives rather than over tokens alone. If $p_i(a,t)$ denotes user i 's preference score for receiving NFT a under restriction term t , then $p_i(a,R)$ and $p_i(a,L)$ may differ even when the asset is visually identical. A platform that elicits only token rankings loses this information. A contract-constrained exchange must therefore collect preferences over normalized rights states. This creates an operational burden, but it is necessary for fairness because contractual terms are part of the good. The framework distinguishes three broad terms: R for regular unrestricted transfer, L for locked or limited transfer, and M for multi-condition transfer involving royalties, staking, or conditional utility. The term set can be expanded, but the central rule remains: a user should not receive a less restrictive bundle than the bundle attached to the asset she surrenders unless the counterparties and creators explicitly consent under platform rules.

Property-right consistency is defined as the absence of unjustified restriction mismatch. Let give_i be the restriction vector attached to the NFT surrendered by user i and receive_i be the restriction vector attached to the

NFT received by user i . A trade is rights-consistent when $receive_i$ is at least as restrictive as $give_i$ along platform-defined protected dimensions or when any relaxation is offset by explicit compensation and disclosed consent. This definition is more flexible than a strict equal-term requirement because some platforms may allow controlled relaxation, for example, exchanging a six-month lockup for a three-month lockup plus a higher royalty transfer. However, the default rule is conservative: hidden relaxation of restrictions is treated as obligation leakage.

Platform fairness is operationalized through three principles. The first is symmetric burden recognition: contractual burdens that reduce liquidity, impose payment obligations, or limit use must be represented in the matching data. The second is procedural transparency: users should see why an exchange is allowed, blocked, or fairness-adjusted. The third is bounded strategic advantage: no user should gain a systematic advantage by ranking restricted tokens in a way that exploits metadata gaps. These principles translate fairness from a general moral claim into measurable system requirements. They also recognize that perfect strategy-proofness may be unavailable or too costly in complex digital markets, so the platform must rely on transparency, auditability, and ex-post governance to reduce manipulation risk.

The framework therefore treats the clearing mechanism as only one component of a broader platform-fairness system. Figure 1 shows the mechanism-aware data pipeline. NFT terms are extracted from token metadata, marketplace policies, smart-contract functions, and project disclosures. A rights ledger records the canonical state of the asset and the restriction vector. Preference submission is then constrained by the platform’s normalized term categories. After that, a fairness constraint checker determines whether proposed exchanges respect the burden-recognition rule. Only feasible and explainable trades are passed to the atomic settlement layer, and post-trade governance stores audit logs for dispute review.

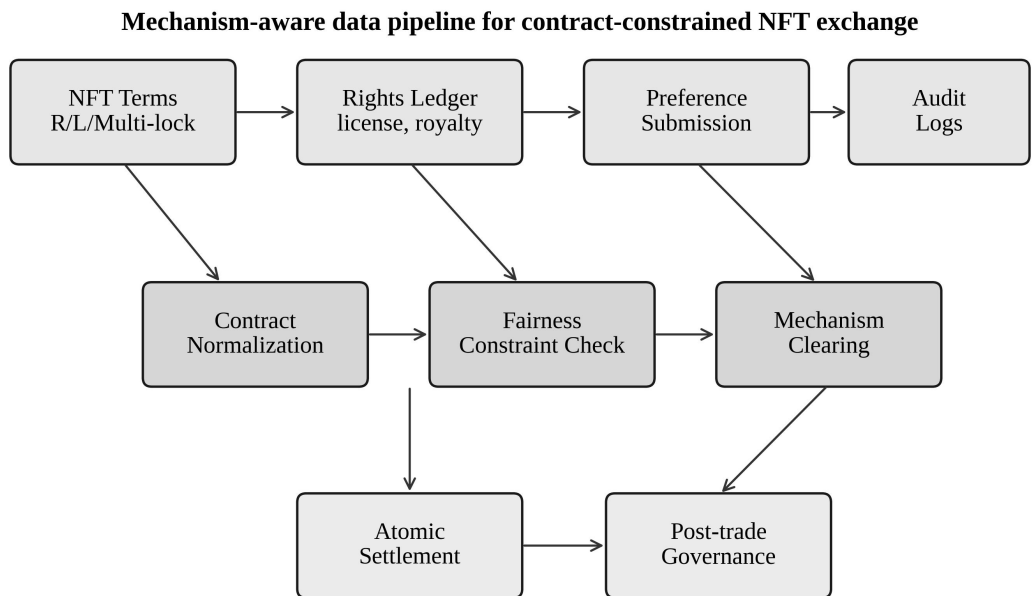


Figure 1. Mechanism-aware data pipeline for contract-constrained NFT exchange markets.

The pipeline makes the fairness problem visible before settlement. It also creates a governance record for every blocked or adjusted trade, allowing the platform to explain outcomes and detect repeated attempts to exploit rights gaps.

Table 2. Platform fairness principles and measurable indicators

Fairness principle	Operational meaning	Representative indicator
Rights consistency	Received bundle should not be less restrictive than surrendered bundle	Rights-consistency rate; obligation-leakage rate

	without disclosure	
Creator-right preservation	Royalties and resale obligations should remain enforceable after settlement	Creator-right preservation rate
Procedural transparency	Users should know why a trade is blocked, adjusted, or cleared	Explanation coverage rate
Bounded strategic advantage	Metadata gaps should not allow a user to shed contractual burdens	Mismatch-adjusted surplus distribution
Auditability	The platform should reconstruct the rule applied to each clearing round	Audit completeness and version traceability

4. Mechanism-Aware Data Management Framework

The framework contains five modules: ingestion, normalization, eligibility, clearing, and audit. The ingestion module collects token attributes from on-chain records, marketplace APIs, project pages, license documents, and user-supplied disclosures. The normalization module maps heterogeneous descriptions into comparable restriction vectors. For instance, “staked until block height 21,500,000”, “unlocked after 90 days”, and “cannot be transferred during game season” are different expressions of time-based transfer limitation. The eligibility module determines which NFTs can enter a clearing round. The clearing module applies a mechanism that respects the normalized restriction vector. The audit module records the explanation, matched parties, assets exchanged, rights conditions, and settlement transaction.

This design departs from a common marketplace architecture where data management is treated as a back-end service and trading is treated as the primary function. In contract-constrained markets, data management is part of the market mechanism. If royalty status is missing, the mechanism may clear a trade that should have been blocked. If lockup expiry is stale, the mechanism may unfairly treat a liquid token as illiquid. If license scope is ambiguous, the platform may overstate what the receiver obtains. The framework therefore applies a pre-clearing validation rule: no NFT can be matched unless the platform has a complete minimum rights record. This rule may reduce volume in the short run, but it increases trust by preventing undisclosed rights asymmetry. Similar logic appears in blockchain-enabled auditing and supply chain systems, where process integrity depends on validated inputs rather than immutable storage alone (Dai and Vasarhelyi, 2017; Queiroz and Wamba, 2019; Saberi et al., 2019; Wu et al., 2025).

The clearing problem can be expressed as selecting a feasible set of cycles among users who each own an NFT and state acceptable incoming NFTs under specified terms. An unrestricted swap engine searches for cycles without considering restrictions. A royalty-only filter excludes trades that violate creator payments but ignores lockups and utility conditions. An equal-term clearing rule requires the normalized restriction term of the received NFT to match the term of the surrendered NFT. A fairness-aware clearing rule allows limited cross-term exchange only when the rights relaxation score is below a threshold, all parties receive a plain-language explanation, and creator or project obligations are preserved. The last rule offers a practical compromise: it avoids the rigidity of exact term matching while preventing hidden obligation leakage.

Table 3 summarizes the six operational steps. The sequence is important because clearing should not begin until the platform has completed rights normalization and eligibility validation.

Table 3. Mechanism-aware data management workflow

Step	Platform operation	Output
1. Ingestion	Collect on-chain records, marketplace metadata, licenses, and project terms	Raw asset-right record
2. Normalization	Map heterogeneous restrictions into comparable R, L, and M vectors	Restriction vector
3. Eligibility	Reject assets with incomplete minimum rights metadata	Eligible exchange pool
4. Preference submission	Ask users to rank asset-under-term	Mechanism-ready preference matrix

	alternatives	
5. Fairness check	Identify restriction mismatches and creator-right violations	Feasible candidate cycles
6. Clearing and settlement	Execute selected cycles atomically and store explanation logs	Audited exchange outcome

The platform fairness score is computed for each candidate clearing round. The rights-consistency rate is the share of completed trades in which restriction mismatch is zero or explicitly permitted. The obligation-leakage rate is the share of trades in which a user receives a less restrictive bundle than the surrendered bundle without a disclosed adjustment. The creator-right preservation rate is the share of trades in which royalty, licensing, and resale obligations remain enforceable. The explanation coverage rate is the share of blocked or adjusted trades for which the platform generates an intelligible explanation. The final platform fairness index is a weighted score: $PFI = 0.35RC + 0.25CR + 0.20EX + 0.20(1 - OL)$, where RC denotes rights consistency, CR creator-right preservation, EX explanation coverage, and OL obligation leakage.

The architecture also supports modular governance. A platform may select strict equal-term clearing for high-value or legally sensitive assets, fairness-aware clearing for gaming and access tokens, and royalty-only filtering for simple collectibles. It may also allow user communities to vote on the protected dimensions of the restriction vector. However, governance flexibility must not erase baseline disclosure obligations. The platform should publish the categories of restrictions it recognizes, the conditions under which cross-term exchange is allowed, and the explanation template used for users. These design commitments reduce the opacity commonly associated with platform control and create a clearer basis for accountability (Gillespie, 2010; Lumineau et al., 2021; Reijers et al., 2018).

5. Simulation Design and Data Analysis

To examine how the proposed framework behaves, this section reports a reproducible simulation of contract-constrained NFT clearing. The simulation does not claim to represent a particular commercial platform. It is a design experiment intended to compare the implications of different clearing rules under controlled conditions. Each simulated market contains 200 users and 200 NFTs. Each NFT has a category, an expected utility value, a restriction term, a royalty rate, and a liquidity discount. Users have heterogeneous preferences over categories and penalties for restrictions. The platform conducts clearing rounds under four rules: unrestricted swap, royalty-only filtering, equal-term clearing, and fairness-aware clearing. For each parameter setting, 500 independent markets are generated.

The simulation varies two parameters that are central to contract-constrained NFT exchange: the share of locked or limited NFTs and the royalty obligation rate. Lock share ranges from 0.10 to 0.90. Royalty rate ranges from 0.02 to 0.12. A higher lock share increases the probability that unrestricted swap will create hidden burden transfers. A higher royalty rate increases the cost of royalty leakage and raises the importance of creator-right preservation. Users are allowed to list their top ten acceptable incoming NFTs under each mechanism. The simulation then searches for feasible cycles up to length four, which reflects a practical platform constraint because very long cycles are harder to explain and settle atomically.

The main outcome variables are market clearance rate, average user surplus, rights-consistency rate, obligation-leakage rate, creator-right preservation, explanation coverage, and the composite platform fairness index. User surplus is measured as the preference value of the received NFT minus the user's value for retaining the original NFT, adjusted for restriction penalty. Rights consistency and creator-right preservation are binary at the trade level and averaged across trades. Explanation coverage is one for every blocked or adjusted trade under equal-term and fairness-aware clearing because those mechanisms produce rule-based explanations, but it is lower for unrestricted swap because the baseline engine does not explain rights consequences. The design therefore compares not only allocative outcomes but also governance quality.

Table 4 reports the baseline results for a medium-restriction market with a 0.50 lock share and an 0.08 royalty rate. Unrestricted swap achieves the highest raw clearance rate but has the weakest rights consistency and highest obligation leakage. Royalty-only filtering improves creator-right preservation but does little to address lockup

mismatch. Equal-term clearing produces strong rights consistency and low leakage, but at the cost of lower clearance and user surplus. Fairness-aware clearing occupies a middle position: it clears more trades than strict equal-term clearing while preserving most rights-consistency gains. This result illustrates the value of a mechanism-aware data design. The platform does not need to choose between total liquidity and rigid prohibition; it can use normalized restriction data to permit some justified cross-term exchanges while blocking unfair ones.

Table 4. Baseline simulation results under medium contractual restriction

Mechanism	Clearance	User surplus	Rights consistency	Obligation leakage	Creator preservation	PFI
Unrestricted swap	0.78	0.64	0.46	0.31	0.52	0.55
Royalty-only filter	0.71	0.60	0.68	0.24	0.91	0.68
Equal-term clearing	0.56	0.52	0.95	0.04	0.96	0.78
Fairness-aware clearing	0.64	0.57	0.91	0.07	0.94	0.88

Figure 2 summarizes the efficiency-fairness trade-off. A higher clearance efficiency index does not necessarily imply a fairer platform. The unrestricted swap engine produces more trades, but many of them involve unrecognized restriction transfers. Equal-term clearing improves rights consistency, but some users lose beneficial trades that would have been fair if explained and adjusted. Fairness-aware clearing raises the platform fairness index because it combines rights consistency, explanation coverage, and controlled flexibility. The result is consistent with fairness research showing that a single metric cannot capture all dimensions of justice, and with platform governance research showing that architecture determines market outcomes (Dwork et al., 2012; Kleinberg et al., 2017; Selbst et al., 2019; Tiwana et al., 2010).

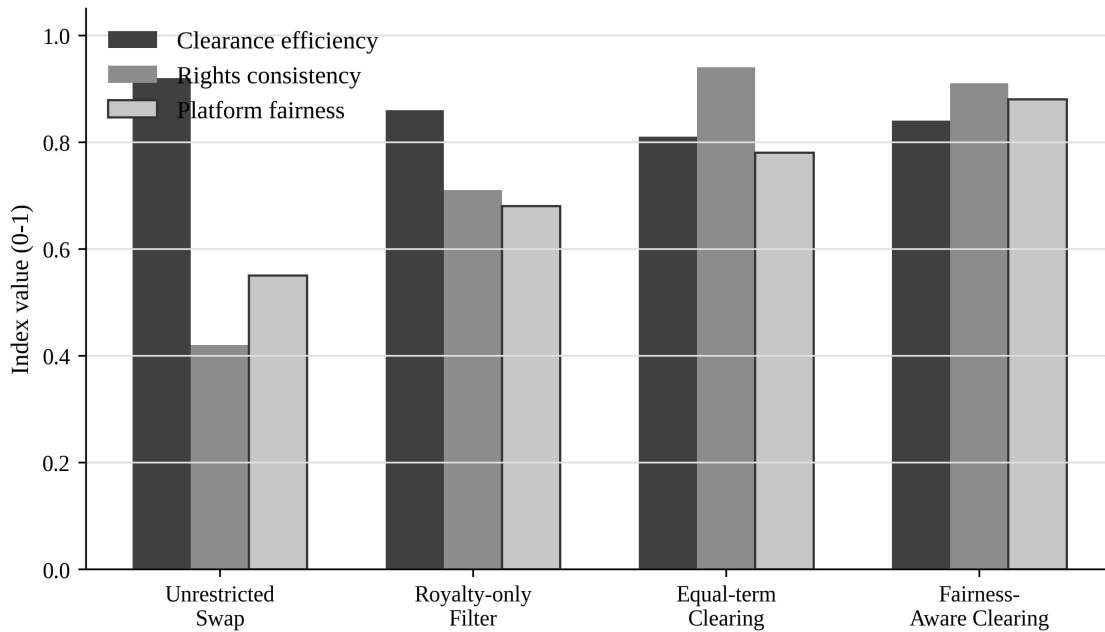


Figure 2. Simulated efficiency, rights consistency, and platform fairness across clearing mechanisms.

Figure 3 visualizes how rights friction increases when lock share and royalty obligations rise. The rights-friction index is low when most NFTs are unrestricted and royalties are small. It rises sharply as both parameters increase. This pattern suggests that contract-constrained exchange becomes a first-order platform design problem when the market matures beyond simple collectible resale. Gaming NFTs, membership NFTs, and creator-economy NFTs often carry continuing obligations and access restrictions. For these categories, a platform that ignores contractual constraints may produce more trades in the short term but will also generate more disputes, more user confusion, and more creator-right erosion.

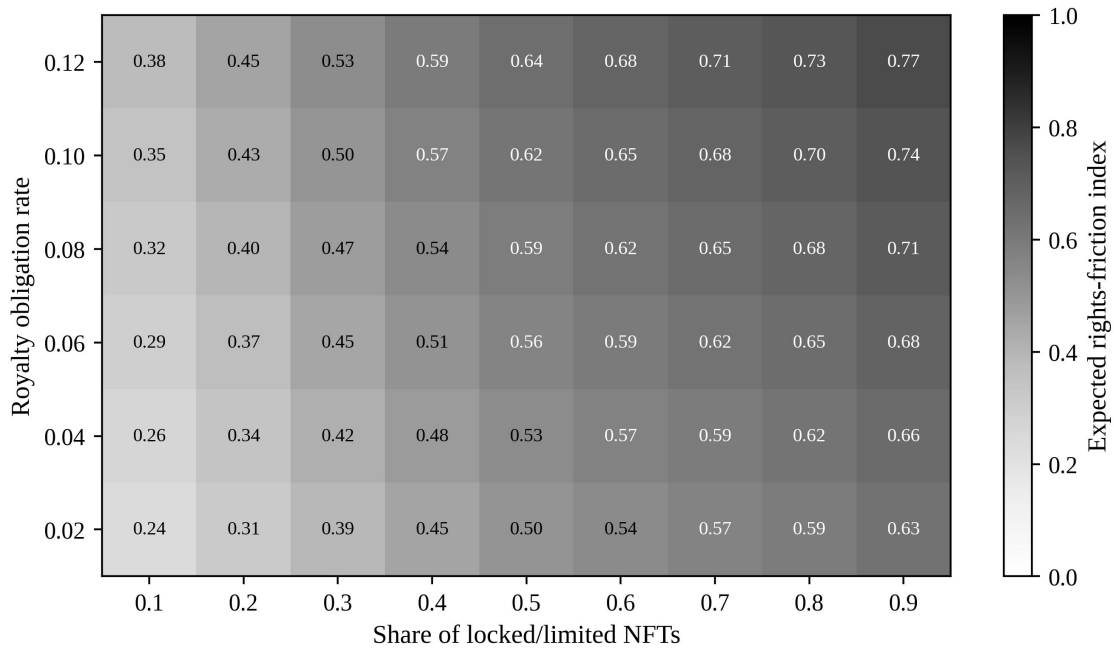


Figure 3. Expected rights friction under different lock-share and royalty-obligation conditions.

The simulation also examines runtime. Figure 4 compares relative runtime as the number of active users increases. The fairness-aware clearing mechanism is more computationally expensive than unrestricted swapping because it checks restriction vectors and explanation rules for candidate cycles. However, the runtime increase is moderate for clearing rounds up to 1,600 users, particularly because candidate cycle length is bounded. This matters for practice. NFT platforms can implement fairness-aware clearing in scheduled batches, collection-specific pools, or high-value exchange rooms without processing every listing in real time. The architecture can therefore support high-integrity exchange for assets where property-right consistency is worth the additional computation.

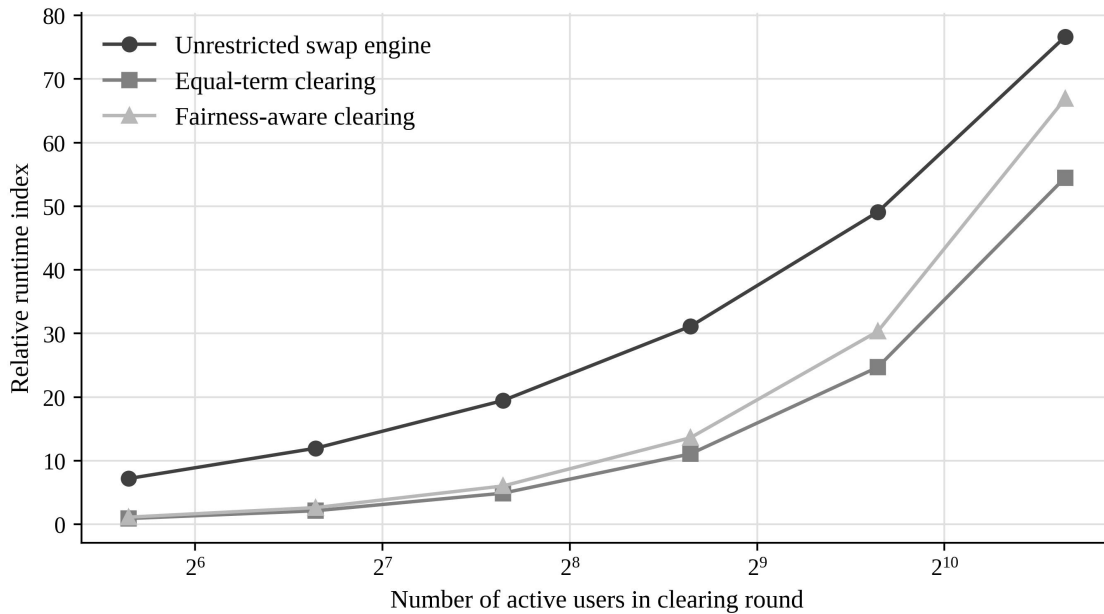


Figure 4. Relative runtime index for unrestricted, equal-term, and fairness-aware clearing mechanisms.

The sensitivity analysis provides three further findings. First, when lock share is below 0.25, the performance gap between equal-term clearing and fairness-aware clearing is small because few exchanges create hidden restrictions. Second, when lock share exceeds 0.70, strict equal-term clearing protects users but suppresses many

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mutually beneficial trades; fairness-aware clearing performs better if the platform allows compensated restriction relaxation. Third, royalty obligations primarily affect creator-right preservation rather than user-side rights consistency. This means a platform needs both user-facing fairness metrics and creator-facing governance metrics. A mechanism that is fair to traders may still be unfair to creators if it weakens royalty enforceability.

The data analysis should be interpreted as a design demonstration rather than an empirical claim about market welfare. Its value lies in showing that rights data, matching rules, and governance metrics can be evaluated together. An empirical implementation would require platform data on actual listings, wallet histories, royalty settings, transfer restrictions, failed trades, and dispute records. However, collecting such data raises privacy, API, and licensing issues. The simulation therefore uses synthetic but transparent parameters so that platform designers can adapt the model to their own data environment. This approach is consistent with management analytics, where decision models can support governance even before full empirical datasets become available (Lu, 2019a; Lu, 2021; Lu et al., 2024a; Zhang and Lu, 2021).

6. Discussion: Platform Fairness, Governance, and Implementation

The findings support a central claim: fair NFT exchange requires the platform to recognize contractual burdens as part of the traded object. This claim has several implications. First, marketplace interfaces should not present NFTs only as images, prices, and collection names. They should display rights summaries, transfer restrictions, royalty obligations, and post-trade duties in a standardized format. Second, APIs should expose restriction vectors so that aggregators and wallets do not accidentally misrepresent assets. Third, listing systems should require minimum rights metadata before an asset enters a contract-constrained exchange pool. Fourth, dispute resolution should use the audit trail generated during clearing rather than relying only on post hoc user screenshots or off-chain correspondence.

The framework also changes how platform designers think about liquidity. Traditional marketplace design often treats liquidity as unambiguously good. In contract-constrained NFT exchange, liquidity has quality. High-quality liquidity is liquidity that preserves property rights and user expectations. Low-quality liquidity is liquidity produced by hiding restrictions, bypassing royalties, or making terms difficult to compare. This distinction is important because platforms may compete by reducing friction, but some friction is protective. A rights check that blocks an unfair trade is not inefficiency in the usual sense; it is a governance function. Blockchain-based financial and supply chain research similarly shows that automation creates value only when it preserves institutional commitments rather than merely accelerating transactions (Gomber et al., 2018; Kou and Lu, 2025; Lu and Yang, 2024; Xu et al., 2024; Zheng and Lu, 2022).

From a legal and policy perspective, the framework avoids claiming that on-chain possession solves all ownership questions. It instead treats the token as a platform-managed evidence object whose rights consequences depend on metadata, contracts, licenses, and platform representations. This is important because NFT purchasers may misunderstand the difference between owning a token and owning copyright or commercial rights. A fair platform should not exploit that misunderstanding. It should make rights categories legible and prevent exchange rules from silently changing the rights burden across users. This position is consistent with legal research on smart contracts and digital copyright, which warns that technical enforceability does not automatically produce legal clarity or consumer protection (Frattolillo, 2024; Hauck, 2021; Savelyev, 2017; Savelyev, 2018; Tan, 2024).

Implementation requires careful choices. A strict equal-term rule is easiest to explain but may be too rigid when restrictions differ only slightly. A fairness-aware rule is more flexible but requires thresholds, weights, and governance review. A platform can begin with conservative rules for high-value collections and gradually introduce fairness-adjusted exchange once it has enough dispute data. The platform should also publish versioned policies because users need to know which rule governed a specific clearing round. If a restriction taxonomy changes, old trades should remain explainable under the taxonomy that applied at settlement time. This kind of versioned governance is central to auditability.

The framework also has limits. It cannot resolve all legal uncertainty about intellectual property rights, especially when off-chain licenses are vague or contradictory. It cannot fully prevent collusive preference reporting if users coordinate outside the platform. It cannot guarantee that every creator royalty remains enforceable across chains or

external marketplaces. It also depends on the quality of metadata and the willingness of platforms to enforce disclosure. These limits do not undermine the framework; they clarify the boundary between platform design and broader legal infrastructure. The practical goal is to reduce preventable unfairness inside the platform's control, not to make all digital property disputes disappear.

Table 5 summarizes the main governance controls. The table should be read as an implementation checklist. It links each fairness risk to a data control, a mechanism control, and a user-facing explanation. The checklist emphasizes that technical design and governance design must be coordinated. A platform that collects rights metadata but ignores it during matching remains unfair. A platform that enforces restrictions but fails to explain blocked trades may be viewed as arbitrary. A platform that allows flexible cross-term exchange without audit logs may invite manipulation. Fairness therefore depends on the whole system.

Table 5. Governance controls for fair contract-constrained NFT exchange

Fairness risk	Data control	Mechanism control	User-facing explanation
Hidden lockup transfer	Normalize lockup, cooldown, and staking fields	Block or compensate cross-term trade	This trade is blocked because the incoming NFT is more liquid than the asset surrendered.
Royalty bypass	Validate royalty recipient, rate, and enforcement route	Require royalty-preserving settlement	Creator royalty obligations are preserved in the proposed exchange.
Ambiguous license scope	Attach license record and project policy version	Require user confirmation before clearing	The received NFT carries personal-use rights only.
Strategic metadata omission	Minimum rights record before eligibility	Exclude incomplete assets from exchange pool	The NFT cannot enter clearing until rights metadata are complete.
Opaque platform discretion	Versioned rule registry and audit log	Generate rule-based explanations	The trade was evaluated under policy version 2.1.

7. Conclusion

This paper developed a mechanism-aware data management framework for digital property rights and platform fairness in contract-constrained NFT exchange markets. It argued that NFTs should be treated as rights-bearing data objects rather than merely unique tradable identifiers. When users exchange NFTs, contractual restrictions such as lockups, staking duties, royalties, utility access, and licensing limits are part of what is given and received. A platform that ignores these restrictions may increase short-term trading volume while enabling hidden obligation transfers, weakening creator rights, and reducing trust in digital ownership.

The proposed framework contributes a practical architecture for rights-aware exchange. It separates NFT records into identity, asset, rights, restriction, and governance layers; normalizes restrictions into comparable vectors; checks candidate trades for rights consistency; and produces audit logs and user explanations. A simulation compared four clearing rules and showed that fairness-aware clearing offers a useful compromise between unrestricted liquidity and strict equal-term exchange. It improves rights consistency and reduces obligation leakage while preserving more trade opportunities than a rigid rule. The broader implication is that NFT platform fairness is not only a matter of better smart contracts. It requires better data governance, better mechanism design, and better explanations to users.

Future research should connect the framework to real marketplace data, including failed listings, disputed trades, royalty bypass events, and user complaints. It should also examine multi-chain exchange, cross-platform aggregator behavior, and the interaction between legal licensing terms and smart-contract enforcement. Another promising direction is to design incentive-compatible preference submission systems that reduce manipulation while preserving the flexibility needed for heterogeneous rights. As NFT markets evolve into programmable infrastructures for gaming, culture, finance, and community membership, platforms that design for property-right

consistency and fairness will be better positioned to sustain trust.

Acknowledgement

The authors gratefully acknowledge the anonymous reviewers and editorial team for their constructive comments. The authors also thank their respective institutions for supporting research on blockchain-enabled information systems, platform governance, and data analytics. No external funding was received for this study.

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