Proceedings of ICFTBA 2025 Symposium: Financial Framework's Role in Economics and Management of Human-Centered Development
DOI: 10.54254/2754-1169/2025.GL27520

Standardization of the Digital Collectibles Market: The Starkelberg Game

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Abstract. Leveraging emerging blockchain technology and visionary metaverse concepts, digital collectibles have emerged as an indispensable force in the digital economy. However, developing markets are increasingly exposed to issues such as information asymmetry, technical vulnerabilities, and market manipulation, leading to disorder and hindering sustainable economic growth. The underdeveloped regulatory framework has yet to resolve these challenges effectively, making standardized development imperative. By constructing a multi-stage Stakelberg game model to analyze strategic interactions among regulators, platforms, investors, and consumers, this study proposes recommendations including appropriate policy intensity, optimized trading mechanisms, rational investment practices, and consumer education to facilitate the standardized evolution of the digital collectibles market.

Keywords: Digital collectibles, Stakelberg game, Market regulation

1. Introduction

Digital collectibles, as NFTs (Non Fungible Tokens) localized in China, have gradually become an innovative force in the digital economy.Its uniqueness, indivisibility, and traceability meet the needs of digital art, collectibles, game assets, and other fields, making it an ideal carrier for digital art [1]. However, while this emerging market is rapidly developing, it has also exposed a series of problems.

The problems in China's digital collectibles market mainly focus on three aspects. One is the institutional defect, where regulatory lag leads to a vacuum in the system, providing opportunities for speculative behavior [2]. The second is technological risk, as blockchain security vulnerabilities and information asymmetry exacerbate market instability [3]. The third issue is market chaos, where some illegal elements take advantage of the above loopholes to engage in manipulative activities such as false bidding, money laundering, and insider trading, seriously disrupting market order and harming the rights and interests of creators and investors [3].

To address these issues, China has introduced a series of laws and regulations, which have achieved certain results in curbing market speculation and financial risks [3]. However, it also faces the dual contradiction of "excessive constraints on innovation" and "insufficient risk prevention and control".On the one hand, excessive trading restrictions may limit market vitality; On the other hand, there are still regulatory blind spots in some areas, which pose risks [3]. Therefore, it is imperative to promote the standardized construction of the digital collectibles market.

Existing literature mostly focuses on a single perspective of technical characteristics or market chaos, lacking systematic analysis of multi-party strategic interactions [4]. Game theory, as an effective analytical tool, can reveal the dynamic relationship between regulatory agencies and market participants, providing a theoretical basis for formulating reasonable policies [5]. This paper constructs a game model to analyze the strategic interactions among various parties in the digital collectibles market, revealing the internal mechanism of market standardization, and providing theoretical basis and practical reference for promoting the long-term healthy development of the digital collectibles market.

2. Model assumptions

This paper constructs a three-stage Stackelberg game model to analyze the strategic interactions among regulatory agencies, platforms, investors, and consumers in the digital collectibles market.The model adopts a three-level structure of "leader follower": regulatory agencies, as leaders, first formulate policies; The platform subsequently designs a trading mechanism; Investors and consumers make the final decision.Regulatory agencies pursue the maximization of social welfare, platforms pursue the maximization of profits, and investors and consumers seek optimal returns and satisfaction respectively.The model is based on the assumption of perfect information, where all participants understand each other's objective function and strategy space, and the posterior actor can fully observe the actions in the previous stage.This framework provides a theoretical basis for analyzing the standardization of the digital collectibles market.

3. Model construction and solution

To solve the equilibrium of multi-stage Stackelberg games, this paper adopts the reverse induction method to solve the subgame Perfect Nash Equilibrium (SPNE) layer by layer, ensuring that the strategies of each stage are optimal in subsequent games and avoiding the problem of "unbelievable threats".

Firstly, analyze the final stage of the game, which is the decision-making between consumers and investors. Given the strength of regulatory policies (r), platform transaction fees (p), and service quality (q), consumers choose the digital collectibles purchase combination (x*) that maximizes utility, while investors determine the optimal investment amount and target (I*).Then going back to the platform decision-making stage, the platform designs the transaction fee rate (p*) and service quality (q*) that maximize profits based on the regulatory policy intensity (r) and the predicted consumer/investor reactions (x*) and (I*). Finally, the regulatory agency's decision is analyzed, and based on a complete prediction of the platform, investors, and consumers' subsequent behavior, the regulatory agency selects the policy intensity (r*) that can maximize social welfare.

3.1. Phase three: decisions of investors and consumers

The goal of investors is to maximize investment returns (R), with the decision variable being the investment amount (I). The investment return function can be expressed as:

$$R(I,p) = (\gamma - p)I - \delta I^2 \tag{1}$$

Among which:

- (p) is the transaction handling fee charged by the platform;

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• (γ) represents the return on investment, which is influenced by market environment and platform policies;

• (δ) represents the investment risk coefficient, indicating the degree of investment risk and its impact on investment returns.

To find the optimal strategy (I*) for investors, we need to take a partial derivative of expression (1) and make it equal to zero. Solving the equation can yield the optimal investment amount:

$$I^*\left(p\right) = \frac{\gamma-p}{2\delta} \tag{2}$$

The goal of consumers is to maximize utility (U), with the decision variable being the purchase quantity (x). The utility function can be expressed as:

$$U\left(x,p,q\right) = \theta x + \eta q x - p x - \varphi x^2 \tag{3}$$

Among which:

• (θ) represents the value of digital collectibles (such as scarcity, artistic value, etc.);

• (η) represents the gain coefficient of service quality on utility;

• (φ)represents the negative impact of excessive purchasing.

To find the optimal strategy (x*) for consumers, we need to take the derivative of expression (3) and make it equal to zero. Solving the equation yields the optimal purchase quantity:

$$x^*\left(p,q\right) = \frac{\theta+\eta q-p}{2\varphi} \tag{4}$$

3.2. Phase two: platform decision making

The goal of the platform is to maximize profits Π, with decision variables being transaction fees (p) and service quality (q). The profit function can be expressed as:

$$\Pi(p,q,r) = p \bullet N(p,q,r) - C(q,r) \tag{5}$$

Among which:

• N(p,q,r) is a function of the number of users (investors and consumers), which can be expressed as:

$$N\left(p,q,r\right) = k_1 I^*\left(p\right) + k_2 x^*\left(p,q\right) + m \bullet r \tag{6}$$

a) (k_1, k_2) respectively represent the contribution coefficients of investors and consumers to the number of users;

b) ($m \bullet r$) indicates that regulatory policies have increased market transparency and attracted additional users (m>0).

• C(q,r) is a service cost function, which can be expressed as:

$$C\left(q,r\right) = fq^2 + c \bullet r \bullet q \tag{7}$$

a) (q) represents service quality;

b) (r) is the policy intensity of regulatory agencies;

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c) (f) and (c) are cost sensitivity parameters.

The service cost consists of two parts: basic service cost and compliance cost.The basic service cost (fq^2) is a quadratic function of service quality, reflecting the increasing marginal cost, indicating that the platform will face the problem of diseconomies of scale when pursuing high quality, and the cost will rise sharply.The cost of basic services is a quadratic function of service quality, reflecting the increasing marginal cost, indicating that platforms will face the problem of diseconomies of scale when pursuing high quality, resulting in a sharp increase in costs.

The compliance cost ($c \bullet r \bullet q$) is the linear product of policy strength (r) and service quality (q), reflecting the amplification effect of regulatory strength on costs: the stricter the policy, the higher the marginal cost of improving service quality.This cross item also reveals the interactive impact between policy and quality, that is, regulation not only directly increases costs, but also indirectly affects the platform's operational strategy through service quality, requiring the platform to consider the constraint effect of policy strength when making service quality decisions.

In order to find the optimal strategies (p*) and (q*) for the platform, we need to substitute expressions (2), (4), (6), and (7) into expression (5), and take partial derivatives of (p) and (q) respectively to make them equal to zero:

To simplify the symbols, note:

$$\alpha = \frac{k_1}{\delta} + \frac{k_2}{\varphi} - \frac{k_2{}^2\eta^2}{8\varphi^2 f}, \beta = m - \frac{k_2\eta c}{4\varphi f}, \Gamma = \frac{k_1\gamma}{2\delta} + \frac{k_2\theta}{2\varphi} \tag{8}$$

After solving the equation and backtracking, the optimal handling fee rate (p*) and optimal service quality (q*) can be obtained:

$$p^*\left(r\right) = \frac{\Gamma}{\alpha} + \frac{\beta}{\alpha}r, q^*\left(r\right) = \frac{k_2\eta\Gamma}{4\varphi f\alpha} + \left(\frac{k_2\eta\beta}{4\varphi f\alpha} - \frac{c}{2f}\right)r \tag{9}$$

3.3. Phase one: regulatory decision-making

The goal of regulatory agencies is to maximize the social welfare function (W), with the decision variable being policy intensity (r) , such as regulatory strength, transaction transparency requirements, etc.

The model in this paper simplifies the social welfare function as follows:

$$W(r) = S(r) - C(r) = \left[ar - b \bullet p^*(r)\right] - cr^2 \tag{10}$$

Among which:

- $S(r)$ represents market stability (such as reducing market manipulation, fraud, etc.).
- (ar) indicates that policy intensity (r) directly enhances market stability;
- [−bp∗(r)] indicates that excessive platform transaction fees (p*) may suppress market vitality.
- $C(r)$ represents regulatory costs (such as policy implementation costs, decreased market vitality, etc.).

In order to find the optimal policy (r*) for regulatory agencies, we need to substitute expression (9) into expression (10), take the derivative and make it equal to zero, and solve the equation to obtain the optimal policy strength (r*):

$$r^* = \frac{a - \frac{b\beta}{\alpha}}{2c} \tag{11}$$

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Through the reverse induction process described above, the optimal strategies for regulatory agencies, platforms, investors, and consumers are obtained. These strategies collectively constitute the equilibrium solution of the multi-stage Stackelberg game, namely the refined Nash equilibrium (SPNE) of the subgame.

3.4. Phase four: equilibrium analysis

3.4.1. The optimal strategy of regulatory agencies (r*)

The solution result for the optimal policy intensity of regulatory agencies is expression (11). Among them, item (a) reflects the market stability benefits brought by strengthening regulation, namely the positive externalities in terms of information transparency and risk control.The ($\frac{b\beta}{\alpha}$) item reflects the indirect impact of regulation on market vitality through influencing platform strategies. When $\beta > 0$, regulation can alleviate the inhibitory effect by attracting users; When $\beta < 0$, there will be a dual suppression dominated by compliance costs.Item (2c) reflects the accelerated increase in implementation costs and the non-linear growth of regulatory complexity.Therefore, for high (β) markets (with significant user growth), regulation can be strengthened; For low (α) markets (price sensitive), cautious measures need to be taken. When $\frac{b\beta}{\alpha} \geq a$, there will be r*=0 or an "ineffective regulatory interval", and regulatory policies should be suspended or adjusted to shift to other governance tools.

3.4.2. The optimal strategy for the platform (p*), (q*)

The solution result for the optimal handling fee rate on the platform is expression (9). The constant term reflects the price level determined by the platform based on the basic market characteristics without regulatory intervention (r=0), mainly influenced by four factors: investment return rate(γ), collection evaluation value(θ), investment risk(δ), and consumer sensitivity(φ).The linear term reflects the marginal impact of regulatory intensity (r) on the handling fee rate (p). This includes positive market expansion effects (regulation attracts more users, allowing platforms to increase transaction fees) and negative compliance cost transmission effects (regulation increases operating costs, forcing platforms to lower transaction fees). The net effect direction depends on:

$$\mathrm{sign}\left(m - \frac{k_2\eta c}{4\varphi f}\right) \tag{12}$$

• When $m > \frac{k_2\eta c}{4\varphi f}$, the net regulatory effect is positive. Regulation significantly improves market reputation and attracts a large number of new users.

• When $m < \frac{k_2\eta c}{4\varphi f}$, the net regulatory effect is negative. Regulation has led to high compliance costs for platforms, squeezing profit margins.

We can also imagine an extreme situation: if regulation completely suppresses transaction fees, i.e. p*→0, it may trigger market exit. Therefore, if regulation significantly increases transaction fees, it may suppress user engagement.p*(r) reveals the dual logic of platform pricing: market fundamentals determine the underlying price level; Regulatory policies influence pricing strategies through the channel of "user size-compliance cost".

The solution result for the optimal service quality of the platform is expression (9).The constant term reflects the optimal quality level selected by the platform based on market demand (consumer

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preference for quality (η), investor return rate (γ), collection value (θ)) and cost structure (service quality cost (f)) without regulatory intervention (when r=0).The linear term reflects the marginal impact of regulatory intensity (r) on (q*). This includes negative compliance cost effects (regulatory policies directly increase compliance costs, forcing platforms to lower quality) and positive user scale effects (regulation can attract more users, offsetting some cost pressures). The net effect direction depends on:

$$\operatorname{sign}\left(\frac{k_2\eta\beta}{4\varphi f\alpha}-\frac{c}{2f}\right) \tag{13}$$

• When $\frac{k_2\eta\beta}{4\varphi f\alpha} > \frac{c}{2f}$, the net effect is negative. Regulatory oversight significantly reduces service quality (q*), manifested as “compliance cost dominance”.

• When $\frac{k_2\eta\beta}{4\varphi f\alpha} < \frac{c}{2f}$, the net effect is positive. Regulatory measures have significantly increased the user base (m is large enough), which may lead to an increase in (q*), reflecting the dominance of market expansion

3.4.3. Investors' optimal strategy (I*)

The solution result for the optimal investment amount is expression (2). The investment return rate (γ) reflects the basic market law of "high returns attract more funds". The transaction fees (p) charged by the platform directly reduce investors' net income and have a suppressive effect.(δ) is in the denominator position, reflecting its amplification and inhibition effect: the larger the risk aversion coefficient (δ), the higher the risk compensation required by investors for the same return, leading to a decrease in investment amount.

3.4.4. The optimal strategy for consumers (x*)

The solution result for the optimal purchase quantity is expression (4). This expression reveals three key dimensions of consumer behavior: value driven, service quality leverage effect, and price suppression effect.The (θ) item represents the fundamental value of the collection and is suitable for measuring inherent attributes such as cultural value and scarcity.(ηq) explains why the platform continues to optimize user experience: (η) quantifies consumers' quality sensitivity, reflecting the characteristics of the "experience economy"; And the quality investment (q) has diminishing marginal returns.The (-p) term conforms to the classical law of demand, while adding quality adjustment, namely cross price quality elasticity: quality improvement can partially offset the negative impact of price increases.

4. Conclusions

This paper systematically analyzes the strategic interaction between regulatory agencies, platforms, investors, and consumers in the digital collectibles market by constructing a multi-stage Stackelberg game model, providing theoretical support and practical paths for the standardized development of the market.Research has found that the intensity of regulatory policies needs to be dynamically adjusted to achieve a balance between market stability and compliance costs, while platforms need to consider both user scale effects and compliance cost effects when formulating fee rates and service quality.The rational decision-making of investors and consumers, as the foundation of market stability, is significantly influenced by price, service quality, and risk preference.

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Based on the research findings, this article proposes three standardization suggestions:At the regulatory level, it is recommended to adopt a "regulatory sandbox" mechanism to implement differentiated supervision, and set special rules such as trading limits and cooling off periods for highly speculative areas; At the same time, it is necessary to improve the basic systems such as the legal attributes and transaction rules of digital collectibles.Platform enterprises should optimize their trading mechanisms, increase the audit coverage of smart contracts to industry standards, and introduce blockchain certification technology to reduce infringement risks; In addition, strict user authentication and anti money laundering mechanisms need to be established.For investors and consumers, it is recommended to establish a suitability management system, set investment thresholds, and enhance value assessment capabilities through education and popularization.

This paper is based on the assumption of perfect information and can be further extended to incomplete information game models in the future to better fit the information asymmetry situations that exist in reality;At the same time, it can be combined with simulation to quantify policy effects and explore the potential application of digital collectibles in cross-border transactions and other fields.The healthy development of the digital collectibles market requires the dynamic optimization of regulatory policies, the continuous improvement of platform operation mechanisms, and the rational behavior of market participants. Through the joint efforts of multiple parties, the standardization and sustainable development of the market can be achieved.

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