

Platform regulation and seller blockchain adoption strategies under government penalties: An evolutionary game-theoretical perspective

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ABSTRACT

The prevalence of counterfeit goods hinders the platform economy's growth. To tackle this, we model the strategic interaction between an online platform and a seller using a bilateral evolutionary game. The platform chooses between strict or lenient regulation, while the seller decides on blockchain adoption for product authentication, with government penalties as a key context. We derive the evolutionary stable strategies (ESSs) under four scenarios. Results show that the seller's blockchain adoption depends critically on its cost and the intensity of anti-counterfeiting enforcement by both the government and the platform. Excessively high penalties or insufficient subsidies can deter adoption, highlighting the need for the platform to balance subsidies and penalties. Once the seller adopts blockchain, the platform prefers lenient regulation; otherwise, the platform's decision hinges on her regulatory costs and potential government intervention. Initial strategy choices also significantly impact the evolutionary outcomes.

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1. Introduction

The rapid growth of the platform economy has led to a surge in online sellers, exacerbating the global challenge of counterfeit goods (He et al., 2023). To maximize profits, some sellers deliberately distribute counterfeits or mixed inventories, products often indistinguishable from genuine items in appearance and functionality, deceiving consumers and undermining market integrity (He et al., 2023). While traditional technologies like RFID and holography have aided product information disclosure, their centralized storage and vulnerability to tampering limit their effectiveness (Fan et al., 2022; Guan & Chen, 2017; Li et al., 2023). In contrast, blockchain technology has emerged as a transformative solution, offering decentralized, tamper-proof traceability for supply chains (Babich & Hilary, 2020).

Blockchain's distributed ledger ensures real-time, immutable data sharing among supply chain participants, enhancing transparency and reducing transaction costs (Babich & Hilary, 2020; Chod et al., 2020). For instance, major sellers (e.g., Nestlé, Chow Tai Fook) leverage blockchain to verify product origins, boosting consumer confidence and purchase intent (Kang et al., 2024; Ma et al., 2022; T. Zhang et al., 2023). However, adoption barriers persist, including high implementation costs (e.g., technology development, personnel training) and uncertain returns, deterring many sellers (Li et al., 2023).

Counterfeits also harm platforms, eroding consumer trust and competitiveness (Sun et al., 2020). In response, platforms like Amazon and Taobao have intensified seller oversight, penalizing violations and compensating affected buyers (Wang, 2025). Blockchain's traceability further aids compliance, enabling sellers to demonstrate authenticity and avoid sanctions (Wang et al., 2024; Z. Zhang et al., 2022). Yet, research on platforms' regulatory (rather than transactional) role in fostering blockchain adoption remains limited, a gap this study addresses.

Governments worldwide have intervened through measures like China's E-Commerce Law and the U.S. Executive Order 1304, which penalize platforms and sellers for counterfeit proliferation (Lefouili & Madio, 2022; Shen et al., 2021). Prior studies often idealize government roles (e.g., subsidies (Zhong et al., 2023)), overlooking punitive actions against platforms

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for lax regulation. We bridge this gap by analyzing how government penalties—targeting both sellers and platforms—shape platform governance and sellers’ blockchain adoption.

Motivated by these above observations, we are interested in addressing the following research questions:

- (1) What key factors influence the dynamic evolution of the seller’s blockchain adoption strategy and the platform’s regulation strategy?
- (2) Under what conditions can both parties achieve dynamic evolutionarily stable strategies (ESSs)?
- (3) How do government punitive measures, initial intentions of the platform and the seller, and technology subsidies affect the seller’s decisions to adopt blockchain?

2. Literature review

This study is mainly related to two streams of literature: the phenomenon of counterfeits on platforms and the application of blockchain technology.

2.1 Counterfeits research on platforms

The proliferation of counterfeit goods, fueled by the growth of e-commerce, has emerged as a critical global issue (Cho et al., 2015). Counterfeits are broadly classified into non-deceptive (e.g., knowingly purchased low-price replicas) and deceptive (i.e., products masquerading as genuine, misleading consumers) (Wang et al., 2024). Our study focuses on the latter, where sellers posing as authorized distributors exploit price differentials to profit from low-quality or unsafe imitations. Such practices erode consumer trust, damage platform reputation, and reduce social welfare (Peinkofer & Jin, 2023). To combat counterfeiting, brands employ strategies like price signaling and quality differentiation (Sun et al., 2020), while e-commerce platforms leverage authentication mechanisms (e.g., certification badges) and stricter monitoring to curb fake listings and boost consumer confidence (Lei et al., 2025). Governments play a pivotal role through enforcement measures (e.g., penalties), which incentivize retailers to proactively address counterfeiting (Yu et al., 2024). However, limited research examines governmental interventions specifically within platform-governed markets. Unlike prior work, this paper positions the platform as a market regulator and investigates how its enforcement stringency shapes seller behavior. We further integrate government penalties (targeting both platforms and sellers) to assess their long-term equilibrium effects on anti-counterfeiting dynamics.

2.2 Blockchain applications in supply chain management

Our work aligns with research on blockchain’s role in combating counterfeiting and enhancing supply chain transparency. While traditional anti-counterfeiting technologies (e.g., RFID, barcodes) face limitations such as centralized data storage and susceptibility to tampering (Fan et al., 2022), blockchain’s decentralized and immutable properties offer superior traceability (Kang et al., 2024). Studies demonstrate its effectiveness in improving consumer trust by verifying product origins (Montecchi et al., 2019) and preventing counterfeit infiltration (Kamble et al., 2020). However, blockchain adoption is context-dependent, with scholars exploring implementation conditions across scenarios (He et al., 2023; Shen et al., 2022). In platform-driven markets, blockchain’s traceability benefits extend to on-demand services, such as diamond certification (Choi, 2019) and closed-loop supply chains (Ma et al., 2022). Platform sales models (e.g., agency vs. reselling) and consumer risk aversion further influence adoption incentives (Hou et al., 2025; Zhao et al., 2024). Unlike prior work framing platforms as retailers or channels, we emphasize their regulatory role, analyzing how governance mechanisms (e.g., rewards/penalties) shape sellers’ blockchain strategies. Government interventions also play a critical role. Subsidies can incentivize blockchain adoption more effectively than enforcement alone (Peinkofer & Jin, 2023), particularly when government oversight is weak (He et al., 2023). Extending this literature, we incorporate government penalties targeting both counterfeit sellers and platforms as regulators, examining their joint impact on equilibrium strategies.

3. Problem description and basic assumptions

3.1. Problem description

Consider a platform supply chain that consisting of an upstream seller (called “he” hereafter) and a downstream online platform (called “she” hereafter). The seller, acting as an agent or distributor of branded products, sells products through the platform. However, there is a certain probability that the seller may inadvertently distribute counterfeit items. The platform employs two regulatory strategies: strict regulation and lenient regulation. As key stakeholders in the supply chain, both the platform and the seller engage in a dynamic evolutionary game, characterized by bounded rationality. Under strict regulation, the platform incurs monitoring costs and imposes fines on the seller when counterfeit sales are detected. Furthermore, as the responsible entity in the online market, the platform compensates consumers who have been harmed. In contrast, under a lenient regulatory strategy, if the platform fails to detect counterfeit activities promptly, both the platform and the seller are subject to fines imposed by the government. To enhance consumer trust, some sellers actively disclose product information using blockchain technology, ensuring the authenticity of the products they sell. However, without blockchain, consumers and the platform cannot verify product authenticity based solely on the information provided, which means that there is a certain

probability that some dishonest sellers may sell counterfeit products. In this context, under strict regulation, the platform incentivizes the seller to adopt blockchain by providing technical subsidies. Additionally, the seller’s blockchain adoption has a positive spillover effect on the platform, primarily through improved reputation and increased consumer confidence.

3.2. Basic assumptions

Assumption 1: Consider the market role of the platform that collaborates with the seller through an agency selling format. In this arrangement, the seller is required to pay the platform a commission, calculated as a proportion φ of each product unit sold on the platform.

Assumption 2: Assuming that the strategy set of the upstream seller is $X=\{\text{adopt blockchain, not adopt blockchain}\}$, and the strategy set of the platform is $Y=\{\text{strict regulation, lenient regulation}\}$. In the initial stage of the game between the two parties, the probability that the seller adopts blockchain technology is x , while the probability of non-adoption is $1-x$. The possibility of the platform implement strict regulation is y , while the possibility of lenient regulation is $1-y$, where $0 \leq x, y \leq 1$.

Assumption 3: In the case of strict regulation, the platform incurs a regulatory cost of s_1 . Furthermore, if the seller is found to be selling counterfeits, a fine of f will be imposed on the seller by the platform.

Assumption 4: In the case of lenient regulation, if the platform fails to promptly detect a counterfeit sale, the government not only imposes a fine f_m on the seller, but also imposes a fine n on the platform for inadequate oversight.

Assumption 5: The cost of blockchain adoption per unit is c_b . By adopting blockchain, the seller can offer consumers traceability services for product information. Additionally, due to the decentralized nature of blockchain technology, it reduces transaction costs, amounting to a reduction of g per unit. When the seller chooses not to adopt blockchain technology, there is a risk of selling counterfeits, which may result in counterfeit production or the sale of substandard products. The probability of the seller selling counterfeits is represented by ξ .

Assumption 6: By adopting blockchain technology, the seller can enhance consumer trust in products, which yields additional benefits for the platform. This adoption increases consumer purchasing utility, contributing to an improved platform image and an enhanced overall reputation. Therefore, the platform stands to gain significantly from integrating blockchain technology. To quantify this, let ηG represent the positive spillover effect on the platform’s reputation, where G denotes the platform’s existing reputation level, and η indicates the additional reputation enhancement coefficient due to blockchain technology. Consequently, the platform will encourage the seller to actively adopt blockchain and provide subsidies to the blockchain seller under strict regulation, at a rate of a per unit.

Assumption 7: As the market regulator and responsible party, the platform will provide additional compensation s_2 to affected consumers in order to uphold the reputation and foster consumers’ loyalty when fraudulent activities by the sellers is exposed.

4. Model analysis

This section constructs a payoff matrix for the dynamic game between the platform’s regulatory strategies and the seller’s blockchain adoption strategies, as shown in Table 1. The matrix incorporates government intervention and the potential for seller fraud. Using this payoff matrix, we first calculate the dynamic replication equations for both the platform and the seller, and analyze the stability of their dynamic evolutionary strategies. Next, we determine the equilibrium points in the evolutionary game system and identify the evolutionarily stable strategies (ESSs). We then use the Jacobian matrix to evaluate the stability of each equilibrium point. Finally, we analyze the stability of these equilibrium points in the evolutionary game system.

Table 1
Payoff Matrix

		The seller	
		Adopt (x)	Not adopt ($1-x$)
The platform	Strict regulation (y)	$(1-\varphi)p-c_b+g+a,$ $\varphi p+\eta G-s_1-a$	$(1-\varphi)p-\xi f,$ $\varphi p+G-s_1+\xi(f-s_2)$
	Lenient regulation ($1-y$)	$(1-\varphi)p-c_b+g,$ $\varphi p+\eta G$	$(1-\varphi)p-\xi f_m,$ $\varphi p-(1-\xi)G-\xi(n+s_2)$

4.1. Strategy stability analysis of the seller

The seller’s expected profit Π_{x_1} when adopting blockchain, the expected profit Π_{x_2} when not adopting blockchain, and the average expected profit $\bar{\Pi}_x$ are as follows:

$$\Pi_{x_1} = y[(1-\varphi)p - c_b + g + a] + (1-y)[(1-\varphi)p - c_b + g] \tag{1}$$

$$\Pi_{x_2} = y[(1-\varphi)p - \xi f] + (1-y)[(1-\varphi)p - \xi f_m] \tag{2}$$

$$\bar{\Pi}_x = x\Pi_{x_1} + (1-x)\Pi_{x_2} \tag{3}$$

According to the theory of evolutionary game and the replication dynamic equation (Friedman, 1991), the replication dynamic equation when the seller chooses to adopt blockchain technology is as follows:

$$E(x) = \frac{dx}{dt} = x(\Pi_{x_1} - \bar{\Pi}_x) = x(1-x)\{y[\xi(f - f_m) + a] + f_m\xi - c_b + g\} \tag{4}$$

Taking the first derivative of the formula (4) with respect to x , we get:

$$E'(x) = \frac{d[E(x)]}{dx} = (1-2x)\{y[\xi(f - f_m) + a] + f_m\xi - c_b + g\} \tag{5}$$

Letting $E(x) = 0$, we obtain $x_1 = 0$, $x_2 = 1$, $y^* = \frac{\xi f_m + g - c_b}{(f_m - f)\xi - a}$.

According to the stability principle of differential equations, the seller’s strategy for adopting blockchain technology is stable when $E(x) = 0$ and $E'(x) < 0$. Furthermore, Proposition 1 presents the stability analysis of the seller’s blockchain adoption strategy.

Proposition 1. When $y = y^*$, it follows that $E'(x) \equiv 0$. In this scenario, the seller’s blockchain strategy remains in an evolutionarily stable state, independent of the value of x . (ii) When $y \neq y^*$, let $F_1 = y[\xi(f - f_m) + a] + f_m\xi - c_b + g$, then $\frac{\partial F_1}{\partial y} = \xi(f - f_m) + a$. There are two possible cases:

Case 1: when $\xi(f - f_m) + a > 0$, F_1 is monotonically increasing in y . In this case, if $y < y^*$, then $E'(x)|_{x=0} < 0$ and $E'(x)|_{x=1} > 0$, indicating that $x = 0$ is the seller’s evolutionarily stable strategy (ESS). Consequently, the seller is disinclined to adopt blockchain technology. Conversely, if $y > y^*$, then $E'(x)|_{x=0} > 0$ and $E'(x)|_{x=1} < 0$, indicating that $x = 1$ becomes the seller’s ESS. In this instance, the seller is inclined to adopt blockchain technology.

Case 2: when $\xi(f - f_m) + a < 0$, F_1 is monotonically decreasing in y . In this case, if $y < y^*$, then $E'(x)|_{x=0} > 0$, $E'(x)|_{x=1} < 0$, and $x = 1$ is the seller’s ESS, indicating that the seller is inclined to adopt blockchain technology. Consequently, if $y > y^*$, then $E'(x)|_{x=0} < 0$, $E'(x)|_{x=1} > 0$, and $x = 0$ is the seller’s ESS. In this case, the seller is also inclined to adopt blockchain technology.

Based on the above analysis, the dynamic evolution process and phase diagram of the seller’s blockchain adoption strategy can be obtained, as shown in Fig. 1.

Proposition 1 shows that the seller's blockchain adoption depends on parameters ξ , f , f_m , and a . When platform subsidies are high (i.e., $a > \xi(f_m - f)$), with government fines approaching platform penalties ($f_m - f$), strict regulation ($y > y^*$) strongly incentivizes adoption to ensure authenticity, while lenient regulation ($y < y^*$) reduces adoption pressure.

When subsidies are low ($a < \xi(f_m - f)$) and government fines substantially exceed platform penalties, adoption motivation remains weak even under strict regulation ($y > y^*$). Conversely, lenient regulation ($y < y^*$) in this low-subsidy scenario may paradoxically encourage some adoption. This creates competitive opportunities for early adopters in otherwise reluctant markets.

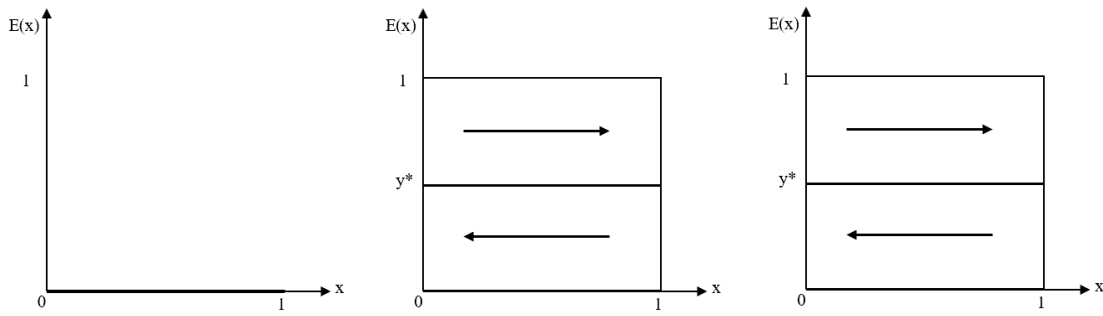


Fig. 1. The Upstream Seller's Dynamic Phase Diagram

4.2. Strategy stability analysis of the platform

The platform's expected profit Π_{y1} when implementing strict regulation, Π_{y2} when implementing lenient regulation, and the average expected profit $\bar{\Pi}_y$ are as follows:

$$\Pi_{y1} = x[\varphi p + \eta G - s_1 - a] + (1-x)[\varphi p + G - s_1 + \xi(f - s_2)] \tag{6}$$

$$\Pi_{y2} = x[\varphi p + \eta G] + (1-x)[\varphi p + (1-\xi)G - \xi(n + s_2)] \tag{7}$$

$$\bar{\Pi}_y = y\Pi_{y1} + (1-y)\Pi_{y2} \tag{8}$$

According to the theory of evolutionary game and the replication dynamic equation (Friedman, 1991), the replication dynamic equation when the platform chooses strict regulatory strategy is as follows:

$$F(y) = \frac{dy}{dt} = y(\Pi_{y1} - \bar{\Pi}_y) = y(y-1)\{x[\xi(f+n+G)+a] - \xi(f+n+G) + s_1\} \tag{9}$$

Taking the first derivative of the formula (9) with respect to y , we get:

$$F'(y) = \frac{d[F(y)]}{dy} = (2y-1)\{x[\xi(f+n+G)+a] - \xi(f+n+G) + s_1\} \tag{10}$$

Letting $F(y) = 0$, we get $y_1 = 0$, $y_2 = 1$, $x^* = \frac{(f+n+G)\xi - s_1}{(f+n+G)\xi + a}$.

According to the stability principle of differential equations, the platform's strategy for implementing strict regulation is stable when $F(y) = 0$ and $F'(y) < 0$. Based on this, Proposition 2 presents the stability analysis of the platform's regulatory strategy.

Proposition 2. When $x = x^*$, then $F'(y) \equiv 0$. At this point, regardless of the value of y , the platform's regulatory strategy is an evolutionarily stable state. (ii) When $x \neq x^*$, let $F_2 = x[\xi(f+n+G)+a] - \xi(f+n+G) + s_1$, then $\frac{\partial F_2}{\partial x} = \xi(f+n+G) + a$. There are two possible cases:

Case 1: If $x < x^*$, then $F'(y)|_{y=0} > 0$, $F'(y)|_{y=1} < 0$, and $y = 1$ is the platform's evolutionary stable strategy (ESS), indicating that the platform tends to implement strict regulatory strategy.

Case 2: If $x > x^*$, then $F'(y)|_{y=0} < 0$, $F'(y)|_{y=1} > 0$, and $y = 0$ becomes the platform's ESS, indicating that the platform tends to implement lenient regulatory strategy.

Based on the above analysis, the dynamic evolution process and phase diagram of the platform's regulatory strategy can be obtained, as shown in Fig. 2.

Proposition 2 reveals the correlation between the platform's regulatory strategy and the probability of the upstream seller

adopting blockchain technology. When the probability of adopting blockchain technology is low ($x < x^*$), there is a significant risk of counterfeit sales. This situation compels the platform to implement stricter regulatory measures. Conversely, when the probability of adopting blockchain technology is high ($x > x^*$), the authenticity of the products sold can be more reliably assured. As a result, the platform is inclined to adopt a more lenient regulatory policy.

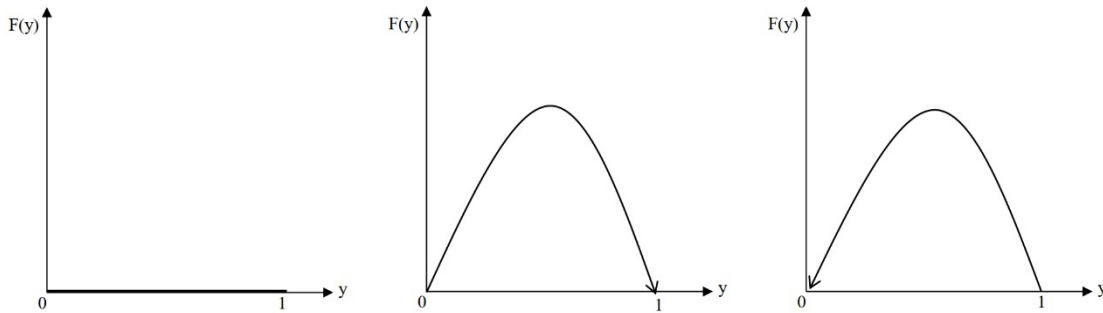


Fig. 2. The Platform's Dynamic Phase Diagram

4.3. System equilibrium point solution

Based on the replication dynamic equations of the seller and the platform, a two-dimensional dynamic system (I) has been obtained, as shown in Eq. (11).

$$\begin{cases} \frac{dx}{dt} = x(1-x)\{y[\xi(f-f_m)+a] + f_m\xi - c_b + g\} \\ \frac{dy}{dt} = y(y-1)\{x[\xi(f+n+G)+a] - \xi(f+n+G) + s_1\} \end{cases} \tag{11}$$

Proposition 3. There are five local equilibrium points in system (I), specifically: $P_1(0,0)$, $P_2(0,1)$, $P_3(1,0)$, $P_4(1,1)$ and $P_5(x^*, y^*)$.

4.4. Stability analysis of system equilibrium points

According to the equilibrium point stability testing method (Friedman, 1991). the stability of the evolutionary equilibrium points in system (I) can be assessed by analyzing the local stability of the Jacobian matrix for each of the equilibrium points. This analysis can further yield the evolutionarily stable strategy (ESS). The Jacobian matrix for system (I) is presented in Eq. (12):

$$J = \begin{bmatrix} \frac{\partial E(x)}{\partial x} & \frac{\partial E(x)}{\partial y} \\ \frac{\partial E(y)}{\partial x} & \frac{\partial E(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \tag{12}$$

where $a_{11} = (1-2x)\{y[\xi(f-f_m)+a] + \xi f_m - c_b + g\}$, $a_{12} = x(1-x)[a - \xi(f_m - f)]$, $a_{21} = y(y-1)[\xi(f+n+G)+a]$, $a_{22} = (2y-1)\{x[\xi(f+n+G)+a] - \xi(f+n+G) + s_1\}$.

Furthermore, the determinant and trace of the Jacobian matrix are respectively given by:

$$Det(J) = a_{11}a_{22} - a_{12}a_{21} \tag{13}$$

$$Tr(J) = a_{11} + a_{22} \tag{14}$$

When both conditions $Det(J) > 0$ and $Tr(J) < 0$ are simultaneously satisfied, the equilibrium point is locally stable and represents the evolutionarily stable strategy (ESS) of the system. By substituting these equilibrium points into the Jacobian matrix of system (I), we can derive the determinants and traces for each point, as presented in Table 2.

Table 2
The Equilibrium Points of System (I) in the Stability Analysis

Equilibrium point	$Det(J)$	$Tr(J)$
$P_1(0,0)$	$(\xi f_m + g - c_b)((f + n + G)\xi - s_1)$	$\xi(f + n + G + f_m) - c_b + g - s_1$
$P_2(0,1)$	$-((f + n + G)\xi - s_1)(\xi f + a - c_b + g)$	$(-n - G)\xi + a - c_b + g + s_1$
$P_3(1,0)$	$(a + s_1)(\xi f_m - c_b + g)$	$-\xi f_m + c_b - g - a - s_1$
$P_4(1,1)$	$-(a + s_1)(\xi f + a - c_b + g)$	$-\xi f + c_b - g + s_1$
$P_5(x^*, y^*)$	$\frac{(a + s_1)(\xi f + a - c_b + g)(-\xi f_m + c_b - g)((f + n + G)\xi - s_1)}{((f - f_m)\xi + a)((f + n + G)\xi + a)}$	0

It can be observed intuitively that the values of the determinant and trace are derived from the products or sums of the expressions involving $(\xi f_m + g - c_b)$, $((f + n + G)\xi - s_1)$, $(\xi f + a - c_b + g)$ and $(a + s_1)$. In Propositions 4-7, we further investigate the evolutionarily stable strategies of the system under different conditions.

Proposition 4. If $c_b < \min\{\xi f_m + g, \xi f + a + g\}$ and $\xi n > s_1 - \xi(f + G)$ (defined as scenario 1), then $P_3(1,0)$ is the stability point of the entire system. Consequently, the corresponding evolutionarily stable strategies for the upstream seller and the platform are {adopt blockchain, implement lenient regulation}.

The seller's blockchain adoption depends on fraud penalties (f, f_m) and platform subsidies (a). Proposition 4 establishes a critical threshold: when the actual adoption costs $((c_b - g)/(c_b - g - a))$ are lower than potential counterfeit penalties, sellers prefer genuine products and blockchain adoption. Higher fraud penalties or greater subsidies strengthen this preference. Notably, even with low regulatory costs ($s_1 < \xi n + \xi(f + G)$), the positive spillovers from blockchain adoption reduce the platform's incentive for strict regulation. Consequently, the system evolves toward stability point $P_3(1,0)$, converging to {adopt blockchain, implement loose regulation} regardless of initial strategies.

Proposition 5. If $c_b < \min\{\xi f_m + g, \xi f + a + g\}$ and $\xi n < s_1 - \xi(f + G)$ (defined as scenario 2), then $P_3(1,0)$ is the stability point of the entire system. Consequently, the corresponding evolutionarily stable strategies for the upstream seller and the platform are {adopt blockchain, implement lenient regulation}.

Proposition 5 shows that sellers are more likely to adopt blockchain when implementation costs are low or when anti-counterfeit measures intensify. However, if platform regulatory costs are high and penalties for counterfeit sales are inadequate - particularly when these penalties fall significantly below combined government fines and reputational losses (i.e., $\xi(n + G) < s_1 - \xi f$) - the platform may opt for lenient regulation. Consequently, the system converges to {adopt blockchain, implement loose regulation} regardless of initial strategies.

Corollary 1. When the seller adopts blockchain, the platform tends to implement a lenient regulatory strategy, and this tendency is independent of the platform's regulatory costs and the government's penalties for counterfeit incidents.

Propositions 4 and 5 reveal a key insight: blockchain adoption by sellers consistently leads to lenient platform regulation, independent of regulatory costs or government penalties. The platform benefits from reputation spillovers, effectively free-riding on sellers' blockchain adoption. This demonstrates the platform's persistent incentive for lenient regulation to capitalize on these benefits.

Proposition 6. If $c_b > \max\{\xi f_m + g, \xi f + a + g\}$ and $\xi n > s_1 - \xi(f + G)$ (defined as scenario 3), then $P_2(0,1)$ is the stability point of the entire system. Consequently, the corresponding evolutionarily stable strategies for the upstream seller and the platform are {not adopt blockchain, implement strict regulation}.

Proposition 6 demonstrates that when blockchain implementation costs $(c_b - g/c_b - g - a)$ exceed potential counterfeit fines, sellers may prefer counterfeit sales for profit maximization. Conversely, if platform regulatory costs $(s_1 - \xi f)$ are lower than potential fines and reputational losses $(\xi(n + G))$, strict regulation emerges. The system consequently converges to {not adopt blockchain, implement strict regulation} regardless of initial conditions.

This analysis reveals that despite enhanced platform oversight and subsidies, sellers may resist blockchain adoption due to unfavorable cost-benefit calculations. These findings suggest punitive measures alone are inadequate for technological transformation. More effective policy would combine targeted subsidies to offset implementation costs, flexible regulatory frameworks, and collaborative governance among stakeholders. Such integrated strategies can reduce adoption barriers while promoting sustainable supply chain transparency through balanced incentive structures.

Proposition 7. If $c_b > \max\{\xi f_m + g, \xi f + a + g\}$ and $\xi n < s_1 - \xi(f + G)$ (defined as scenario 4), then $P_1(0,0)$ is the stability point of the entire system. Consequently, the corresponding evolutionarily stable strategies for the upstream seller and the platform are {not adopt blockchain, implement lenient regulation}.

Proposition 7 establishes that government penalties and blockchain cost structures jointly determine seller adoption and platform regulation. Under lenient platform regulation without economic subsidies, sellers avoid blockchain adoption due to high costs. When platform regulatory costs exceed potential counterfeit-related losses (fines + reputational losses), lenient regulation persists. The system thus converges to {not adopt blockchain, implement lenient regulation} regardless of initial conditions.

Corollary 2. When the seller does not adopt blockchain, the platform's regulatory strategy is influenced by both the regulatory costs and the potential losses resulting from counterfeit incidents, including government fines and reputational damage.

Propositions 6 and 7 collectively demonstrate that without seller blockchain adoption, the platform's regulatory strategy depends on the balance between regulatory costs and potential counterfeit losses (government fines + reputational damage). When regulatory costs are lower than potential losses, strict regulation prevails to deter counterfeits. Conversely, when costs exceed potential losses, lenient regulation emerges as the cost-effective choice.

5. Simulation analysis

The dynamic evolution process between the seller and the platform under various constraints is illustrated intuitively through numerical simulations. Additionally, the evolutionarily stable strategies (ESSs) derived from the previous analytical analysis have been validated. To assess the accuracy of the numerical analysis, we demonstrate the dynamic strategic changes of both parties across different scenarios. Furthermore, the influence of each party's initial strategies on the evolutionary paths of the other is explored. Finally, the impact of parameter changes on stakeholders' strategic choices throughout the evolutionary process is analyzed. The initial parameter settings are presented in Table 3.

Table 3

Initial Parameter Value

Parameters	c_b	a	g	s_1	n	G	f	f_m	ξ
Initial value	6	4	3	4	12	3	7	20	0.2

5.1. ESS in different scenarios and the impact of initial value changes

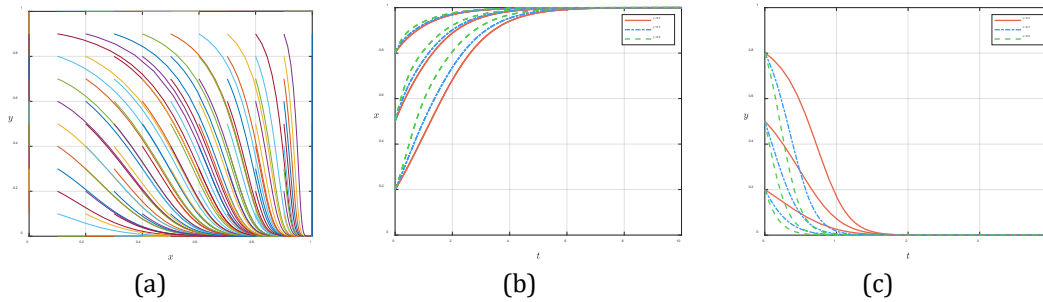


Fig. 3. Evolutionary Paths of the System, Trajectories of x, y with Different Initial States in Scenario 1

Fig. 3 illustrates the evolutionary paths and effects of the initial states of the seller and platform in scenario 1. Specifically, Fig. 3a indicates that $P_3(1,0)$ is the ESS in scenario 1, where varying initial states lead to different evolutionary paths. The further the initial state is from $P_3(1,0)$, the longer it takes for the system to reach equilibrium, consistent with Proposition 4. Fig. 3b further depicts the influence of the initial value of platform regulatory intensity y on the evolution of seller's blockchain strategy x in scenario 1. The analysis reveals that, when the initial probability of the seller adopting blockchain is fixed, a higher initial value of regulatory intensity accelerates the convergence of seller's blockchain strategy x towards 1. This finding suggests that as platform regulatory intensity increases, the seller is more inclined to adopt blockchain technology. Lastly, Fig. 3c shows the effect of the initial probability of the seller adopting blockchain technology on the evolution of the platform's regulation strategy in scenario 1. The analysis indicates that regardless of the initial strategy of platform regulatory intensity, a higher initial probability of the seller adopting blockchain results in a faster convergence of platform strategy y towards 0. This implies that in scenario 1, as the probability of the seller adopting blockchain technology increases, the platform tends to reduce regulatory intensity, given that blockchain technology can effectively ensure product authenticity. Fig. 4 illustrates the evolutionary paths and effects of the initial states of the seller and platform in scenario 2. Since the results are consistent with those in scenario 1, further details are omitted here.

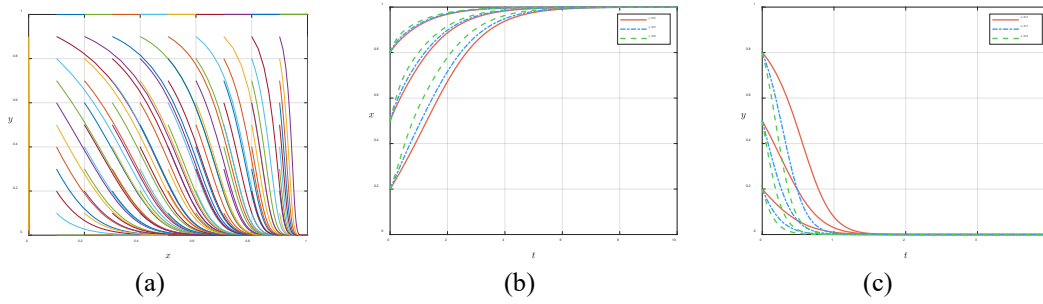


Fig. 4. Evolutionary Paths of the System, Trajectories of x, y with Different Initial States in Scenario 2

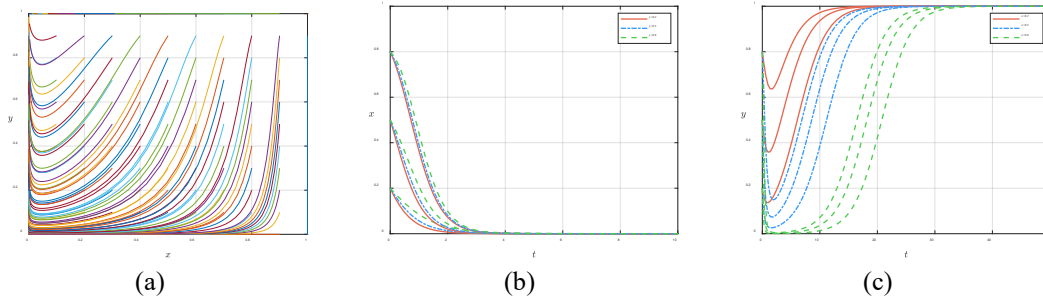


Fig. 5. Evolutionary Paths of the System, Trajectories of x, y with Different Initial States in Scenario 3

Fig. 5 presents the evolutionary paths and initial state effects in scenario 3. Fig. 5a confirms $P_2(0,1)$ as the ESS, consistent with Proposition 6, showing that greater initial distances from $P_2(0,1)$ prolong equilibrium attainment, highlighting initial states' importance in system dynamics. Fig. 5b examines how the platform's initial regulatory intensity y affects the seller's blockchain adoption x evolution. Results indicate smaller y values accelerate x 's decline to 0, revealing that lenient regulation prompts quicker decisions against adoption. Fig. 5c shows that with fixed y , smaller x values drive y faster toward 1, demonstrating the platform's initial regulatory hesitation when adoption likelihood is high, followed by progressively stricter measures as adoption probability decreases until equilibrium is achieved.

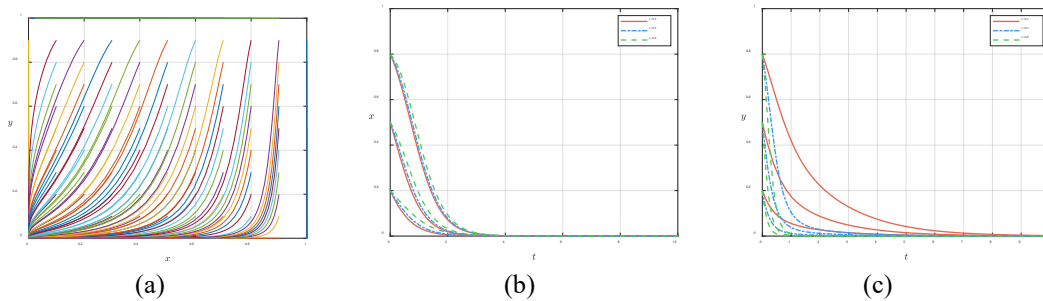


Fig. 6. Evolutionary Paths of the System, Trajectories of x, y with Different Initial States in Scenario 4

Fig. 6 shows the evolutionary paths and effects of initial states in scenario 4. Fig. 6a reveals that supply chain members reach dynamic equilibrium at point $P_1(0,0)$, with initial states determining their evolutionary paths and convergence time. Fig. 6b demonstrates that regardless of the platform's initial regulatory strictness, the seller's strategy stabilizes at non-adoption. Notably, more lenient regulation accelerates the seller's strategy x approaching 0, consistent with Proposition 7, indicating the seller's long-term conservative attitude toward blockchain adoption under platform influence. Fig. 6c shows that as the seller's adoption probability increases, the platform stabilizes into lenient regulation regardless of initial stance, with faster equilibrium attainment at higher adoption probabilities. This suggests the platform acts as a blockchain free-rider, adapting regulatory intensity to optimize benefits from the seller's adoption.

Figs. 3-6 collectively highlight how initial states shape system dynamics and reveal bidirectional platform-seller interactions. The platform's regulatory adjustments significantly influence the seller's adoption behavior, while the seller's decisions conversely affect regulatory strategy. This interdependence underscores that supply chain members must consider mutual reactions when making strategic choices. These findings offer theoretical and practical insights for managing blockchain adoption dynamics and designing effective regulatory policies.

5.2. Parameter sensitivity analysis

Fig. 7a demonstrates how government penalties influence the seller's blockchain adoption strategy. Lower penalties result in seller reluctance to adopt blockchain, while higher penalties significantly increase adoption willingness. Notably, stronger penalties lead to faster stabilization of the seller's decision point, indicating that stringent government measures effectively promote blockchain implementation for enhanced supply chain transparency and compliance.

Figs. 7b-c reveal the platform's dual impact on the seller's adoption behavior. Fig. 7b shows that technology subsidies effectively incentivize adoption by reducing initial investment costs. While Fig. 7c indicates that anti-counterfeiting measures also encourage adoption, subsidies prove more effective in achieving rapid strategy equilibrium. This suggests the platform should balance subsidies with regulatory pressure - reducing adoption barriers while maintaining deterrence against counterfeits to accelerate blockchain implementation and ensure market integrity.

Figs. 7c-d collectively analyze the platform's regulatory strategy determinants. The platform adopts lenient regulation when seller penalties are low, but increases strictness as government penalties rise. This reflects the platform's cost-benefit analysis, weighing regulatory expenses against potential fines from both sellers and government authorities. The findings confirm that the platform's regulatory strategy emerges from careful economic calculations involving these competing factors.

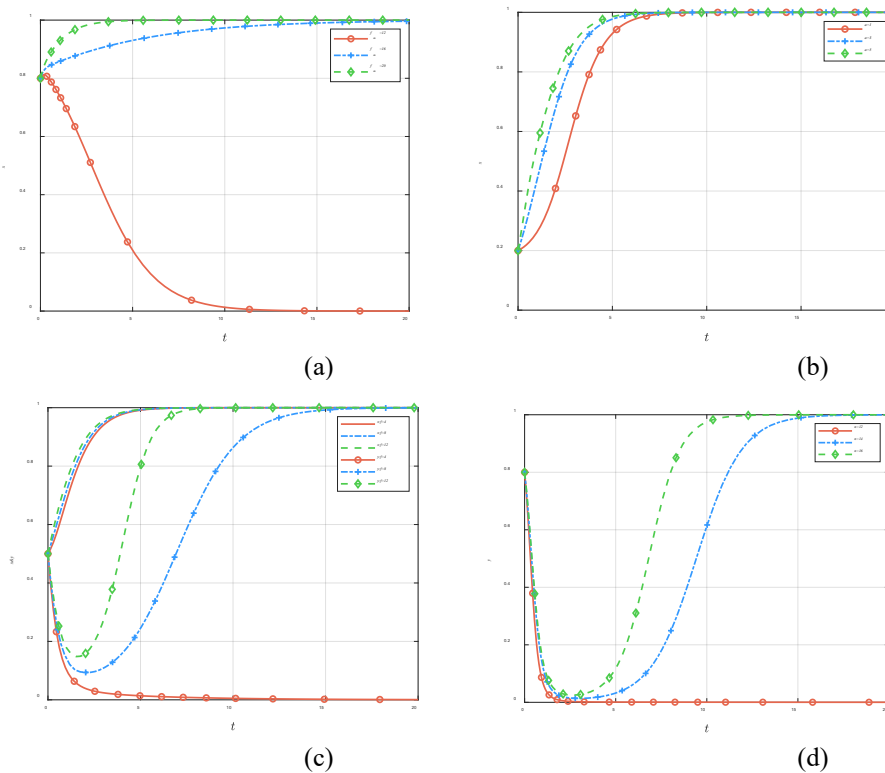


Fig. 7. The Impact of f_m , a , f , and n

6. Conclusions

6.1. Concluding remarks

Amid the growing challenges posed by counterfeits, the government has intensified focus on issues related to fraud, while platforms enforce regulations on sellers to ensure transaction security. Concurrently, to increase consumers trust and enhance competitiveness, some sellers are adopting blockchain technology to improve supply chain transparency and facilitate product traceability. Based on this, we develop an evolutionary game model that incorporates an online platform and an upstream seller, with the aim of investigating how the platform's regulatory strategy and the seller's blockchain adoption strategy evolve in the context of government penalties for counterfeit incidents. We first construct the payment matrix and replicator dynamics equations for both parties, analyzing the strategic stability of the individuals involved. Subsequently, the evolutionarily stable strategies (ESSs) within the dynamic system formed by the platform and the seller are examined. Finally, through simulation analysis, we explain how initial conditions and key parameters influence the evolutionary trajectories of both parties and their eventual stable strategies. The main conclusions of this study are as follows:

- (1) The seller's blockchain adoption strategy is primarily influenced by the actual costs of technology adoption and the intensity of counterfeit crackdowns by both the government and the platform. Specifically, when the penalties imposed by the government and the platform for counterfeits are rigorous and the blockchain subsidies provided by the platform are substantial, a strict regulatory approach enhances seller's motivation to adopt blockchain. Conversely, if the penalties for counterfeits are lenient and the subsidies are minimal, a more relaxed regulatory strategy is more likely to incentivize genuine sellers to adopt blockchain.

(2) Excessive penalties and inadequate technological subsidies hinder the motivation of the seller to actively adopt blockchain technology. While blockchain is recognized for its potential to reduce transaction costs, if the adoption costs significantly exceed the fines that the seller might incur for selling counterfeits, they may be disinclined to invest in blockchain for product traceability. In this context of economic incentives, some unscrupulous sellers may continue to engage in the risky practice of selling counterfeit products in pursuit of profit maximization. Consequently, the platform should strive to find an optimal balance between technological subsidies and penalties for counterfeits.

(3) The seller's strategy in adopting blockchain technology subsequently influences the platform's regulatory approach. When the seller adopts blockchain, the platform tends to implement a more lenient regulatory strategy, which remains unaffected by regulatory costs or the severity of government penalties for counterfeit incidents. This is because the seller's blockchain adoption generates positive spillover effects for the platform, thereby enhancing the platform's reputation. As a result, the platform, acting as a non-cooperative beneficiary or "free rider", is incentivized to maintain a lenient regulatory stance, independent of fluctuations in regulatory costs or government penalties, in order to capitalize on the benefits derived from the seller's blockchain adoption strategy.

(4) When the seller does not adopt blockchain technology, the platform's regulatory strategy is primarily shaped by actual regulatory costs and the potential severity of government actions against counterfeits. If the platform's regulatory costs are relatively low and below the potential fines imposed by the government, as well as the reputational damage associated with counterfeit incidents, the platform is more inclined to implement stringent regulatory policies.

(5) The initial strategy of the seller and the platform significantly influences evolutionary outcomes. When the platform enforces a higher level of regulation, the seller is more inclined to adopt blockchain technology, which accelerates the transition towards equilibrium strategies. Furthermore, as the probability of the seller adopting blockchain increases, the platform, acting as a potential free-rider, will ultimately shift towards a more lenient regulatory strategy, irrespective of her initial regulatory stance. This indicates that the platform will reevaluate his regulatory strategy during the blockchain adoption process to align with the evolving behavior of the seller.

6.2. Managerial implications

This study provides insights for practical management work. Firstly, it is imperative for the government and platforms to strike a balance between technology subsidies and penalties for counterfeits. Excessive penalties may diminish sellers' motivation to adopt new technologies, whereas appropriate subsidies can effectively reduce the costs associated with technology adoption, thereby incentivizing sellers to embrace blockchain technology. Secondly, platforms should implement dynamic regulatory strategies tailored to the rate of blockchain adoption among sellers. Continuous monitoring of market dynamics is essential, and regulatory strategies should be reassessed and adjusted in response to shifts in sellers' behavior. This includes tracking incidents of counterfeits, evaluating the probability of sellers adopting blockchain technology, and maintaining sensitivity to evolving market conditions. Moreover, it is crucial for platforms to acknowledge the long-term implications of initial regulatory strategies on sellers' behavior. A relatively strict initial level of regulation can facilitate faster adoption of blockchain technology among sellers, leading to a quicker attainment of market equilibrium. Lastly, fostering long-term collaborative relationships among the government, platforms, and sellers is vital for jointly advancing the digital transformation of the supply chain, thereby achieving mutually beneficial outcomes.

6.3. Future research

There are potential limitations in this work that suggest directions for future research. First, this study has examined only the government's penalties for counterfeit incidents. With the application and promotion of blockchain technology, the government has introduced various incentive policies to encourage enterprises to adopt blockchain technology. Future research could further explore how government subsidies influence sellers' adoption of blockchain. Additionally, consumer factors have not been considered in this study. In reality, the types and behaviors of consumers significantly influence supply chain decisions. Therefore, future research could incorporate various consumer types (e.g., expert versus novice consumers) and their behaviors (e.g., purchasing preferences and post-purchase regret) to analyze how these factors influence the regulatory strategies of platforms and blockchain adoption strategies of sellers.

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