# Collaborative Regulation of the "Personalization-Privacy" Dilemma Based on Stochastic Catastrophe Theory

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**Abstract.** The frequent occurrence of privacy - risk events such as "APP eavesdropping", "excessive data collection", and "big data price discrimination" has made the "personalization - privacy" dilemma that users face in precision marketing increasingly severe. There is an urgent need for collaborative regulation by enterprises and the government. However, there are many uncertain factors in the complex external environment, which can easily trigger mutations in the collaborative regulation involving multiple participants. This paper expands the evolutionary game model using random interference and stochastic dynamics equations. Based on catastrophe theory, the stochastic dynamics equations are transformed into a catastrophe model through the limiting probability density to study the nonlinear evolution process of collaborative regulation and reveal the mutation control strategies for collaborative regulation. This research provides new insights into the internal mutation mechanism of collaborative regulation evolution, offering a new way to solve the "personalization - privacy" dilemma of users in precision marketing.

**Keywords:** "personalization-privacy" dilemma; evolutionary game theory; Catastrophe; collaborative regulation

## 1 Introduction

In the digital - intelligence era, precision marketing relies on users' permission for enterprises to collect sensitive data in exchange for customized products and services [1,2]. This has significantly enhanced user experience and enterprise operational efficiency. However, with the occurrence of privacy incidents such as "APP eavesdropping", although users express strong concerns about online data, they still disclose information gratuitously to obtain personalized services [3]. While precision marketing by enterprises improves user satisfaction, it also triggers psychological resistance among users due to the infringement of their autonomy[4], thus forming the "personalization - privacy" dilemma. Based on systems theory, some scholars have already proposed the concept of "collaborative regulation". Nevertheless, the complex external environment can easily induce regulatory mutations involving multiple participants.


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Therefore, only by constructing an efficient regulatory mechanism and preventing regulatory mutations with the participation of multiple parties can the regulatory effectiveness be consolidated.

There have been numerous studies on collaborative regulation both at home and abroad. Ayres et al. [5] pointed out the drawbacks of single - government regulation. Wu Wusheng et al. [6] proposed the need to construct a security - collaborative regulatory mechanism. Ye Jun et al. [7] believed that collaboration can exert a regulatory effect of "1 + 1>2". Drawing on the research results of evolutionary games considering random perturbations, Xu Yan et al. [8] showed that the decision - making in complex systems is uncertain, and He Yitang and Xie Fuji [9] pointed out that deterministic formulas cannot describe the change law of the decision - making distribution probability over time. Therefore, this paper constructs a game model by combining evolutionary game theory and introduces white noise and stochastic dynamics equations.

In addition, collaboration is the internal coordination among subsystems within a subordinate system, where multiple factors interact non - linearly, resulting in a "catastrophe" phenomenon in regulation. This paper introduces the catastrophe theory proposed by Thom [10], which studies the nonlinear changes of systems, to determine the catastrophe points of the overall properties of the system in a complex environment and conduct prediction, management, and optimization accordingly.

In summary, this paper expands the evolutionary game model with random interference and stochastic dynamics equations. Based on catastrophe theory, it reveals the mutation control strategies for collaborative regulation, aiming to obtain conclusions that are instructive for the collaborative regulation of the "personalization - privacy" dilemma.

# 2 Model Design

## 2.1 Problem Description

The collaborative regulation aiming at the "personalization - privacy" dilemma mainly consists of heteronomous regulatory entities (regulatory authorities, consumers) and autonomous regulatory entities (enterprises). The two parties reach a consensus through communication and negotiation, alleviate interest conflicts, and jointly address privacy - norm issues.

The behavioral states of regulatory authorities (enterprises) have two relatively stable states: active regulation and passive regulation. Under the combined influence of the level of privacy concern, reputation loss, punishment, and excess returns, the behavior - decision - making of the profit - chasing entities will switch between these two stable states of active regulation and passive regulation.

## 2.2 Model Construction

Assume that both the regulatory authorities and enterprises are boundedly rational. In the initial stage of regulation, the regulatory authorities and enterprises waver in their strategic choices. The two parties continuously improve their own strategies during long - term cooperation until an equilibrium is reached. Since the enterprises and regulatory authorities studied in this paper are in an equal position in terms of the utility of collaborative regulation, they are homogeneous in this sense.

The collaborative regulation revenue obtained is denoted as *I* and the regulatory cost invested is *C*. When one party adopts passive regulation, it can obtain excess returns *U*, but also needs to accept the punishment *F* from the superior government. The probability of successful regulation is *g*, and the level of privacy concern represents the participation degree of consumers, with the probability of successful regulation by the superior government denoted as $h$. When both members choose passive regulation, the regulatory entities will face potential reputation risks, denoted as *T*. Therefore, as shown in Table 1, the pay - off matrix of the two parties can be described by a two - party symmetric game.

**Table 1.** Pay - off Matrix of the Two - Party Symmetric Game.

| Player 1 | Player 2 | |
|---|---|---|
| | Active Regulation | Passive Regulation |
| Active Regulation | $I-C/2$<br>$I-C/2$ | $I-C$<br>$U-qF$ |
| Passive Regulation | $U-qF$<br>$I-C$ | $U-qF-hT$<br>$U-qF-hT$ |

Based on the pay - off matrix, the expected returns of the regulatory entities when adopting the "active regulation" and "passive regulation" strategies, and the average expected return of collaborative regulation are respectively:

$$E_1 = x(I - C/2) + (1 - x)(I - C) \tag{1}$$

$$E_2 = x(U - qF) + (1 - x)(U - qF - \alpha T) \tag{2}$$

$$\overline{E} = xE_1 + (1 - x)E_2 \tag{3}$$

The rate of change of the probability that the regulatory entity chooses the active regulation strategy is:

$$F(x) = \frac{dx}{dt} = x(E_1 - \overline{E}) = x(1 - x)[I + (x - 1.5)C - U + qF + (1 - x)\alpha T] \tag{4}$$

$$G(x) = (\alpha T - 0.5C)x^3 + (1.5C - I + U - qF - 2\alpha T)x^2 + (I - C - U + qF + \alpha T)x \tag{5}$$

Let $a = \alpha T - 0.5C$ , $b = 1.5C - I + U - qF - 2\alpha T$, $c = I - C - U + qF + \alpha T$, Equation (5) can be simplified as:

$$G(x) = ax^3 + bx^2 + cx \tag{6}$$

For a game involving multiple participants, its regulatory process exhibits characteristics of nonlinear evolution. By introducing catastrophe theory , it is transformed into a stochastic cusp catastrophe model of collaborative regulation to analyze the mutation phenomena in the evolution of collaborative regulation within the "Personalization - Privacy" dilemma. For the convenience of analysis, the following linear transformation is performed on Equation (6):

$$M' = y^3 + ux + v \tag{7}$$

Equation (7) is the equilibrium surface equation of the standard cusp catastrophe model. Drawing on the research of other scholars, white noise is introduced to reflect random perturbations and eliminate the interference of uncertain factors. The deterministic system (6) is extended to a stochastic dynamical system, thereby generating a stochastic differential equation of the [type] form, that is:

$$dx(t) = (ax^3 + bx^2 + cx)dt + \varepsilon(x)dw(t) \tag{8}$$

In the stochastic system of Equation (8), the value of the variable is uncertain, and there are countless possible evolutionary trajectories. To describe the non - periodic and irregular evolution state of this dynamical system, it is necessary to utilize the probability density function of the stochastic cusp catastrophe theory and explain it from the equilibrium state in a statistical sense.

Assume that the initial value of the random variable in the stochastic system is the $x_0$, then the probability density function of Equation (10) at time point $t$ is:

$$f(r, t, x_0) = \frac{d}{dr} Prob\{x(t) < r | x(0) = x_0\} \tag{9}$$

Equation (8) can be written as the expression of the following stochastic catastrophe model:

$$dx(t) = \frac{\partial V(x,g)}{\partial x} dt + \varepsilon(x)d\omega(t) \tag{10}$$

According to Cobb's research on stochastic catastrophe theory, when $f(r, t, x) \rightarrow f^*$, the limiting probability density function can be expressed as:

$$f^*(x) = N_a exp[-V_{sto}(x)] \tag{11}$$

$$V_{sto}(x) = -2 \int_a^x \frac{\frac{\partial V(z,g)}{\partial z} - \frac{[\varepsilon^2(z)]'}{2}}{\varepsilon^2(z)} dz \tag{12}$$

Since the equilibrium points of the potential function of collaborative regulation are consistent with the modes of the static probability density function, the mutation of the stochastic process can be transformed into studying the mutation or phase transition in the topological structure of the limiting probability density function with respect to the mode and antimode.

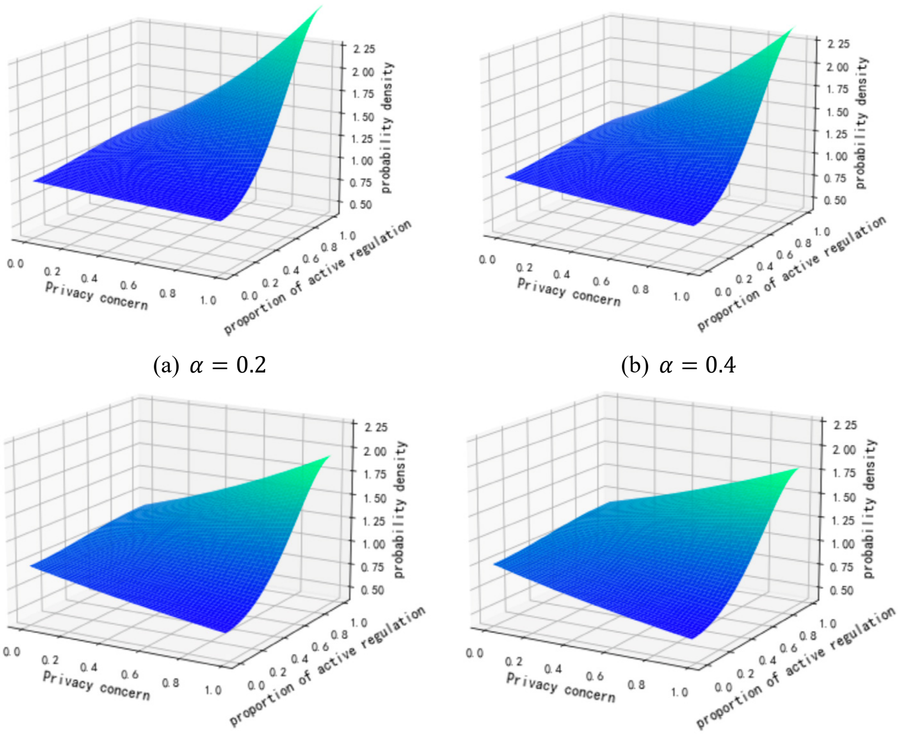
## 3 Simulation Analysis

To further clarify the control strategies for the collaborative regulation of the "personalization - privacy" dilemma, it is necessary to quantitatively analyze the impacts of the level of privacy concern, reputation loss, punishment intensity, and excess returns during the mutation process.

Referring to the actual regulatory process, in the following simulation experiments, a set of basic values are set: $\alpha = 0.5$, $I = 30$, $C = 18$, $T = 20$, $F = 20$, $U = 30$, $g = 0.5$. We will explore the probability density function graphs generated by the changes of parameters within a specific range under different initial probabilities of active regulation. Combining the mutation phenomena of collaborative regulation and practical cases, we will discuss the control strategies for the collaborative regulation of the "personalization - privacy" dilemma.

### 3.1 Level of Privacy Concern

As shown in Figure 1, when the level of privacy concern varies within the interval [0,1], we explore the impact of different initial probabilities of active regulation on the stability of collaborative regulation.




(a) $\alpha = 0.2$ (b) $\alpha = 0.4$

(c) $\alpha = 0.6$ (d) $\alpha = 0.8$

**Fig. 1.** The graph of the limiting probability density function under the change of the privacy concern level *h*.

When the level of privacy concern is relatively low, there is no tendency of a "high - rising tail" on the left side of the graph. This indicates that when the level of privacy concern is low, the regulatory attitude of the regulatory entities is unclear. However, when the level of privacy concern is relatively high, the right - tail area of the probability density graph shows a "right - high - rising tail" phenomenon. It shows that when the consumers' level of privacy concern exceeds a certain value, the participants in collaborative regulation will choose active regulation with a relatively high probability.

By comparing the "left - tail" areas of the four graphs, when the consumers' level of privacy concern is at a low level, continuously increasing the initial probability of active regulation does not lead to obvious changes in the degree of the "left - high - rising tail". This suggests that when the level of privacy concern is low, relying solely on the participation of regulatory entities cannot promote the healthy development of collaborative regulation.

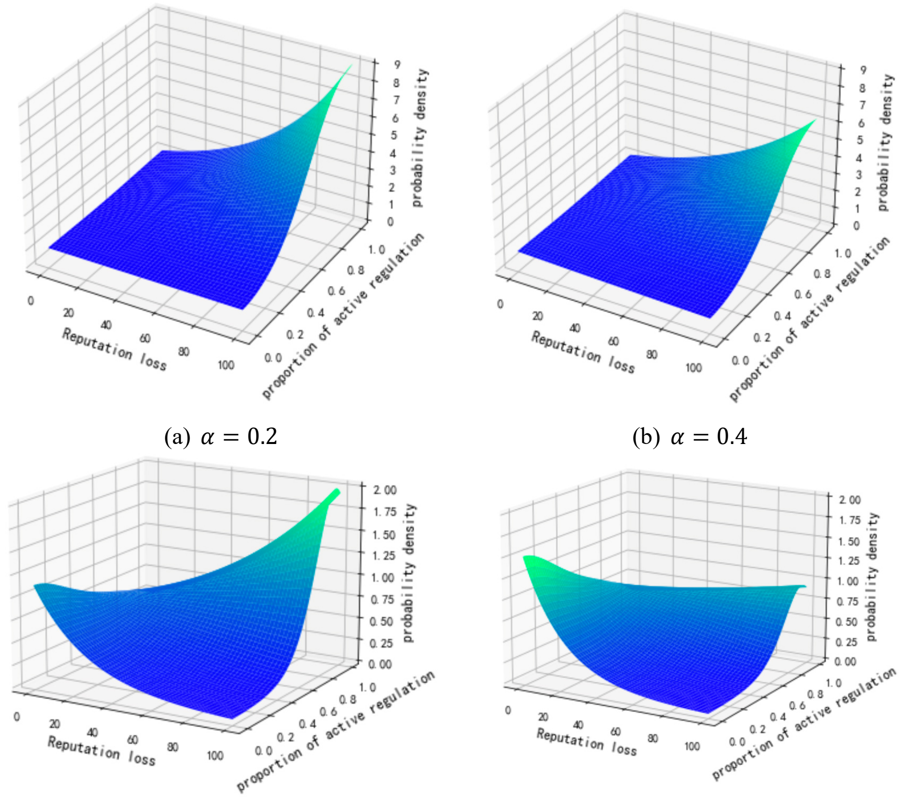
In conclusion, when the consumers' level of privacy concern is very low, simply increasing the initial probability of active regulation cannot encourage regulatory entities to conduct active regulation. On the other hand, even if the initial probability of active regulation is very low, a high level of privacy concern can prompt all parties involved in collaborative regulation to adopt active regulatory strategies. When the consumers' level of privacy concern exceeds a certain critical value, the steady - state of collaborative regulation abruptly changes from passive regulation to active regulation.

For example, the popularity of online shopping has given rise to express - delivery - related frauds that exploit information loopholes. In November 2020, an employee of YTO Express leased internal accounts for profit, resulting in the leakage of 400,000 citizens' personal information. Criminals used the accurately obtained personal information of consumers to carry out fraud. As frauds became more frequent, consumers gradually attached importance to the privacy and security of express - delivery information, which prompted regulatory authorities to launch special governance actions on personal information security in the express - delivery sector. Under the dual supervision, enterprises began to vigorously implement a series of measures such as real - name registration for parcel sending, privacy face - sheets, and virtual phone numbers. By November 2022, the daily usage of privacy face - sheets in the entire industry exceeded 150 million.

Therefore, as the direct handlers of their own information, consumers should be encouraged by government departments to play a full supervisory role in privacy regulation. By paying attention to their own information security from the source, a trustworthy atmosphere can be reconstructed in the personalized marketing environment.

### 3.2 Reputation Loss

As shown in Figure 2, when the reputation loss varies within the interval [0, 100], we explore the impact of different initial probabilities of active regulation on the stability of collaborative regulation.




(a) $\alpha = 0.2$ (b) $\alpha = 0.4$

(c) $\alpha = 0.6$ (d) $\alpha = 0.8$

**Fig. 2.** The graph of the limiting probability density function under the change of the reputation loss *T*.

As shown in Figure 2(c), when the initial probability of active regulation as the reputation loss increases, the graph of the limiting probability density function shows a saddle - shaped depression with "high - rising tails on both sides". When the reputation loss is relatively small, it presents a "left - high - rising tail", indicating that the regulatory entities are more likely to choose passive regulation. When the reputation loss increases to 80, the evolutionary trajectory of active regulation suddenly jumps from near 0 to 1, and the regulatory state undergoes a mutation, with the degree of the "right - high - rising tail" increasing. This shows that when the reputation loss exceeds a certain value, the regulatory entities will choose active regulation with a relatively high probability.

Observing the "right - tail" area, as the initial probability of active regulation increases, when the reputation loss is relatively high, the "right - high - rising tail" weakens continuously, and the probability of the regulatory entities choosing active regulation decreases. This indicates that increasing the initial probability of active regulation will weaken the positive effect of increasing the reputation loss on collaborative regulation. Observing the "left - tail" areas of the four graphs, as the initial probability of active regulation increases, the degree of the "high - rising tail" rises continuously, indicating that when the reputation loss is relatively low, increasing the initial probability of active regulation will make the regulatory entities more likely to choose passive regulation. This is because when the regulatory entities choose active regulation with a relatively high probability, they need to pay certain regulatory costs, while passive regulation does not bring large reputation losses, so the entities tend to choose passive regulation.

In conclusion, reputation loss has a certain inhibitory effect on the mutation of collaborative regulation, but it needs to be restricted by the initial probability of regulation. When the reputation loss caused by public opinion and other factors exceeds a certain value, the regulatory entities and enterprises will choose active regulation with a relatively high probability to maintain the stability of the system. For example, in 2022, the learning software "Learning Pass" suffered a database leak of 1.7 billion user data, which seriously damaged its reputation. To deal with the trust crisis, it had to improve encryption technologies and standards. Therefore, when the reputation loss is low, the regulatory authorities should expose the privacy - infringing and other credibility - damaging behaviors of marketing enterprises and restrict the reputation - related activities of relevant enterprises, so that they face high reputation losses, enhance the enterprises' willingness for collaborative regulation, and at the same time increase the initial proportion of active regulation; when the reputation loss is high, relevant appeal mechanisms should be introduced to guarantee the legitimate rights and interests of enterprises, prevent malicious boycotts by consumers, and the initial probability of active regulation should be reduced to create a positive atmosphere guided by reputation.

## 4 Conclusions

To explore effective means to break the "personalization - privacy" dilemma, this paper extends the evolutionary game model using random disturbances and stochastic dynamic equations to study the evolutionary process of collaborative regulation in the "personalization - privacy" dilemma. Based on catastrophe theory, the stochastic dynamic equations are transformed into a catastrophe model through the limiting probability density to reveal the control strategies for the mutation of collaborative regulation. The following conclusions and insights are obtained:

(1) The consumers' level of privacy concern has a positive effect on active regulation, but the initial probability of active regulation is negatively correlated with active regulation. Interestingly, when the level of privacy concern is low, simply increasing the initial probability of active regulation cannot encourage regulatory entities to conduct active regulation. Therefore, government regulatory departments should encourage consumers to play a full - fledged supervisory role in privacy regulation, pay attention to their own information security from the source, and reconstruct the trust atmosphere in the personalized marketing environment.

(2) Increasing the reputation loss can inhibit the mutation of collaborative regulation. However, increasing the initial probability of active regulation will weaken the

positive effect of reputation loss on collaborative regulation. Thus, a multi - level control mechanism that combines reputation loss and the initial probability of active regulation should be established, and multiple reputation - guiding mechanisms such as exposure and appeal should be provided.

## References

1. Arpetti J, Delmastro M. The privacy paradox: a challenge to decision theory?[J]. Journal of Industrial and Business Economics, 2021, 48(4): 505–525.
2. Chellappa R K, Sin R G. Personalization versus Privacy: An Empirical Examination of the Online Consumer’s Dilemma[J]. Information Technology and Management, 2005, 6(2–3): 181–202.
3. Norberg P A, Horne D R, Horne D A. The Privacy Paradox: Personal Information Disclosure Intentions versus Behaviors[J]. Journal of Consumer Affairs, 2007, 41(1): 100–126.
4. Martin K. Breaking the Privacy Paradox: The Value of Privacy and Associated Duty of Firms[J]. Business Ethics Quarterly, 2020, 30(1): 65–96.
5. Yu, H., Liu, Y., Liu, C., et al. Spatiotemporal V ariation and Inequality in China's Economic Resilience across Cities and Urban Agglomerations[J]. Sustainability, 2018, 10(12): 1-19.
6. Wu Wusheng, Xu Sanyuan, Chen Guohua. Research on safety supervision mechanism from the perspective of synergy theory[J]. Journal of Safety Science and Technology, 2013, 9(4): 150–155.
7. Ye Jun, Wang Junhua. Research on China's food safety supervision mechanism from the perspective of synergy theory[J]. Chinese Health Service Management, 2012, 29(7): 504–506.
8. Xu Yan, Hu Bin, Qian Ren. Stability analysis and simulation of strategic alliance based on stochastic evolutionary game[J]. Systems Engineering - Theory & Practice, 2011, 31(5): 920–926.
9. He Yitang, Xie Fuji. Stochastic evolutionary game analysis of industry - university - research collaborative innovation[J]. Management Review, 2020, 32(6): 150–162.
10. Thom R. Structural stability and morphogenesis[J]. Pattern Recognition, 1976, 8(1): 61.