Key stakeholder perceived value's influence on autonomous vehicles' privacy and security governance – an evolutionary analysis based on the prospect theory

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Abstract

Purpose – The promotion of autonomous vehicles introduces privacy and security risks, underscoring the pressing need for responsible innovation implementation. To more effectively address the societal risks posed by autonomous vehicles, considering collaborative engagement of key stakeholders is essential. This study aims to provide insights into the governance of potential privacy and security issues in the innovation of autonomous driving technology by analyzing the micro-level decision-making processes of various stakeholders.

Design/methodology/approach – For this study, the authors use a nuanced approach, integrating key stakeholder theory, perceived value theory and prospect theory. The study constructs a model based on evolutionary game for the privacy and security governance mechanism of autonomous vehicles, involving enterprises, governments and consumers.

Findings – The governance of privacy and security in autonomous driving technology is influenced by key stakeholders' decision-making behaviors and pivotal factors such as perceived value factors. The study finds that the governmental is influenced to a lesser extent by the decisions of other stakeholders, and factors such as risk preference coefficient, which contribute to perceived value, have a more significant influence than appearance factors like participation costs.

Research limitations/implications – This study lacks an investigation into the risk sensitivity of various stakeholders in different scenarios.

Originality/value – The study delineates the roles and behaviors of key stakeholders and contributes valuable insights toward addressing pertinent risk concerns within the governance of autonomous vehicles. Through the study, the practical application of Responsible Innovation theory has been enriched, addressing the shortcomings in the analysis of micro-level processes within the framework of evolutionary game.

Keywords Perceived value, Prospect theory, Responsible innovation, Key stakeholder, Autonomous vehicles, Evolutionary game

Paper type Research paper

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1. Introduction

In an epoch characterized by technological progress, the convergence of autonomous vehicles (AVs) with travel behavior emerges as a pivotal domain deserving investigation. The emergence of AVs can significantly reduce road accidents, improve transportation convenience, alleviate congestion, minimize pollution and optimize both the comprehensive safety of traffic (Levy and Haddad, 2022). In addition, to expedite the technological diffusion of AVs and foster active consumer participation, enterprises actively develop relevant technology platforms, shaping employment opportunities, such as "Baidu Apollo." The advent of AV platforms has further intensified the potential risks associated with privacy and security concerns. However, the requisite installation and deployment of intricate embedded systems for this technology have become more prone to network attacks due to the increased attack surface and increased adversarial motivations (Khan *et al.*, 2023). For instance, when consumers contemplate the AV platform established by enterprises, they are mandated to provide a significant amount of personal privacy information to AVs, thereby elevating the risk of privacy violations and compromising information security (Becker and Axhausen, 2017). Privacy and security concerns have diminished consumer trust and acceptance of the technology (Haboucha *et al.*, 2017). To facilitate the effective diffusion of the technology, there is an imminent need for proactive governance research.

The pledged environmental and societal advantages of AVs will only materialize if the associated privacy and security risks are adequately mitigated. In response, Wang advocated technological measures, including privacy protection via digital signatures (Wang and Fan, 2022), and Lu suggested implementing privacy-preserving techniques grounded in a Federated Learning architecture (Lu *et al.*, 2020). These represent new responsibilities for enterprise technology, signifying the shift of contemporary enterprises from a conventional emphasis on business technology toward a focus on social responsibility (Mahnoor *et al.*, 2021). However, the governance of the privacy dilemma of AVs requires the collaborative participation of multiple stakeholders, and it is not enough to rely on suggestions at the technical level. It is necessary to explore the interaction impact of decisions of key stakeholders from the micro process.

In the early 21st century, scholars in the Western world initiated discussions on the concept of "Responsible Innovation" (RI). RI is a dynamic process involving the collaborative participation of numerous stakeholders (Stilgoe *et al.*, 2013). Adhering to the tenet that enterprises assume foreseeable liabilities and that all stakeholders collectively shoulder technical responsibilities, the theoretical framework of RI furnishes a conceptual foundation for the study. The proactive implementation of RI by enterprises is conducive to guiding innovation toward moral acceptability and societal satisfaction. However, existing studies predominantly concentrate on theoretical frameworks and behavioral agents, often overlooking a thorough understanding of the behavioral changes exhibited by key stakeholders (Yang *et al.*, 2021). Therefore, the research gap lies in addressing how to guide enterprises in the implementation of RI behaviors within the practical dynamics of the "human-vehicle-road" interactive collaboration in AVs.

Previous research has demonstrated that evolutionary game theory can addresses the limitations of traditional approaches by accounting for individual and social behaviors of key stakeholders (Yuan *et al.*, 2022). However, the theory ignores the influence of individual subjective differences and other factors on decision-making. And recent research has found that variations in the values, perceptions of profit and loss and risk attitudes among decision-makers result in significant disparities in psychological preferences (Zhang *et al.*, 2022). These differences directly impact the perceived value of stakeholders for making decisions. Moreover, stakeholders dynamically adapt their behavioral decisions based on comparative benefits and psychological advantages within the confines of bounded rationality (Brüne and Wilson, 2020). Therefore, it is crucial to include the perceived value of key stakeholders in the evolutionary game theory for a more nuanced analysis of governance in addressing privacy and security concerns.

The research question is to scrutinize and analyze the micro-level processes involved in the governance of privacy and security issues in AVs through the implementation of RI by enterprises. Furthermore, it delves into an in-depth examination of the impact of decision-making behaviors of key stakeholders and other crucial parameters, ensuring that the research question possesses both practical significance and authenticity.

To effectively address the aforementioned issues, the study integrates key stakeholder theory, perceived value theory and prospect theory to provide a comprehensive understanding. Subsequently, we construct a model based on evolutionary game theory, wherein government, enterprises and consumers play pivotal roles as key actors. Furthermore, leveraging the established model, the objective is to elucidate equilibrium strategy choices among key stakeholders and analyze the mechanistic influence of factors on the decision-making processes of these stakeholders. Finally, the study proposes recommendations based on the findings to encourage multi-participation and effective governance of AVs, ensuring societal stability and healthy development.

This study presents three primary innovations:

(1) To tackle privacy and security challenges in AVs, the study integrates RI theory, providing novel ideas and recommendations for enterprises to fulfill their responsibilities. The research adopts an anticipatory governance approach, analyzing influencing factors to offer insights into AV-related governance issues.

(2) The study incorporates RI theory into the problem governance process, enhancing its practical application.

(3) Acknowledging the substantial impact of irrational factors on decision-makers' behavioral choices and the evolutionary game, the research incorporates prospect theory and perceived value theory.

By examining the influence of various perceived values, such as risk preference and efficiency preference, on the evolutionary game analysis, the study addresses the limitations of the evolutionary game in considering subjective factors.

2. Literature review

2.1 The governance of privacy and security in autonomous vehicles

With the advent of internet and data analysis, issues surrounding the protection or sharing of personal data have emerged as crucial nexuses of economic and policy debate (Acquisti *et al.*, 2016). In a recent survey, 93% of respondents voiced concerns about data privacy, with identity theft and fraud being the top worries (Keszey, 2020). Without addressing privacy and security risks, the promised environmental and societal benefits of AVs will remain mere rhetoric.

The governance of privacy and security in AVs has garnered extensive attention from scholars. Zhu indicated the application of blockchain technology in the vehicular crowdsensing of AVs, thereby proposing solutions to mitigate privacy and security risks (Zhu *et al.*, 2022). Yuan designed an aggregation scheme based on differential privacy and a reputation model of the data receiving interface circuit vehicles for the problem of data privacy leakage (Yuan *et al.*, 2023). Research on the governance of privacy and security in

AVs is vigorously progressing at the technical level. However, ethical and moral constraints are poised to be more significant issues, as ethical principles will foster fairness in technical governance (Brandao *et al.*, 2020). However, there remains a notable deficiency in research concerning the ethical and moral aspects at the governance of privacy and security.

Drawing from considerations of ethical and moral constraints in innovation, the concept of RI was first introduced in 2003, emphasizing the shared social responsibility undertaken by actors and societal stakeholders. It guides the innovation process toward ethical acceptability, sustainable development and societal satisfaction (Owen *et al.*, 2012). The theory of RI promotes creative approaches to assessing and managing risk, opening up new avenues for productive and socially responsible technology innovation (Maynard and Scragg, 2019). Hemphill argues that enterprises collecting and managing such data bear the responsibility of safeguarding the data against misuse and exploitation (Hemphill, 2019). Goering advocated for responsible approaches to innovation, including improved informed consent practices and default settings that require an active opt-in for sharing brain data to solve the privacy and security risks (Goering *et al.*, 2021).

Existing research suggests that the theory of RI effectively addresses privacy security issues. However, current studies mainly focus on theoretical aspects and behavioral recommendations for individuals, neglecting the examination of micro-interactions among diverse stakeholders. The governance of AVs requires collaboration among various parties, making it essential to consider the impact of key stakeholders.

2.2 Stakeholder theory and autonomous vehicles' key stakeholders

Freeman emphasized the close relationship between stakeholders and enterprises, highlighting their significant role in the development of organizations (Freeman, 1984). As social and economic organizations, enterprises primarily aim to fulfill the needs of consumers and society through production, thereby generating profits to sustain their survival and growth. Corenell and Shapiro asserted that meeting the implicit needs of key stakeholders, such as consumers, not only enhances an enterprise's reputation but also positively impacts its value enhancement (Cornell and Shapiro, 1987). Ansell and Gash proposed that incorporating key stakeholders, such as consumers, into collaborative governance would foster a sense of shared responsibility, thereby enhancing governance efficiency (Ansell and Gash, 2018). At the level of privacy and security governance, consumers can establish close connections with enterprises on platforms incorporating artificial intelligence technology, thereby facilitating enterprises in undertaking privacy and security governance (Wang and Wu, 2014). Furthermore, scholars argue that effective governance of privacy and security issues relies on ethical principles of mutual benefit among stakeholders like enterprises and consumers (Arthur and Owen, 2019). The governance process can achieve greater responsiveness and effectiveness only through the collaborative participation of key stakeholders, conducted in a responsible manner.

The implementation process necessitates being rooted within an innovation ecosystem comprising relevant stakeholders, such as government, enterprises and consumers (Bacq and Aguilera, 2022). Therefore, it is anticipated that significant preparation on the part of key stakeholders, including enterprises, consumers and governing authorities, would be needed before the market can fully accept AVs (Sinha *et al.*, 2020). To investigate the challenges encountered during the diffusion of AVs, scholars identified technology firms, manufacturing companies, drivers, government and transport policy consortiums as key stakeholders (Pettigrew *et al.*, 2018).

The exploration of privacy and security governance in the context of AVs should focus on key stakeholders to uncover crucial challenges. Furthermore, this exploration should extend beyond theoretical discussions and address the research gap in the existing literature concerning stakeholder interactions in the micro process.

2.3 The theory of evolutionary game and its application in Responsible Innovation

Using the theory of evolutionary games enables a more comprehensive examination of the micro-processes involved in stakeholders' interactions. Currently, numerous studies have explored the implementation of RI and the process of risk management, using the evolutionary game method. In the simulation and analysis of behavioral strategies used by the government, enterprises and the general public, Yang devised a trilateral evolutionary game model. This model elucidates the manner in which RI within infrastructure projects can contribute to their sustainable development (Yang *et al.*, 2021). Lacroix conceptualized the societal dilemma within the framework of moral progression in artificial intelligence through the application of an evolutionary game model (LaCroix and Mohseni, 2022).

However, the theory of evolutionary games also has inherent limitations For example, agent decisions are frequently asynchronous, and each agent may have unique preferences, payoffs, and strategy alternatives (Szabo and Fath, 2007). Moreover, within the realm of AVs, recent research suggests that decision-making processes are notably impacted by the attributes of key stakeholders and the element of perceived value, potentially serving as pivotal determinants (Mo *et al.*, 2021).

2.4 Prospect theory and the perceived value

Multiple scientific inquiries have illustrated the diversity in stakeholders' attitudes and behaviors regarding novel technology and its associated risks, influenced by a spectrum of psychological, cultural and cognitive factors (Frewer *et al.*, 1998). Additionally, Thaler's research highlighted that individuals tend to compare and evaluate the perceived value of potential gains and losses when making decisions (Thaler, 1985).

Tversky created a prospect theory with increased explanatory efficacy, seeking a thorough investigation into the impact of irrational factors on stakeholders' decision-making processes (Tversky and Kahneman, 1979). Prospect theory posits that stakeholders assess the gains and losses associated with a decision using reference points. In addition, stakeholders' risk aversion and loss sensitivity will impact their assessment of perceived value, which will alter the results of behavioral choices in turn (Wang *et al.*, 2023). The rise of prospect theory has influenced research in the fields of economy and risk management (Lindner *et al.*, 2022).

Zheng created models to analyze the interactions between local governments and producers of new energy vehicles based on prospect theory, and then investigated the effects of various initial values on the game's evolutionary outcomes (Zheng *et al.*, 2023). Wang proposed an evolutionary game model based on prospect theory to address the issue of building infrastructure for electric vehicle charging (Wang *et al.*, 2022a, 2022b).

However, there is a lack of research on the application of prospect theory in the field of autonomous driving cars. As previously highlighted, the perceived value of stakeholders significantly influences the behavior of making decisions. Therefore, there is a need to further explore the use of prospect theory in studying and addressing specific challenges.

Building upon the analysis of existing studies, this research concludes that implementing RI is beneficial for proactively addressing potential privacy and security concerns in AVs. However, there is a lack of research on the micro-level implementation processes of RI. There is a need for supplementary studies that align with the collaborative dynamics of "human-vehicle-road" interactions. Additionally, while acknowledging the significant impact of key stakeholders interactions in the micro-level governance process, the current use of evolutionary game theory lacks sufficient consideration of subjective perceptual differences among stakeholders, leading to potential disparities with real-world situations.

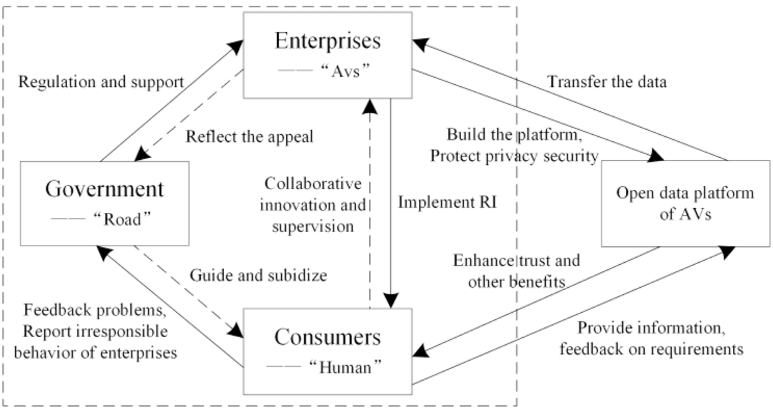
To address the aforementioned issues, this study comprehensively examines the micro-level process of governing privacy and security issues in the implementation of RI by enterprises, taking into account the interactive influences of stakeholders and subjective perceptual differences. This study integrates prospect theory, perceived value theory, key stakeholder theory and evolutionary game theory to examine the governance of privacy and security in AVs. By exploring the micro-processes of key stakeholders' interactions and their impact on RI, the research aims to provide insights into the privacy and security governance of AVs. Furthermore, the study conducts simulation analysis to evaluate the influence of internal and external factors and draws conclusions regarding privacy and security governance.

3. Model building and assumption

In the diffusion of AVs, the key stakeholders, namely, government, enterprises and consumers, play pivotal roles. For the governance of privacy and security issues, it is crucial to consider the differences in perceived value caused by the diversified risk preferences and interest preferences of these stakeholders. Based on the interactions among key stakeholders in AVs and the practical behaviors of stakeholders in governing privacy and security issues, this study presents the behavioral framework for governing these concerns in AVs, as depicted in Figure 1.

3.1 Model assumption

Assumption 1. Enterprises, driven by their quest to advance technologies, proactively establish data platforms. However, these platforms also give rise to potential risks, such as privacy breaches and ethical obligations (Han *et al.*, 2023). Consequently, all parties are actively urging enterprises to further fulfill their responsibilities. So, this study assumes that the strategic choices available to enterprises are (implement RI, not implement RI), with corresponding proportions of x and $1 - x$, $x \in [0, 1]$. Assuming that consumers can engage in communication, cooperation and supervision to report irresponsible behavior by enterprises, their strategic choices encompass the options of (collaborative innovation and supervision,



Source: Figure by authors

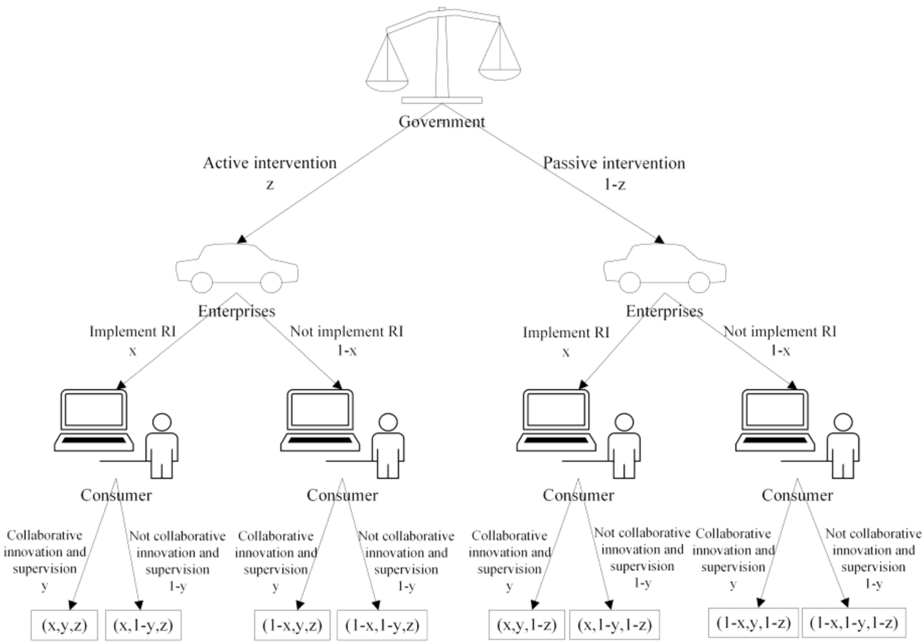
Figure 1.
System analysis framework for the governance of privacy and security in AVs

not collaborative innovation or supervision), with corresponding proportions of y and $1-y$, $y \in [0, 1]$. In the process of privacy and security governance, the government advocates for the integration of innovation and ethics within enterprises, assuming the roles of regulating enterprises and guiding consumer participation. Therefore, the decision-making space of the government is set as (active intervention, passive intervention), with corresponding proportions of z and $1-z$, $z \in [0, 1]$. Based on the assumptions, the many strategies were laid out in a game tree, as illustrated in Figure 2.

Assumption 2. The perception gap regarding the risks and benefits of AVs can lead different perceived value and influence individual decisions (Lee *et al.*, 2019). This study uses E to represent the perceived value of decision makers, with the expression $E = \sum_i \pi(\varepsilon)[V(f) - Z(f)]$. $\pi(\varepsilon)$ represents the decision function, $V(f) - Z(f)$ represents the difference between the valence account and the cost account, ε represents the probability. Attributable to the inclination of individuals to overestimate the likelihood of high-probability events, the decision function $\pi(\varepsilon)$ exhibits the following properties: $\lim_{\varepsilon \to 0} w(\varepsilon) > \varepsilon$, $\lim_{\varepsilon \to 1} w(\varepsilon) < \varepsilon$, $\pi(1) = 1$, $\pi(0) = 0$. Furthermore, the decision weight function can be represented as follows:

$$\pi^{\pm}(\varepsilon) = \frac{\varepsilon^r}{\left[\varepsilon^r + (1 \pm \varepsilon)^r\right]^{\frac{1}{r}}} \tag{1}$$

In equation (1), $\pi^{\pm}(\varepsilon)$ represents the valence or cost, and r is the decision sensitivity coefficient. Due to the limited research on the perceived value of privacy and security in



Source: Figure by authors

Figure 2. The structural tree of the game model

AVs, the decision sensitivity coefficients of the valence account and the cost account are unified and represented by the symbol r. A higher value of r reflects a greater subjective identification rate of individuals.

Drawing on the research of prospect theory, decision makers demonstrate distinct characteristics. Deterministic rewards cause decision-makers to display a certain degree of risk aversion. When given a choice between two possibilities, the majority of decision-makers choose the riskier option in search of greater rewards (Wang *et al.*, 2023). Therefore, this study decomposes decision makers' perceived value into two components: the valence account and the cost account (Wenner, 2015). The expressions for the functions of the valence account and cost account are provided as follows:

$$V(f) = \begin{cases} (f - U_0)^{\theta}, f \geq U_0 \\ -\lambda(U_0 - f)^{\beta}, f \leq U_0 \end{cases}, \quad Z(f) = \begin{cases} \delta(f - U_1)^{\phi}, f \geq U_1 \\ -(U_1 - f)^{\sigma}, f \leq U_1 \end{cases} \tag{2}$$

In equation (2), $V(f)$ signifies the value function associated with the valence account, while λ denotes the sensitivity to valence loss aversion. On the other hand, $Z(f)$ indicates the value function of the cost account, δ represents the sensitivity to cost loss aversion degree. U_0, U_1 represent the valence reference point and the cost reference point. θ, β represent the risk preference coefficient when the valence is relative to gain-loss, ϕ, σ represent the risk preference coefficient when the cost is relative to the loss-benefit, and with the risk preference coefficient become greater, the sensitivity of decision makers to risk perception will be higher.

Assumption 3. Assuming that the probability of consumer privacy leakage risk due to factors such as hacking attacks on the data platforms of AVs is denoted as p, and it will lead to consumer losses because of the negative externalities. Enterprises implementing RI as a form of expected governance can effectively mitigate potential negative externalities and steer innovation toward socially desirable and morally acceptable outcomes (Bechtsis *et al.*, 2018).

Assumption 4. Due to individual differences among consumers, their knowledge levels regarding the development of AVs vary. Let the knowledge level be denoted as T, $T \in [0, 1]$. And the differences in consumer knowledge levels will influence their behavior toward the governance of AVs (Gkartzonikas and Gkritza, 2019). Because of the negative externalities of AVs, consumers suffer risk pD_r when enterprises do not take responsibility. When consumers engage in collaborative innovation and supervision, they have to pay the cost C_c. At this point, if enterprises implement RI, consumers will gain experiential value TB_c based on their firsthand experience. If consumers discover that enterprises have not implemented RI, they will legally demand compensation, and the amount of compensation is related to consumers' level of knowledge. We denote the parameter as TV_c. Furthermore, consumers will receive policy support S_c guided by government's active intervention.

Assumption 5. When enterprises engage in AVs, they will reap foundational benefits such as technological advancements, and the foundational benefits are R_e. Meanwhile, enterprises will attain additional benefits B_e, due to the collaborative innovation and supervision of consumers. If enterprises choose the strategy of implementing RI, their additional expenditure costs are C_e. In this scenario, the enterprises will receive subsidy support S_e under government's active intervention, although the subsidy provided is lower than the costs incurred by the enterprise. On the contrary, in the event that the enterprises fail to implement RI and is detected by consumers, enterprises will provide the compensation TV_c. Moreover, the enterprise would be subjected to fines imposed under government's active intervention, and the penalty values are K_e.

Assumption 6. The government will obtain societal benefits B_g as a result of the enterprise's decision to implement RI. However, the government may experience reputation loss pG due to privacy risks faced by consumers associated with AVs. When strategy is active intervention, government's supervision cost will be C_s. Besides, with the aim of facilitating the achievement of privacy and security governance objectives, the government will provide incentive policies S_c, S_e to enterprises and consumers. Simultaneously, the government will require irresponsible enterprises to bear financial penalties, which denoted as K_e. When strategy is passive intervention, the government does not punish and incentivize (Liu *et al.*, 2018).

All of the parameters and abbreviations used in this study are categorized as stated in Table 1 to make understanding it easier.

3.2 Model construction

In accordance with the study's assumptions and grounded in prospect theory, the payoff matrix of key stakeholders in this evolutionary game is presented in Table 2. The matrices' formulas delineate the government's payoffs under diverse decisions by other stakeholders in the first row, the enterprise's payoffs in the second row and consumers' payoffs in the third row. For example, when enterprises opt for the implement RI and consumers choose strategies of collaborative innovation and supervision, the government's payoffs function at the instance of choosing active intervention is $V(B_g) - Z(C_s + S_e + S_c)$.

4. Model analysis

4.1 Analysis of stakeholders' strategies stability

According to Table 2, we computed the anticipated payoffs for enterprises opting to either implement or not implement from RI, denoted as E_x and E_{1-x}. The mean expected payoffs were symbolized by $\overline{E}$:

Parameter	Meaning
R_e	The foundational benefits that enterprises gain from engaging in AVs
C_e	The cost of enterprises to implement RI
S_e	The incentive policies gave to enterprises by the government
K_e	The financial penalties gave to enterprises by the government
B_e	The additional benefits of enterprises by the collaborative innovation of consumers
V_c	The compensation from enterprises to consumers
B_c	The experiential value based on consumers' firsthand experience
C_c	The cost of consumers for collaborative innovation and supervision
S_c	The incentive policies gave to consumers by the government
D_r	The risk faced by consumers due to the negative risks of AVs
B_g	The societal benefits which government obtained
G	The reputation loss of government
C_s	The cost of the government for active intervention
p	The probability of consumer privacy leakage risk
T	Consumers' knowledge level
x	The decision probability of enterprises to implement RI
y	The decision probability of consumers for collaborative innovation and supervision
z	The decision probability of the government for active intervention

Source: By authors

Table 1. Acronyms and parameters within this study

Government	Enterprises	Consumers Collaborative innovation and supervision y	Not collaborative innovation or supervision 1 − y
Active intervention z	Implement RI x	$V(B_g) - Z(C_s + S_e + S_c)$ $V(R_e + S_e + B_e) - Z(C_e)$ $V(TB_c + S_c) - Z(C_c)$	$V(B_g) - Z(C_s + S_e)$ $V(R_e + S_e) - Z(C_e)$ $V(0) - Z(0)$
	Not implement RI $1 - x$	$V(K_e) - Z(C_s + S_c + pG)$ $V(R_e + B_e) - Z(K_e + TV_c)$ $V(S_c + TV_c) - Z(C_c + pD_r)$	$V(K_e) - Z(C_s + pG)$ $V(R_e) - Z(K_e)$ $V(0) - Z(pD_r)$
Passive intervention $1 - z$	Implement RI x	$V(B_g) - Z(0)$ $V(R_e + B_e) - Z(C_e)$ $V(TB_c) - Z(C_c)$	$V(B_g) - Z(0)$ $V(R_e) - Z(C_e)$ $V(0) - Z(0)$
	Not implement RI $1 - x$	$V(0) - Z(pG)$ $V(R_e + B_e) - Z(TV_c)$ $V(TV_c) - Z(C_c + pD_r)$	$V(0) - Z(pG)$ $V(R_e) - Z(0)$ $V(0) - Z(pD_r)$

Source: By authors

Table 2. Payoff matrix of the model

$$E_x = \pi(y)\pi(z)[V(R_e + S_e + B_e) - Z(C_e)] + \pi(1-y)\pi(z)[V(R_e + S_e) - Z(C_e)] \\ +\pi(y)\pi(1-z)\left[V(R_e + B_e) - Z(C_e)\right] + \pi(1-y)\pi(1-z)\left[V(R_e) - Z(C_e)\right] \quad (3)$$

$$E_{1-x} = \pi(y)\pi(z)[V(R_e + B_e) - Z(K_e + TV_c)] + \pi(1-y)\pi(z)[V(R_e) - Z(K_e)] \\ +\pi(y)\pi(1-z)[V(R_e + B_e) - Z(TV_c)] + \pi(1-y)\pi(1-z)\left[V(R_e) - Z(0)\right] \quad (4)$$

$$\overline{E} = xE_x + (1-x)E_x \quad (5)$$

According to equations (3)–(5), we derived the replicator dynamic equation applicable to enterprises engaged in the implementation of RI, as follows:

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x\left(E_x - \overline{E}\right) = x(1-x)(E_x - E_{1-x}) \\ &= x(1-x)\{\pi(y)\pi(z)\left[V(S_e) - Z(C_e) + Z(K_e + TV_c)\right] \\ &\quad + \pi(1-y)\pi(z)\left[V(S_e) - Z(C_e) + Z(K_e)\right] + \pi(y)\pi(1-z)\left[-Z(C_e) + Z(TV_c)\right] \\ &\quad + \pi(1-y)\pi(1-z)[-Z(C_e)]\} \\ &= x(1-x)\left[\pi(y)\pi(z)A + \pi(1-y)\pi(z)B + \pi(y)\pi(1-z)C + \pi(1-y)\pi(1-z)D\right] \end{aligned} \quad (6)$$

The expected payoffs that consumers choose collaborative innovation and supervision was denoted as C_y, and the expected payoffs that consumers choose not collaborative innovation and supervision was denoted as C_{1-y}. The average expected payoffs were represented by $\overline{C}$:

$$C_y = \pi(x)\pi(z)[V(TB_c + S_c) - Z(C_c)] + \pi(1-x)\pi(z)\left[V(S_c + TV_c) - Z(C_c + pD_r)\right] + \pi(x)\pi(1-z)\left[V(TB_c) - Z(C_c)\right] + \pi(1-x)\pi(1-z)\left[V(TV_c) - Z(C_c + pD_r)\right] \tag{7}$$

$$C_{1-y} = \pi(x)\pi(z)[V(0) - Z(0)] + \pi(1-x)\pi(z)\left[V(0) - Z(pD_r)\right] + \pi(x)\pi(1-z)[V(0) - Z(0)] + \pi(1-x)\pi(1-z)\left[V(0) - Z(pD_r)\right] \tag{8}$$

$$\overline{C} = yC_y + (1-y)C_{1-y} \tag{9}$$

According to equations (7)–(9), we obtained the replicator dynamic equation for consumers selecting the strategy of collaborative innovation and supervision, as follows:

$$\begin{aligned} F(y) = \frac{dy}{dt} = y\left(C_y - \overline{C}\right) &= y(1-y)\left(C_y - C_{1-y}\right) \\ &= y(1-y)\{\pi(x)\pi(z)[V(TB_c + S_c) - Z(C_c)] + \pi(1-x)\pi(z)[V(S_c + TV_c) - Z(C_c)] \\ &\quad + \pi(x)\pi(1-z)\left[V(TB_c) - Z(C_c)\right] + \pi(1-x)\pi(1-z)\left[V(TV_c) - Z(C_c)\right]\} \\ &= y(1-y)\left[\pi(x)\pi(z)F + \pi(1-x)\pi(z)H + \pi(x)\pi(1-z)I + \pi(1-x)\pi(1-z)J\right] \end{aligned} \tag{10}$$

The expected payoffs associated with the government's selection of strategies, whether active intervention or passive intervention were represented as G_z and G_{1-z}, respectively. The average expected payoffs were represented by $\overline{G}$:

$$G_z = \pi(x)\pi(y)\left[V(B_g) - Z(C_s + S_e + S_c)\right] + \pi(1-x)\pi(y)\left[V(K_e) - Z(C_s + S_c + pG)\right] + \pi(x)\pi(1-y)\left[V(B_g) - Z(C_s + S_e)\right] + \pi(1-x)\pi(1-y)\left[V(K_e) - Z(C_s + pG)\right] \tag{11}$$

$$G_{1-z} = \pi(x)\pi(y)\left[V(B_g) - Z(0)\right] + \pi(1-x)\pi(y)[V(0) - Z(pG)] + \pi(x)\pi(1-y)\left[V(B_g) - Z(0)\right] + \pi(1-x)\pi(1-y)[V(0) - Z(pG)] \tag{12}$$

$$\overline{G} = zG_z + (1-z)G_{1-z} \tag{13}$$

According to equations (11)–(13), we obtained the replicator dynamic equation for the government selecting active intervention, as follows:

$$\begin{aligned} F(z) = \frac{dz}{dt} = z\left(G_z - \overline{G}\right) &= z(z-1)\left(G_z - G_{1-z}\right) \\ &= z(1-z)\{\pi(x)\pi(y)[-Z(C_s + S_e + S_c)] + \pi(1-x)\pi(y)\left[V(K_e) - Z(C_s + S_c)\right] \\ &\quad + \pi(x)\pi(1-y)[-Z(C_s + S_e)] + \pi(1-x)\pi(1-y)\left[V(K_e) - Z(C_s)\right]\} \\ &= z(z-1)\left[\pi(x)\pi(y)K + \pi(1-x)\pi(y)L + \pi(x)\pi(1-y)M + \pi(1-x)\pi(1-y)N\right] \end{aligned} \tag{14}$$

Observing equations (6), for the probability of enterprises' decision to be in a steady state, the conditions must be satisfied: $F(x) = 0$ and $d(F(x))/dx < 0$. To further analysis the replicator dynamic equation, when $\pi(y)\pi(z)A + \pi(1-y)\,\pi(z)B + \pi(y)\,\pi(1-z)C + \pi(1-y)\,\pi(1-z)D = 0$, it will lead to $F(x) = 0$, and it means that all strategies of enterprises are stable in this condition. If $\pi(y)\pi(z)A + \pi(1-y)\,\pi(z)B + \pi(y)\,\pi(1-z)C + \pi(1-y)\,\pi(1-z)D < 0$, when $d(F(x))/dx\,|_{x=0} < 0$ and $d(F(x))/dx\,|_{x=1} > 0$, this means $x = 0$ is the stable strategy and the steady state is reached when enterprises choose not to implement RI. On the contrary, if $\pi(y)\pi(z)A + \pi(1-y)\,\pi(z)B + \pi(y)\,\pi(1-z)C + \pi(1-y)\,\pi(1-z)D > 0$, when $d(F(x))/dx\,|_{x=0} > 0$ and $d(F(x))/dx\,|_{x=1} < 0$, the evolutionary equilibrium stable strategy of enterprises is $x = 1$, the achievement of a steady state is observed when enterprises choose to implement RI. The analyses conducted are succinctly portrayed in the replicated dynamic phase diagram, presented in Figure 3(a), illustrating the enterprises' behavior.

Observing Figure 3(a), we can obtain the volume V_{11} of the probability that the enterprises choose the strategy of implementing RI and the volume V_{12} of the probability that the enterprises choose not to implement RI. The likelihood of implementing RI is positively correlated with the foundational benefits that enterprises gain from engaging in AVs, the financial penalties gave to enterprises by the government, the additional benefits derived from collaborative innovation with consumers, the compensation provided by enterprises to consumers and consumers' knowledge level. Conversely, it is negatively associated with the cost incurred by enterprises to implement RI.

Observing equation (10), for the probability of consumers' decision to be in a steady state, the conditions must be satisfied: $F(y) = 0$ and $d(F(y))/dy < 0$. To further analyze the replicator dynamic equation, when $\pi(x)\pi(z)F + \pi(1-x)\,\pi(z)H + \pi(x)\,\pi(1-z)I + \pi(1-x)\,\pi(1-z)J = 0$, it will lead to $F(y) = 0$, which means all strategies of consumers are stable. If $\pi(x)\pi(z)F + \pi(1-x)\,\pi(z)H + \pi(x)\,\pi(1-z)I + \pi(1-x)\,\pi(1-z)J < 0$, when $d(F(z))/dz\,|_{z=0} < 0$ and $d(F(z))/dz\,|_{z=1} > 0$, the evolutionary equilibrium stable strategy of consumers is $y = 0$, a steady state is reached when consumer choose not collaborative innovation or supervision. On the contrary, if $\pi(x)\pi(z)F + \pi(1-x)\,\pi(z)H + \pi(x)\,\pi(1-z)I + \pi(1-x)\,\pi(1-z)J > 0$, $d(F(y))/dy\,|_{y=0} > 0$ and $d(F(y))/dy\,|_{y=1} > 0$, the evolutionary equilibrium stable strategy of consumers is collaborative innovation and supervision. The duplicated dynamic phase diagram for consumers is depicted in Figure 3(b).

We can obtain the volume V_{21} of the probability that consumers choose the strategy of collaborative innovation and supervision and the volume V_{22} of the probability that consumers choose the strategy of not collaborative innovation or supervision. The likelihood

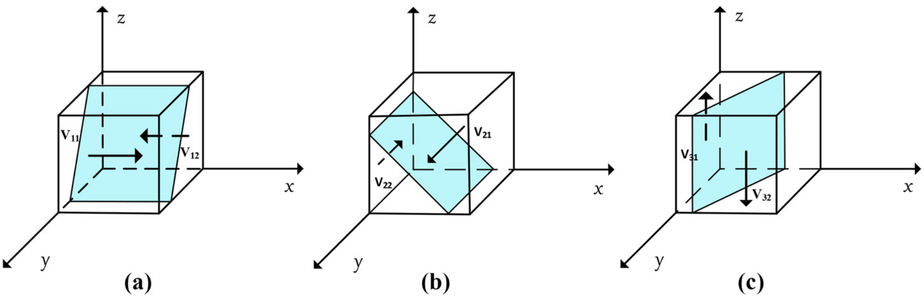


Figure 3. Evolutionary phase diagram of enterprises, consumers and the government

Notes: (a) Enterprises; (b) consumers; (c) government
Source: Figure by authors

of engaging in collaborative innovation and supervision is positively correlated with the incentive policies gave to consumers by the government, the experiential value based on consumers' firsthand experience, the risks faced by consumers due to the negative risks of AVs, consumers' knowledge level and the probability of consumer privacy leakage risk. Conversely, it is negatively associated with the cost borne by consumers for collaborative innovation and supervision.

Observing equation (14), for the probability of the government's decision to be in a steady state, the conditions must be satisfied: $F(z) = 0$ and $d(F(z))/dz < 0$. To further analyze the replicator dynamic equation, when $\pi(x)\pi(z)K + \pi(1-x)\ \pi(z)L + \pi(x)\ \pi(1-z)M + \pi(1-x)\ \pi(1-z)N = 0$, $F(z) = 0$, it means that all strategies of the government are stable in this condition. When $d(F(z))/dz\ |_{z=0} < 0$ and $d(F(z))/dz\ |_{z=1} > 0$, resulted by $\pi(x)\pi(z)K + \pi(1-x)\ \pi(z)L + \pi(x)\ \pi(1-z)M + \pi(1-x)\ \pi(1-z)N < 0$, the evolutionary equilibrium stable strategy of the government is $z = 0$, a steady state is reached when the government choose active intervention. On the contrary, if $\pi(x)\pi(z)K + \pi(1-x)\ \pi(z)L + \pi(x)\ \pi(1-z)M + \pi(1-x)\ \pi(1-z)N > 0$, when $d(F(z))/dz\ |_{z=0} > 0$ and $d(F(y))/dy\ |_{z=1} < 0$, the evolutionary equilibrium stable strategy of the government is passive intervention. The duplicated dynamic phase diagram for consumers is depicted in Figure 3(c).

Analyzing Figure 3(c) allows us to ascertain the probabilities linked to the government's selection between active intervention V_{31} and passive intervention V_{32}. The likelihood of active intervention is positively correlated with the societal benefits accrued by the government, the financial penalties gave to enterprises, the probability of consumer privacy leakage risk and the government's reputation loss. Conversely, it is negatively associated with the cost of the government for active intervention, the incentive policies gave to enterprises and consumers.

4.2 Stability analysis of the equilibrium point in the tripartite game

The decisions of stakeholders in the game model are mutually influential and subject to continuous evolution. Subsequently, a 3D dynamic system for the evolutionary game was constructed by the collective formulation as delineated below:

$$\begin{cases} F(x) = \dfrac{dx}{dt} = x(1-x)\left[\pi(y)\pi(z)A + \pi(1-y)\pi(z)B + \pi(y)\pi(1-z)C + \pi(1-y)\pi(1-z)D\right] = 0 \\ F(y) = \dfrac{dy}{dt} = y(1-y)\left[\pi(x)\pi(y)F + \pi(1-x)\pi(y)H + \pi(x)\pi(1-y)I + \pi(1-x)\pi(1-y)J\right] = 0 \\ F(z) = \dfrac{dz}{dt} = z(z-1)\left[\pi(x)\pi(z)K + \pi(1-x)\pi(z)L + \pi(x)\pi(1-z)M + \pi(1-x)\pi(1-z)N\right] = 0 \end{cases} \tag{15}$$

According to equation (15), let $F(x) = 0$, $F(y) = 0$, $F(z) = 0$, the local stable equilibrium point can be derived as follows: $E_1(0,0,0)$, $E_2(1,0,0)$, $E_3(0,1,0)$, $E_4(0,0,1)$, $E_5(1,1,0)$, $E_6(1,0,1)$, $E_7(0,1,1)$, $E_8(1,1,1)$, $E_9(x', y', z')$. As $x', y', z' \in [0,1]$, $E_9(x', y', z')$ is meaningless. Friedman draws attention to the fact that ESS is limited to pure strategies. So we only investigate the stability of 8 pure tactics in the game of evolution (Friedman, 1998). Asymptotic stability of the equilibrium point is attained when all eigenvalues of the Jacobian matrix exhibit negativity, aligning with Lyapunov's first law (Ritzberger and Weibull, 1995). The Jacobian matrix's outcomes are displayed in Table 3 after combining the known conditions to determine each eigenvalue's positivity and negativity.

In accordance with Lyapunov's local stability theorem, the local asymptotic stability of the evolutionary dynamics process can be achieved when the determinant $\mathrm{Det}(J) < 0$, Tr(J) > 0 and the eigenvalue λ_1, λ_2, $\lambda_3 < 0$. As is shown in Table 3, we ultimately obtained five points $E_1(0,0,0)$, $E_3(0,1,0)$, $E_4(0,0,1)$, $E_5(1,1,0)$, $E_7(0,1,1)$ which is uncertain.

If the point $E_1(0,0,0)$ is the system stability point for the gaming system, the conditions must be satisfied: $D < 0, J < 0, N < 0, V(TV_c) - Z(C_c) < 0$ and $V(K_e) - Z(C_s) < 0$. If the point $E_3(0,1,0)$ is the system stability point for the gaming system, the conditions must be satisfied: $C < 0, -J < 0, L < 0, Z(TV_c) - Z(C_e) < 0, V(TV_c) - Z(C_c) < 0$ and $V(K_e) - Z(C_s + S_c) < 0$. If the point $E_4(0,0,1)$ is the system stability point for the gaming system, the conditions must be satisfied: $B < 0, H < 0, -N < 0, V(S_e) - Z(C_e) + Z(K_e) < 0, V(S_c + TV_C) - Z(C_c) < 0$ and $Z(C_s) - V(K_e) < 0$. When the point $E_5(1,1,0)$ is the system stability point for the gaming system, the conditions must be satisfied: $-C < 0, -I < 0, K < 0, Z(TV_c) - Z(C_c) > 0$ and $V(TB_c) - Z(C_c) > 0$. When the point $E_7(0,1,1)$ is the system stability point for the gaming system, the conditions must be satisfied: $A < 0, -H < 0, -L < 0, V(S_e) - Z(C_e) + Z(K_e + TV_c) < 0, V(S_c + TV_c) - Z(C_c) > 0$. and $V(K_e) - Z(C_s + S_c) > 0$.

The five equilibrium points listed above are all stable locations under specific circumstances. But $E_3(0,1,0)$, $E_4(0,0,1)$ and $E_7(0,1,1)$ are difficult to achieve in real life, because the financial penalties from governments is often lower than the cost of active intervention and the compensation to consumers is often lower than the cost of consumers for collaborative innovation and supervision, which can be presented as $C_s > K_e$ and $C_c > V_c$. As a result, these three stabilization points are only conceivable in theory. And the point $E_1(0,0,0)$ leans more toward the general scenario and fails to address the governance of privacy and security issues in AVs. The stabilization point $E_5(1,1,0)$ is a more desirable and useful outcome; thus, this equilibrium point is likewise disregarded.

5. Simulation analysis

To better assess parameter sensitivity and analyze the evolution of decision choices among the three-party stakeholders, this study used MATLAB software for model simulation. In the simulation, we set the start time as 0 and the end time as 10, while specific units of simulation are not explicitly defined. Some parameters such as θ, β, λ, δ, ϕ, σ refer to the reference of Tversky (Tversky and Kahneman, 1992) and Van (Van and Van, 1995), and others are set based on the conditions of system stability point. All the parameter settings are shown in Table 4. What's more, the simulation process adopts the established approach from prior studies (Wang *et al.*, 2022a, 2022b) where the initial value of valence reference point and cost reference point U_0, U_1 are set at 0.

According to Table 4, the initial stage evolution of the system at point $E_5(1,1,0)$ is illustrated in Figure 4. Figure 4 illustrates the tripartite evolutionary game, wherein initial

Table 3. Eigenvalues of the Jacobian matrix and the stability analysis

System Balance point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3	Det(J)	Tr(J)	Result
$E_1(0,0,0)$	$D(-)$	$J(+,-)$	$N(+,-)$	DJN	$D+J+N$	Uncertain
$E_2(1,0,0)$	$-D(+)$	$I(+,-)$	$M(-)$	−DIM	$-D+I+M$	Instability
$E_3(0,1,0)$	$C(+,-)$	$-J(+,-)$	$L(+,-)$	−CJL	$C-J+L$	Uncertain
$E_4(0,0,1)$	$B(+,-)$	$H(+,-)$	$-N(+,-)$	−BHN	$B+H-N$	Uncertain
$E_5(1,1,0)$	$-C(+,-)$	$-I(+,-)$	$K(-)$	CIK	$-C-I+K$	Uncertain
$E_6(1,0,1)$	$-B(+,-)$	$F(+,-)$	$-M(+)$	BFM	$-B+F-M$	Instability
$E_7(0,1,1)$	$A(+,-)$	$-H(+,-)$	$-L(+,-)$	AHL	$A-H-L$	Uncertain
$E_8(1,1,1)$	$-A(+,-)$	$-F(+,-)$	$-K(+)$	−AFK	$-A-F-K$	Instability

Source: By authors

tactics are randomly generated by MATLAB and remain unfixed, represented by distinct colored lines. After several cycles, they all reached $E_5(1,1,0)$, that is, the ESS of the government, enterprises and consumers is (Enterprises choose to implement RI, Consumers choose collaborative innovation and supervision, Government choose passive intervention). However, over time, the government realizes that even passive intervention can induce a desirable pattern of RI behavior among enterprises and consumers. Hence, $E_5(1,1,0)$ serves as the system stability point in the model under the assurance of the constraint conditions.

5.1 The effect of initial probability

The implementation of RI by enterprises benefits the governance of privacy and security issues in AVs. However, in practice, decision-making behaviors of individual stakeholders are influenced by those of other key stakeholders. To better discern the interactive effects among key stakeholders, this chapter analyzes micro-level behavioral changes resulting from initial strategy variations. Under the condition of ensuring that $E_5(1,1,0)$ is the system stability point and keeping the values of other parameters constant, taking $x = y = z = 0.1$, $x = y = z = 0.3$, $x = y = z = 0.5$, $x = y = z = 0.7$. Figure 5 depicts the strategy evolution process and outcomes.

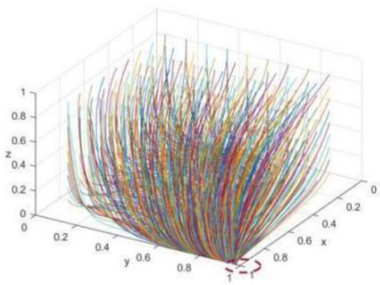
The precise outcomes are displayed in Figure 5. The time unit (not yearly or monthly) is on the x-axis, and the probability value of the behavioral strategy is on the y-axis. As shown in Figure 5, the initial stability point of the system's evolution remains consistent at point (1,1,0) and altering the initial probability distribution of strategy choices among game participants does not exert any discernible influence on the overarching trajectory of system evolution. However, changes in stakeholders' initial levels of willingness have a big impact on how their behavioral strategies evolve over the course of the process.

Overall, a higher initial willingness ratio leads to faster evolution of enterprises and consumers toward stabilization strategies, while the government's evolution is slower. This

Parameter	r	θ	β	λ	δ	ϕ	σ	R_e	B_e	S_e	C_e
Initial value	0.75	0.88	0.88	2.5	2.5	0.98	0.98	2	3	1.5	2.5
Parameter	K_e	V_c	B_c	C_c	S_c	D_r	B_g	C_s	G	T	p
Initial value	4	8	9	1.5	1	5	1.5	4	6	0.8	0.1

Source: By authors

Table 4. Parameter settings



Source: Figure by authors

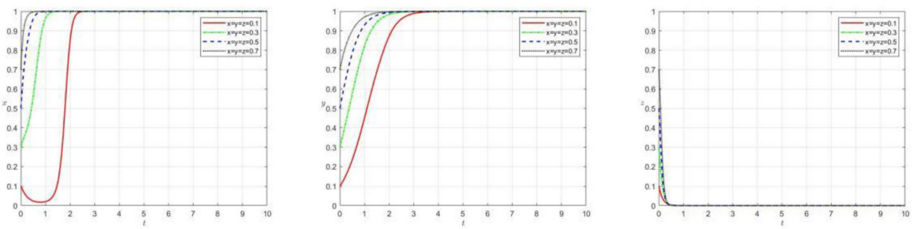
Figure 4. Evolution process of the system in the initial stage

indicates that in the early stage of privacy and security governance, the government should intervene actively, and consumers should opt for collaborative innovation and supervision to expedite the convergence of enterprises toward implementing RI. Moreover, the figure shows that the government converges at a significantly faster rate compared to other stakeholders. This disparity can be attributed to the government's primarily auxiliary role in the governance of issues related to AVs. Given the governance of privacy and security concerns, enterprises and consumers must shoulder greater responsibility.

Following an analysis of the impact of decision-making behaviors among key stakeholders, this study discerns that both enterprises and consumers are significantly influenced by other stakeholders, particularly enterprises. When consumers and the government adopt passive strategies, enterprises, driven by a profit-maximizing mindset, tend initially toward nonimplementation of RI. However, as time progresses, they subsequently shift toward the adoption of implementing RI. Furthermore, the study revealed that even after the government shifted its evolutionary strategy from active intervention to passive intervention, enterprises and consumers continued to evolve toward implementing RI and collaborative innovation. This observation suggests that, following a period of active government intervention, enterprises and consumers gradually acknowledged and embraced their responsibilities in addressing privacy and security concerns in AVs. While the government is less influenced by other key stakeholders, their strategic choices tend to evolve toward passive intervention. This inclination reflects a preference for market-oriented regulation in technological innovation governance. To analyze key stakeholder strategic choices more effectively, this study concentrates on factors related to enterprises and consumers. And the examination reveals that parameters solely associated with the government have a relatively minor impact on the strategic choices of key stakeholders.

5.2 Sensitivity analysis using different parameters in the initial stage

To better analyze variations in key stakeholder decision-making, this section conducts a parameter analysis focusing on crucial influencing factors. For simplicity, the analysis addresses parameters impacting the decision-making of enterprises and consumers, excluding detailed scrutiny of constant and unpredictable profit enhancement parameters, such R_e, B_e. The cost of consumers for collaborative innovation and supervision C_c, consumers' knowledge level T and different perceived value factors were numerically simulated to investigate the impact of parameters on the stakeholders' first stage of strategic evolution. To minimize the effect of initial probabilities on the rate of behavioral evolution



(a) (b) (c)

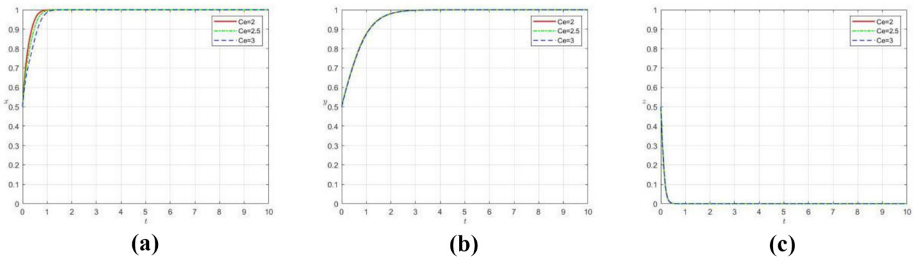
Figure 5. Effect of initial probability on strategy evolution of each party

Notes: (a) Enterprises; (b) consumers; (c) government
Source: Figure by authors

among stakeholders, it was assumed that the initial strategies of key stakeholders were all set to 0.5.

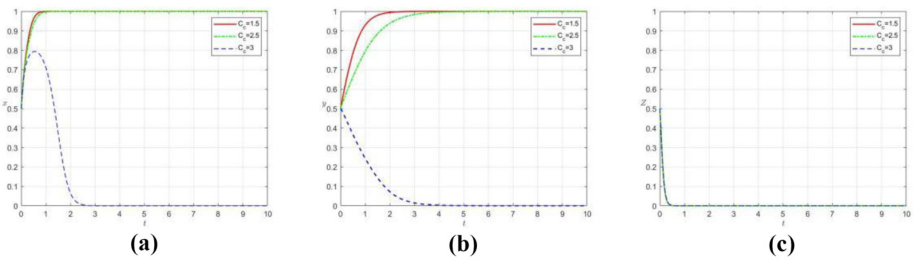
5.2.1 Sensitivity analysis of the cost of enterprises to implement Responsible Innovation. Figure 6 shows the effect of changing the cost of enterprises to implement RI as $C_e = 2, 2.5, 3$ on the evolutionary outcomes, and Figure 6(a)–(c) represents the dynamic evolutionary paths of enterprises, consumers and the government, respectively. Through Figure 6, it is observed that as costs increase, the evolutionary rate of enterprises toward the implementation of RI decreases, aligning with the realistic scenario where enterprises prioritize their own profit maximization. Conversely, consumers and the government exhibit minimal sensitivity to changes in the cost parameters, rendering their influence negligible. Similarly, this study validates a series of parameters directly related to the government, yielding similar conclusions. Therefore, in subsequent parameter analyses, only those parameters with significant impacts were considered.

5.2.2 Sensitivity analysis of the cost for collaborative innovation and supervision. Figure 7 shows the effect of changing the cost of consumers for collaborative innovation and supervision as $C_c = 1.5, 2, 3$ on the evolutionary outcomes, and Figure 7(a)–7(c) represents the dynamic evolutionary paths of enterprises, consumers and the government, respectively. The figures Figure 7(a) and (b) clearly demonstrate the impact of the cost of consumers for collaborative innovation and supervision on the evolution of enterprises and consumers' behavior strategies in privacy and security governance. It is evident that a decrease in cost results in a relatively quick convergence of enterprises and consumers toward a stabilization



Notes: (a) Enterprises; (b) consumers; (c) government
Source: Figure by authors

Figure 6. Stakeholders' sensitivity to changes in the cost of enterprises for implement RI



Notes: (a) Enterprises; (b) consumers; (c) government
Source: Figure by authors

Figure 7. Stakeholders' sensitivity to changes in the cost of consumers for collaborative innovation and supervision

strategy. Conversely, when the cost exceeds a certain threshold, both enterprises and consumers switch strategies. Notably, the government shows limited sensitivity to this parameter.

The reason for this difference can be attributed to the government's auxiliary role in the governance of privacy and security in AVs. As the government primarily focuses on factors directly affecting itself, it is less influenced by factors from other stakeholders. On the other hand, for enterprises and consumers, the cost plays a crucial role. Conversely, as the cost decreases, the expected benefits from implementing RI and collaborative innovation increase, leading to an accelerated rate of evolution.

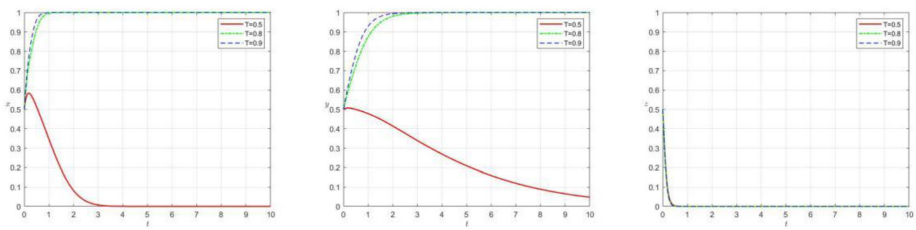
5.2.3 Sensitivity analysis of the consumers' knowledge level. Figure 8 shows the effect of changing consumers' knowledge level as $T = 0.5, 0.8, 0.9$ on the evolutionary outcomes, and Figure 8(a)–(c) represents the dynamic evolutionary paths of enterprises, consumers and the government, respectively. It is evident from Figure 8(a) and (b), the consumers' knowledge level positively affected the evolution of enterprises and consumers' behavior strategies in the governance of privacy and security issues. With consumers' knowledge level increases, enterprises and consumers converge more rapidly toward a stabilization strategy. Conversely, when consumers' knowledge level falls below a certain threshold, both enterprises and consumers undergo strategic shifts.

The rationale behind the government's role aligns with the aforementioned analysis of the cost for collaborative innovation and supervision, where the government primarily assumes a auxiliary role in this process. On the other hand, for enterprises and consumers, a low level of consumer knowledge indicates insufficient understanding of AVs. In this model, when consumers have limited knowledge, their experiential value and compensation demands from enterprises are also affected, resulting in a decrease. Consequently, the expected benefits for consumers to choose cooperative innovation diminish. Similarly, the benefits for enterprises to refrain from implementing RI relatively increase.

5.2.4 Sensitivity analysis of the different perceived value factors

5.2.4.1 Sensitivity analysis of the sensitivity to cost loss aversion degree. Because the initial value of valence reference point and cost reference point are set at 0 in this study, which means $U_0 = U_1 = 0$. Therefore, this study undertakes further analysis by examining the sensitivity of loss avoidance factors with respect to the cost loss aversion degree. If $\delta > 1$, it signifies the aversion of stakeholders toward risk. Figure 8 illustrates the strategy evolution process and outcomes when $\delta = 1.5, 2.5, 3.5$.

Illustrated in Figure 9(a) and (c), the government's behavioral strategies are positively influenced by the sensitivity to cost loss aversion, whereas consumers' behavioral strategies are adversely affected. An increase in this parameter leads to a faster convergence of the



(a) (b) (c)

Figure 8. Stakeholders' sensitivity to changes in consumers' knowledge level

Notes: (a) Enterprises; (b) consumers; (c) government
Source: Figure by authors

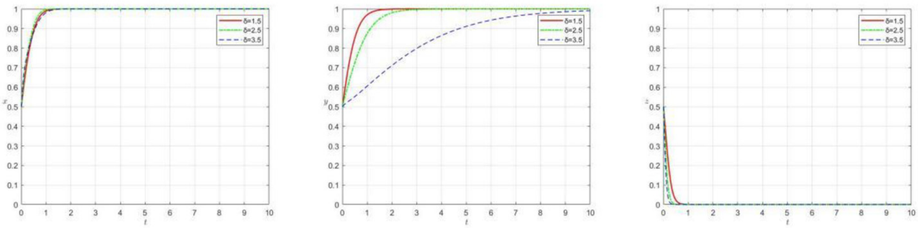
government toward a stabilization strategy, while consumers exhibit a slower convergence. Meanwhile, we found that consumers exhibit the highest sensitivity to this parameter, followed by the government.

Consumers exhibit the highest sensitivity to this parameter, which can be attributed to the influence of individual differences and subjective factors within this group. As consumers actively participate in the governance of privacy and security in AVs, they incur additional costs beyond the norm. Therefore, their willingness to invest time, effort and other resources in governance decreases as the sensitivity to cost loss aversion degree increases.

5.2.4.2 Sensitivity analysis of the sensitivity to the risk preference coefficient. Based on the condition $U_0 = U_1 = 0$, the study take the sensitivity analysis of the risk preference coefficient when the valence is relative to gain-loss and the risk preference coefficient when the cost is relative to the loss-benefit. Taking $\theta = 0.8, 0.88, 0.98$, Figure 10 displays the strategy evolution process and outcomes. The sensitivity to risk preference coefficient when the valence is relative to gain-loss positively affected the evolution of the enterprises and consumers' behavior strategies and has little impact on the government's strategy.

Taking $\phi = 0.8, 0.88, 0.98$, the strategy evolution process and outcomes are depicted in Figure 11. The sensitivity of the risk preference coefficient associated with cost in the context of loss-benefit positively influenced the evolution of government and enterprises' behavior strategies, while concurrently exerting a negative impact on the evolution of consumers' behavior strategies.

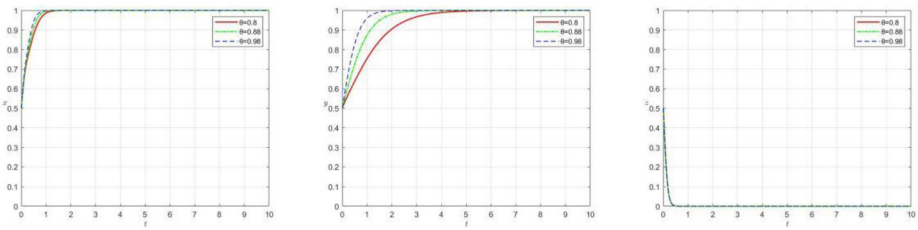
According to the analysis of the sensitivity to the risk preference coefficient from Figures 10 and 11, it is found that both θ and ϕ positively affected the evolution of enterprises' behavior



(a) (b) (c)

Notes: (a) Enterprises; (b) consumers; (c) government
Source: Figure by authors

Figure 9. Stakeholders' sensitivity to changes in the sensitivity to cost loss aversion degree



(a) (b) (c)

Notes: (a) Enterprises; (b) consumers; (c) government
Source: Figure by authors

Figure 10. Stakeholders' sensitivity to changes in the risk preference coefficient when the valence is relative to gain-loss

strategies, while the government exhibits greater sensitivity to the risk preference coefficient when the cost is relative to the loss-benefit ϕ. Concurrently, the risk preference coefficient associated with valence concerning gain-loss, denoted as θ positively influenced the evolution of consumers' strategies, while the risk preference coefficient related to cost in the context of loss-benefit, denoted as ϕ exerted a negative impact on the evolution of consumers.

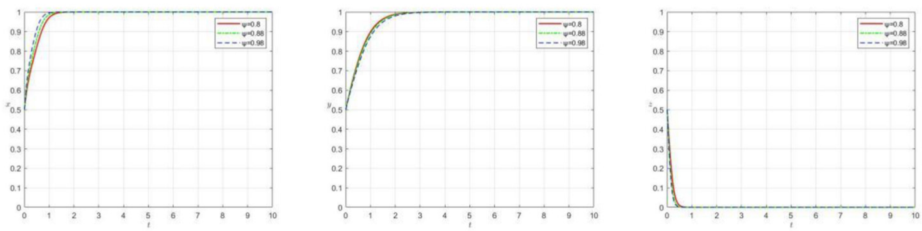
In the event of an increase in the risk preference coefficient associated with valence concerning gain-loss, both enterprises and consumers experience an enhanced perceived value of implementing RI and engaging in collaborative innovation. As a result, the pace of their evolution accelerates. However, the government, primarily concerned with risk losses in relation to social benefits, exhibits relatively lower sensitivity to this parameter θ. The change in this parameter has a minimal impact on the perceived value and the subsequent behavior of the government.

As the parameter ϕ increases, enterprises perceive an increased risk related to penalties and compensations associated with not implementing RI. This perception accelerates their shift toward implementing. Furthermore, both consumers and the government become more sensitive to the costs involved. The government, in particular, prioritizes privacy and security governance at lower costs, resulting in an accelerated evolution toward passive intervention. Conversely, consumers maintain concerns about privacy and security issues, leading them to evolve toward collaborative innovation and supervision, albeit at a slower pace.

6. Discussion

This study integrates the theories of RI, key stakeholders and perceived value to examine the governance of privacy and security in AVs. Using the prospect theory, the study develops an evolutionary game model involving three key stakeholders. Through simulations, influential factors impacting decision-makers are identified, including consumer participation costs, consumers' knowledge levels and the perceived value of each stakeholder.

A comprehensive review of existing literature reveals a notable deficiency in current research concerning the multi-agent interactive aspects and ethical–moral dimensions of governance in privacy and security of AVs. This study advocates for the implementation of RI by enterprises, emphasizing a micro-level perspective that considers the interactive influences among key stakeholders. This approach not only aligns with real-world scenarios but also supplements ethical constraints in practice, thereby promoting the steady development of autonomous driving technology. We also explore the multi-agent interaction process of privacy and security governance in AVs, offering insights for future discussions



(a) (b) (c)

Notes: (a) Enterprises; (b) consumers; (c) government
Source: Figure by authors

Figure 11. Stakeholders' sensitivity to changes in the risk preference coefficient when the cost is relative to the loss-benefit

among key stakeholders in the field of AVs. Notably, we identify the significant role of consumers in the governance of privacy and security, offering valuable insights applicable to real-world scenarios. Thus, assisting enterprises and government agencies in the tangible governance of privacy and security issues, this approach prioritizes consumers. Each stakeholder comprehensively regulates the key factors influencing their decisions, contributing to cost reduction and efficiency improvement.

Moreover, the practical application of RI theory is found to be lacking, highlighting the necessity for strengthening its connection with real-world scenarios. This study focuses on AVs and the practical implementation of RI, thereby expanding the research scope in related fields. Additionally, this study reflects on the shortcomings of evolutionary game theory at the research level. The study also addresses specific gaps in existing evolutionary game models, particularly the lack of consideration for individual stakeholder differences and subjective factors, such as the varying perceived value resulting from the valence account and the cost account.

7. Conclusion

- The enactment of RI by enterprises successfully mitigates privacy and security risks within the framework of AVs. Enterprises' decision-making is influenced by the strategic choices of various stakeholders, with consumers exerting a relatively stronger influence compared to other stakeholders. In contrast, the government focuses on promoting the widespread diffusion of AVs at lower costs, making it less influenced by the strategic choices of enterprises and consumers. Enterprises play a crucial role by ensuring compliance with relevant laws, regulations and privacy standards on their AV platforms. Transparent and easily understandable privacy policies should be provided by enterprises, outlining the methods of data collection, storage and usage explicitly.
- The costs associated with consumers participation in cooperation and supervision have an impact on strategic choices. These costs not only influence consumers' decisions but also affect enterprises' decisions. When consumers face higher participation costs, influenced by perceived value, they are more inclined to choose nonparticipation in cooperation to reduce the burden of costs. Similarly, enterprises are indirectly influenced by consumers' strategic choices, leading to a preference for non-implementation of RI. Therefore, consumers play a crucial role in the diffusion of AVs, and the government should prioritize policies that encourage consumer participation and establish multiple channels for supervision and reporting.
- Consumers' knowledge level influences strategic choices among the stakeholders. Based on the parameter analysis conducted in this study, consumers with a high level of knowledge are more inclined to participate in cooperation and supervision, while enterprises are also influenced by consumers' knowledge level, leading them to prioritize the implementation of RI. Conversely, consumers with lower knowledge levels may have limited awareness of data security risks, leading to lower concerns about personal privacy exposure. This may lead to a more permissive attitude toward data sharing and privacy protection among consumers.
- Intriguingly, stakeholders' perceptions of the value of decision-making will vary widely due to the influence of subjective factors like risk aversion and profit aversion. However, the final stable condition of the evolutionary process is characterized by a wide range of options and a government preference for passive intervention. The numerical simulation and parameter analysis reveal that

government entities are more sensitive to the avoidance of losses compared to other external influences. Additionally, different risk preferences can significantly affect the pace of decision-making evolution for both enterprises and consumers. Therefore, when addressing privacy and security governance issues and designing behavioral norms for decision-makers, it is crucial to fully consider the irrational factors that influence decision-making (Wang *et al.*, 2022a, 2022b).

Summarizing the research findings, this study contributes to the governance of privacy and security issues in AVs by offering new ethical and moral perspectives. By fully considering the roles of key stakeholders and the impact of various factors, it promotes the ethical development of AVs. Theoretical significance is evident in the enrichment of RI theory and the filling of gaps in evolutionary game theory, providing a reference for micro-level theoretical research.

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