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Analytic of B2C E - Commerce Credit Mechanism Mixed Strategy Risk Behavior Based on Logical Game Petri Nets

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ABSTRACT B2C is a commercial retail model of e-commerce for selling products and services directly to consumers. To solve the credit risk issues in B2C e-commerce, in this paper, a credit risk game mechanism is proposed based on game theory and logical Petri nets theory. First, by combining logical Petri nets with game theory, a theoretical modeling method called the logical game Petri nets is proposed. To characterize the utility that each body gained during the competition processes using the least square method, utility functions that describe the relationships between enterprises in different business modes are derived; next, a logical game Petri net model to specify the interactions among different bodies in the enterprise competition module is constructed. To analyze the behavior of the competition module, a reachable marking graph for this logical game Petri net model is established. According to this reachable graph, a utility matrix is subsequently designed to obtain the maximum expected utility for the bodies; finally, through analysis of the logical game Petri nets model for the enterprise competition module, the local optimal utility, as well as the global optimal utility of the individuals and groups, can be guaranteed.

INDEX TERMS B2C e-commerce, credit risk, mixed strategy, least square, logical game Petri net.

I. INTRODUCTION

With the popularization of the Internet and people's increasing knowledge of the network, e-commerce has been thriving and is increasingly connected with people's lives. People are increasingly being transformed from watchers into consumers and participants, and the shopping festivals that are represented by Double 11 and Double 12 also occurred with. Under such a background, B2C e-commerce has developing rapidly because of its fast and convenient online shopping environment, safe and stable payment methods and mature logistics and distribution system. However, there is also risk involved in B2C e-commerce credit mechanisms. e-commerce itself has a certain degree of virtuality, as its transactions occur across time and space, causing uncertainty for both consumers and enterprises. Therefore, the problem of how to address the issue of risk correctly in the B2C e-commerce credit mechanism is worthy of discussion.

B2C is a commercial retail model of e-commerce for selling products and services directly to consumers. In this e-commerce model, enterprises conduct online marketing activities through the Internet. This model's advantages over the traditional business model are as follows: time saving, cost saving, easy to operate, and information is communicated quickly. Therefore, the type and price of goods, logistics, distribution and other information can be updated instantly and dynamically. However, because the B2C e-commerce model of online transactions reaches a wide audience and because there are a large number of frequent transactions across time and space, the credit risk problem is highly prominent. The main reasons for the current credit risk arising from B2C e-commerce include the following: The first reason is information asymmetry. The anonymity, transaction virtualization, non-contact economy and other characteristics of B2C e-commerce result in asymmetric information between buyers and sellers. The second risk is false information. Due to the characteristics of the transaction occurring over time and space, the seller has the opportunity to exaggerate the quality and characteristics of the goods in the description of the goods, provide pictures of better goods than the actual goods they are selling, or provide wrong information to mislead the consumers. The third reason is the policy issue. A user-friendly e-commerce platform is needed to ensure the healthy development of the market and positive growth in the number of transactions, so relevant policies should be put in place to evade credit risk in transactions. The only way to better protect the rights and interests of consumers is to bear as little of the credit risk as possible, as well as to promote the development of the platform. However, many e-commerce platform's credit guarantee policies are not insufficient; therefore, a number of businesses need to carry out fraud management. The fourth reason is an institutional problem. Whether the government's regulation of the e-commerce platform is effective plays an important role in the healthy development of the e-commerce credit mechanism.

At present, the studies on the credit risk in e-commerce [4], [15], [16], [20] mostly focus on the economics area. Several scholars focus on the qualitative analysis of the problem by combining economics, game theory, law and other disciplines to explore the formation and mechanism of the risk problem of the e-commerce credit mechanism to promote the further establishment and improvement of the e-commerce credit system. Another group of scholars focus on the combination of economic theory and mathematical methods by conducting a quantitative analysis of the problem and establishing an early risk warning model or risk dynamic assessment model [18], [28] for different risk situations to provide coping strategies, thereby avoiding risk.

In the process of constructing an early risk warning model or risk dynamic assessment model based on various mathematical methods and algorithms, the difficulty in obtaining the B2C e-commerce data set is one of the problems encountered in the current research process. The low number of data sets and the small number of types will reduce the validity and reliability of the model to a certain degree, and deviations between the results of simulation without the data and the true results are inevitable. When analyzing from the perspective of a game for risk aversion, the construction of a utility function is mostly a simple estimation based on several performance indexes given or in practice; therefore, the problem can only be reflected to a certain extent, and the accuracy of the research on practical problems and specific needs should be discussed.

The main contributions of this paper are as follows:

(1) Combining game theory [43], [44] with the logical Petri net theory [5], [6], [11], [22]–[24], [29], [36]–[39], [41], the Logical Game Petri nets theory is proposed, and its formal definition, dynamic properties and analysis methods are given.

(2) Studying the risk problem of the B2C e-commerce credit mechanism, transforming it into the game problem among four main bodies in the e-commerce mode, and using the theory of Logical Game Petri nets to conduct modeling and analysis.

(3) Conducting research on the risk problem of the credit mechanism in the enterprise's competition module of B2C e-commerce. First, the obtained dataset is segmented by the credit index under the basic assumption. Second, the least squares method is used to solve the utility function in different business models. Third, the Logical Game Petri nets model and reachable marking graph of the module are constructed. Fourth, four traces that describe the problem under given hypotheses are obtained by analysis, and finally, the corresponding utility matrix is established to obtain the optimal decision. The Logical Game Petri nets model of this module is analyzed, which contains property analysis and performance analysis, and the relationship between the different business modes and utility is verified.

Chapter 1 introduces the B2C e-commerce application background, summarizes the current research methods, existing problems and the main contribution of this paper. Chapter 2 describes the current situation of research and analyzes the characteristics of various methods. Chapter 3 introduces some basic knowledge of Game theory and Petri nets. Chapter 4 combines Petri nets with Game theory, proposes the theory of Logical Game Petri nets and provides the related formal definition, graphical representation, dynamic property and analysis method. Chapter 5 applies the Logical Game Petri nets theory to the B2C e-commerce case, conducts research on the risk problem of credit mechanism in the enterprises competition module of B2C e-commerce, constructs the Logical Game Petri nets model and reachable marking graph, and analyzes and verifies the relationship between different business modes and utility. Chapter 6 summarizes the full text and outlines further research directions.

II. RELATED RESEARCH

The risk issue of credit in e-commerce has drawn considerable attention from scholars of all walks of life, and they have conducted diversified studies on this issue from different perspectives and different disciplines. One of the current opinions is that this problem is caused by asymmetric information in the e-commerce transaction process. Under the premise of combining the credit issues in e-commerce with economic theory, some scholars' studies focus on case studies and qualitative descriptions. Others focus on the quantitative analysis by mathematical methods. Of course, this difference is also related to the adequacy of data sets.

E-commerce expert Li [21] explored the "lemon" problem proposed by economist George [8] in 1970 from the perspective of economics. Li believed that both the subject of the transaction and the counterpart in the e-commerce environment were expansions of the ''lemon'' problem in virtual goods that enlarge and deepen the ''lemon'' existing in the traditional market. Li [17] used Game theory to study the external role mechanism of credit risk of e-commerce from an economic perspective and analyzed the roles and interactions among different subjects. Abreu [2] used Game theory to study the credit infinite repetitive game behavior. Zeng [45] made use of the multidisciplinary theories and methods of Marketing theory, Game theory, Artificial Neural network and Hypercycle theory to systematically study the formation mechanism, avoidance mechanism and influence mechanism of e-commerce credit risk research. Economist Zhang [43] performed a series of studies on credit risk in e-commerce from a legal point of view and concluded that the two basic mechanisms for maintaining the normal operation of the market are law and credit. Eric *et al.* [7] and Pauline *et al.* [26], [27] used B2B as the research subject, conducted a qualitative study on the risk in the credit mechanism, proposed a new concept of ''trust'', introduced the impact of this concept in the operation of the e-commerce environment, and emphasized that improving integrity can reduce risk and transaction costs. The above scholars primarily focus on case studies and qualitative descriptions of credit research in e-commerce, and most of them use economic theories or other discipline theories, such as Game theory, to analyze the reasons for credit risk and the formation and establishment of credit mechanisms research in e-commerce, thereby promoting the further establishment and improvement of the e-commerce credit system.

Nir [25] conducted research on the intermediary's good faith under B2B and B2C transactions, pointing out that the strategy of trading intermediaries will affect the strategies of both parties in the transaction. Wang [30] combined the BP neural network and early warning management theory to construct the early warning index system of international electronic commerce credit risk and gave the countermeasures under different risk states. Yu [40] established the least square approximation support vector regression model of credit risk warning in e-commerce and gave different warning management countermeasures. Hu and Jiang [10] used the BP neural network to build a C2C e-commerce trust evaluation model from the perspective of consumers to evaluate the trust accurately. The above scholars' research on the credit risk of e-commerce focuses on the quantitative analysis using mathematical methods, establishing mathematical models to describe and solve problems, and has more accurate and specific characteristics than the qualitative description.

There are also many scholars that discuss the issue of credit in e-commerce from other angles. Although there may be no systematic research, it is enlightening and innovative. For example, Gefen [9] described the completeness of information and the important role of credit in e-commerce. He believes that credit has the function of displaying information, and the role of information is closely related to the degree of information asymmetry in the e-commerce market. The corresponding information in e-commerce markets with better credit is more symmetrical. Jarvenpaa *et al.* [13] examined how the expected size and reputation affect the consumer's expected risk and online shopping intentions by influencing the online store's credit. Head and Hassanein [14] studied third-party credit stamps and empirically demonstrated that in the B2C e-commerce market, consumers' acceptance of the e-commerce market can be increased through a third-party credit rating.

Petri nets are a kind of mathematical model that use to describe the distributed system, and it's a tool of modeling and analysis for the distributed system. In the modeling and property analysis of various practical systems, Petri nets have been widely used. With the continuous development of Petri nets theory, many extended Petri nets have also appeared, such as Logical Petri nets, coloured Petri nets [12], [29], stochastic Petri nets [31]–[35], etc. The existing Petri nets in e-commerce modeling and analysis are focused on the processes between different organizations and the the existing properties.

Han and Guo [12] used coloured cross-organizational Petri nets to model and analyze the workflow of e-commerce, the concept of robustness of the e-commerce model based on coloured cross-organizational Petri nets is given, and the reachable mark graph is used to discussed the robustness. Li *et al.* [19] used workflow net technology to complete the modeling of the e-commerce platform, solved the problem of collaboration between e-commerce platform business processes and online banking business processes. Zhu *et al.* [42] proposed a model based on coloured Petri nets, the modeling process for online shopping system in e-commerce is given and the rationality of the structure is demonstrated. Zhu *et al.* [46] gave a formal definition of an object-oriented timed Petri net (OOTPN), described the business processes of the e-commerce logistics service system, and analyzed the relevant time characteristics of the sub-networks, the properties of reachability, boundedness and conservativeness were analyzed.

The characters of batch processing and value uncertainty in logical Petri nets are well-suited to describe processes across organizations of e-commerce systems, this is the advantage of logical Petri nets to describe the process problem, but the description of the game process by logical Petri nets is insufficient. There are multiple elements in game, such as players, strategies, utilities, information, etc. The existing modeling elements of logical Petri nets cannot accurately describe them, so it is necessary to improve logical Petri nets. Based on the original modeling elements of logical Petri nets, new modeling elements are modified and added to support modeling of game elements. In this way, the game process in the modeling of e-commerce and other systems can be accurately described. At the same time, when describing and analyzing the characteristics of the game problem among the various bodies in the e-commerce system, the original dynamic nature of Petri nets cannot accurately describe the new features related to game, so it needs to be redefine and improve. Therefore, we need to integrate the game theory into logical Petri nets, further improve logical Petri nets, and propose the theory of logical game Petri nets.

The above studies provide a theoretical basis and technical support for us to use the Petri net and Game theory to study the risk problems in the credit mechanism of B2C e-commerce. In this paper, based on B2C e-commerce consumers, enterprises, the e-commerce platform and the government as the four main research subjects, the risk behavior among the various subjects of the credit mechanism is evaluated in the game analysis by applying the theory of logical Petri nets, the theoretical basis of Game theory and the least-squares estimation method to perform qualitative and quantitative analyses of credit risk appearing in e-commerce research that simultaneously combined with and deepened game theory and petri net theory to establish and improve e-commerce credit mechanisms and to provide advice to effectively avoid risks.

III. PRELIMINARIES

This chapter introduces some basics of Game theory and Petri nets.

A. GAME THEORY

The following concept of Game theory is from the literature [43], [44].

1) GAME

A complete game should include five aspects: first, participants in the game, that is, individuals and organizations that independently make decisions during the game and bear the consequences independently; second, the game information, that is, the intelligence information that contributes to the selection strategy for the game player; third, the set of all actions or strategies that the player can choose from; fourth, the order of the game, that is, the order in which the game participants make the choice of strategy, and; fifth, the benefits of all parties in the game, that is, the profits and losses of the various parties after making decisions.

2) NASH EQUILIBRIUM

Nash equilibrium is the optimal strategy for all participants. Given the choices of the other participants in the portfolio, no one can change the strategy alone to increase its utility; therefore, no participant has the motivation to change his or her own strategy. In other words, the portfolio of strategies that make up the Nash equilibrium is optimal for everyone, and a portfolio of strategies that achieve Nash equilibrium can simultaneously achieve the best outcomes for all participants.

A Nash equilibrium point is a strategy combination $S^* = \left(s_1^*, s_2^*, \ldots s_n^*\right)$, for each participant i $\in \{1, 2, \ldots, \text{n}\}$, the strategy combination S^* satisfies the following properties:

$$u_i\left(s_i^*, s_{-i}^*\right) \geq u_i\left(s_i, s_{-i}^*\right)$$

In the above formula, s_i denotes the strategy adopted by participant i, s_{-i} denotes the strategies adopted by all other participants except participant i, $u_i\left(s_i, \text{s}_{-i}\right)$ represents the utility value of participant i adopting strategy s_i and other participants adopting strategy s_{-i}.

3) COMPLETE INFORMATION GAME

It refers to the game in which each participant has accurate information about the characteristics, strategies and utility functions of all other participants.

4) COMPLETE INFORMATION STATIC GAME

In the static game, there is no order of action, that is, the actions of different participants are carried out simultaneously. Under the condition of complete information, each participant in the game knows which types of actions the other participants have and what types of actions occur.

5) COMPLETE INFORMATION DYNAMIC GAME

The information in the game is complete, that is, all participants have a complete understanding of the utility function under the strategy combination and strategy combination of other participants. However, the sequence of actions is in order, the latter can observe the actions of the former and understand all the information about the actions of the former, and this process generally lasts for a longer period of time.

6) MIXED STRATEGY

Participants in the information given situation, with some probability randomly select different actions of a strategy.

B. PETRI NETS

The following definition of Petri nets is from the literature [5], [22].

Definition 1 (Net): A three-tuple $N = (P, T, F)$ that satisfies the following condition is called a net:

(1) $P \cup T \neq \emptyset$.
(2) $P \cap T = \emptyset$.
(3) $F \subseteq (P \times T) \cup (T \times P)$.

Definition 2 (Former Set, Latter Set): Let $N = (P, T; F)$ be a net; for x P T, we have the following:

$$^{\bullet}x = \{y | y \in P \cup T \wedge (y, x) \in F\}.$$
$$x^{\bullet} = \{y | y \in P \cup T \wedge (x, y) \in F\}.$$

where $^{\bullet}x$ is the former set or the input set of x, and $x^{\bullet}$ is the latter set or the output set of x.

Definition 3 (Marked Net): Let $N = (P, T; F)$ be a net. The mapping $M\colon S \rightarrow \{0, 1, 2 \ldots\}$ becomes a mark of the net. The two-tuple (N, M) (i.e., the four-tuple $(P, T; F, M)$) is called a marked net.

Definition 4 (Petri Net): A net system is a marked net $\Sigma = (P, T; F, M)$ and has the following transition firing rules:

(1) For transition t T, if

$$\forall p \in P : p \in {^{\bullet}t} \rightarrow M(p) \geq 1$$

Then, transition t is enabled with mark M and denoted as $M\ [t >$.

(2) If M $[t >$, then with mark M, transition t can occur, change from mark M, and obtain a new mark M' (denoted as M $[t > M$'), for p P,

$$M'(s) = \begin{cases} M(p) - 1, & p \in {}^{\bullet}t - t^{\bullet} \\ M(p) + 1, & p \in t^{\bullet} - {}^{\bullet}t \\ M(p), & otherwise. \end{cases}$$

IV. LOGICAL GAME PETRI NETS

This chapter proposes the theory of Logical Game Petri nets and gives the related formal definitions, graphical representations, dynamic properties and analytical methods.

A. FORMAL DEFINITIONS OF LOGICAL GAME PETRI NETS

This section describes the formal definition of Logical Game Petri nets.

Definition 5 (Logical Game Petri Net): LGPN is an eight-tuple, $LGPN = (R, P, T, F, L, U, D, M)$ that satisfies the following conditions:

(1) R is a set of rational people in the game, $R = \{r_1, r_2, \ldots, r_n\}$, $n < \infty$, $r \in R$, B_r represents the behavior set that rational person r takes;

(2) P is a finite set of places, P represents the state set that rational people can take, $P = \{p_1, p_2, \ldots, p_n\}$, $n < \infty$, P_r represents the state set that rational person r can take, place mark r represents that this place can only hold the state set that rational person r can take;

(3) T is a finite set of transitions, T represents the behavior set that rational people can take, $T = \{t_1, t_2, \ldots, t_m\}$, T_r represents the behavior set that rational person r can take, $T = T_R \cup T_L$;

(i) T_R is the transition set of Petri nets, $t \in T_R$, the firing rules of t are the same as the Petri nets;

(ii) T_L is the logical transition set, $T_L = T_I \cup T_O \cup T_{IO}$, T_I is the logical input transition set, T_O is the logical output transition set, T_{IO} is the logical input-output transition set;

(4) F is a finite set of directed arcs, which connects from the place to the transition or vice versa, $F \subseteq (P \times T) \cup (T \times P)$;

(5) L is the logical function, which is defined on the finite set of transitions T, $L = I \cup O$, logical input function I is used to limit the input of transitions, $\forall t \in T_I \cup T_{IO}$, $I(t) = f_I$ is a logical input expression, logical output function O is used to limit the output of transitions, $\forall t \in T_O \cup T_{IO}$, $O(t) = f_O$ is a logical output expression;

(6) U is the utility function of rational people, which is defined on the finite set of transitions T, U_r represents the utility function of rational person r;

(7) D is the finite set of decision, $\forall p \in P$, $\forall t \in T$, $D_r \langle p, t \rangle$ represents the decision that rational person r chooses to conduct behavior t from state p;

(8) M is a finite set of marks, $\forall p \in P$, $M_i(p)$ representing all tokens in place p under current mark M_i.

Definition 6 (Logical Transition Set):

$$T_L = T_I \cup T_O \cup T_{IO}.$$

(1) T_I is the logical input transition set, $\forall t \in T_I$, all the input places of t are limited by the logical input expression f_I, which indicates that the behavior on the logical input transition of rational people is limited by the corresponding states of the former place set;

(2) T_O is the logical output transition set, $\forall t \in T_O$, all the output places of t are limited by the logical output expression f_O, which indicates that the corresponding states on the later place set of the logical output transition of rational people is limited by the behavior on logical input transition;

(3) T_{IO} is the logical input-output transition set, $\forall t \in T_{IO}$, all the input places of t are limited by the logical input expression f_I, all the output places of t are limited by the logical output expression f_O, which indicates that the behavior on the logical input transition of rational people is limited by the corresponding states of the former place set, the corresponding states on the later place set of the logical output transition of rational people is limited by the behavior on the logical input transition;

Definition 7 (Logical Function): $\forall t \in T_L$, $\forall p_i, p_j \in P$, the syntax is as follows:

(1) logical or operation $\vee$.

(i) $I(t) = p_i \vee p_j$ indicates that t is enabled only if/when there is token in p_i or p_j, p_i and p_j are the former places of transition t;

(ii) $O(t) = p_i \vee p_j$ indicates that after transition t occurs, the tokens in the input place are removed, and the corresponding number of tokens is produced in the output place p_i or p_j.

(2) logical and operation $\wedge$.

(i) $I(t) = p_i \wedge p_j$ indicates that t is enabled only if/when there is a token in p_i and p_j, p_i and p_j are the former places of transition t;

(ii) $O(t) = p_i \wedge p_j$ indicates that after transition t occurs, the tokens in the input place are removed, and the corresponding number of tokens are produced in the output places p_i and p_j.

(3) logical uncertain equivalent operation Δ.

(i) $I(t) = p_i \Delta p_j$ indicates that t is enabled only if/when there is a token in p_i and p_j, p_i and p_j are the former places of transition t, then operator Δ is equivalent to $\wedge$, otherwise operator Δ is equivalent to $\vee$;

(ii) $O(t) = p_i \Delta p_j$ indicates that after transition t occurs, the tokens in the input place are removed, the corresponding number of tokens are produced in the output places p_i and p_j, then operator Δ is equivalent to $\wedge$, otherwise operator Δ is equivalent to $\vee$.

Definition 8 (Utility Function): $\forall t \in T$, $\forall p \in P$, the syntax is as follows:

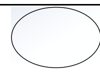
(1) $U_r^p(t)$ represents the utility function when rational person r chooses to conduct behavior t from state p;

(2) $U(D_r \langle p, t \rangle)$ represents the utility function when rational person r chooses to make decision $D_r \langle p, t \rangle$;

(3) $U_r^p(t) = U(D_r \langle p, t \rangle)$.

The rational people can choose to make a decision by the utility function.

TABLE 1. Graphic presentation of Logical Game Petri nets.

Element name	Symbol	Graphical representation
type place	P	
transition	T	
token	token	$(0, x, U_y, \ldots)$
directed arc	F	→

Definition 9 (Mark Set): M represents the set of all the marks. $\forall p \in P$, $M_i(p)$ represents all the tokens in place p under current mark M_i. We usually use the number of tokens or specific content to represent, in *LGPN*, and the type of token is usually represented by rational people or its utility function.

$\forall p \in P$, Mapping $M_i : p \to \{0, x, U_y, \ldots\}$.

Represents the mark M_i of net. 0, x and U_y represent the type of token in place $p1$, $p2$ and $p3$, respectively. $M_i = (0, x, U_y)$ is equivalent to the above mapping.

M_0 is usually used to represent the initial mark, and M_e is used to terminate the mark.

Definition 10 (Individual Decision): In *LGPN*, the process that rational person r makes the decision to conduct behavior t from state p according to utility function U is called an individual decision, that is $D_\mathrm{r}\langle p, t\rangle$.

Definition 11 (Optimal Individual Single Step Decision D_r^{SB}): In *LGPN*, the best individual decision D_r that rational person r can make according to utility function U is called an optimal individual single step decision D_r^{SB}.

Definition 12 (Multi-Step Decision Set D^{Mu}): In *LGPN*, the set of decisions are made by one or more rational people from the initial mark M_0 to the terminate mark M_e is called a multi-step decision set D^{Mu}.

D_r^{Mu} represents the multi-step decision of rational person r.

The multi-step indicates the number of decisions that rational people made from the initial mark M_0 to the terminating mark M_e.

Definition 13 (Optimal Individual Multi-Step Decision Set D_r^{MB}:) In *LGPN*, the bests set of multi-step decisions D^{Mu} that rational person r can make according to multiple utility functions is called an optimal individual multi-step decision set D_r^{MB}.

Definition 14 (Group Decision $D_M^{M'}$): In *LGPN*, under mark M, all rational people $R = \{r_1, r_2, \ldots, r_\mathrm{n}\}$ make decisions sequentially or simultaneously, $M[D_{\mathrm{r}_1} D_{\mathrm{r}_2} \ldots D_{\mathrm{r}_n} > M'$, which is $M[t_1 t_2 \ldots t_\mathrm{n} > M'$, then the set of n decisions is called a group decision $D_M^{M'}$, $D_M^{M'} = \sum_{i=1}^{n} D_{r_i}$, $n < \infty$.

Every rational person only makes a decision once in every group decision.

The utility of the group decision is the sum of the utilities of every individual decision:

$$U\left(D_M^{M'}\right) = \sum_{i=1}^{n} U\left(D_{r_i}\right).$$

Definition 15 (Group Multi-Step Decision Set $D_{M_0}^{M_e}$): In *LGPN*, under initial mark M_0, the different multi-step decision sets are made by all the rational people $R = \{r_1, r_2, \ldots, r_n\}$ sequentially or simultaneously is called a group multi-step decision set $D_{M_0}^{M_e}$.

$D_{M_0}^{M_e}$ consists of different multi-step decisions made by all the rational people.

Definition 16 (Optimal Global Nash Decision $D_{M_0\,nash}^{M_e}$): In *LGPN*, suppose there are n numbers of rational people, if there is a group multi-step decision then not any one of all the rational people can change his or her own decision alone to increase his or her own utility without changing the decisions of the *n-1* others, then the group multi-step decision is called an optimal Global Nash decision $D_{M_0\,nash}^{M_e}$.

B. GRAPHICAL PRESENTATIONS OF LOGICAL GAME PETRI NETS

Table 1 shows the graphical representation of Logical Game Petri nets. The combination of the oval and diamond denotes the type place, the rectangle denotes the transition, and the line with an arrow denotes the directed arc.

C. DYNAMIC PROPERTIES OF LOGICAL GAME PETRI NETS

This section presents the dynamic properties associated with Logical Game Petri nets, including self-individual-local optimality, other-individual-local optimality, self-individual-global optimality, other-individual-global optimality, group-global optimality and three inferences.

Definition 17 (Self-Individual-Local Optimality): In *LGPN*, under mark M, if the utility of the decision D_{r_i} that is made by rational person r_i, is greater than the utility of other decisions that rational person r_i can make, then decision D_{r_i} is the self-individual-local optimality.

Inference 1 Decision that is the self-individual-local optimality is the optimal individual single step decision D_r^{SB}.

Definition 18 (Other-Individual-Local Optimality): In *LGPN*, under mark M, all rational people $R = \{\mathrm{r}_1, \mathrm{r}_2, \ldots, \mathrm{r}_\mathrm{n}\}$ make decisions sequentially or simultaneously, $M[D_{\mathrm{r}_i} \ldots D_{\mathrm{r}_j} > M'$, which is $M[t_\mathrm{i} \ldots t_\mathrm{j} > M'$, the n numbers of decisions make up group decision $D_M^{M'}$. In the k numbers of group decisions $D_M^{M'}, D_M^{M''}, \ldots$ which is started from mark M, if the utility of the decision D_{r_i}, which is made by rational person r_i, is greater than the utility of every other decision that is made by all rational people, then the decision D_{r_i} is the other-individual-local optimality in this round of k numbers of group decisions.

Definition 19 (Self-Individual-Global Optimality): In *LGPN*, under initial mark M_0, if the utility of the multi-step decision set that is made by rational person r_i is greater than the utility of the other multi-step decision sets that rational person r_i can make, then this multi-step decision set is the self-individual-global optimality.

Inference 2 Decision set that is the Self-individual-global optimality is the optimal individual multi-step decision set D_r^{MB}.

Definition 20 (Other-Individual-Global Optimality): In *LGPN*, under initial mark M_0, if the utility of the multi-step decision set that is made by rational person r_i is greater than the utility of every other multi-step decision set that all rational people can make, then this multi-step decision set is other-individual-global optimality.

Definition 21 (Group-Global Optimality): In *LGPN*, under initial mark M_0, all rational people $R = \{r_1, r_2, \ldots, r_n\}$ make different group multi-step decisions sequentially or simultaneously. If the sum of the utilities of one of the group multi-step decisions that are made by all rational people is the maximum in the group multi-step decision set, then the group multi-step decision is the group-global optimality.

Inference 3 Decision that is the group-global optimality is the optimal Global Nash decision $D_{M_0\,nash}^{M_e}$.

D. ANALYTICAL METHODS OF LOGICAL GAME PETRI NETS

This section gives the relevant analysis methods of Logical Game Petri nets, including the reachable marking graph, least square utility function solution method, and utility matrix analysis.

1) REACHABLE MARKING GRAPH

The specific definition of the reachable marking graph is as follows.

Definition 22 (Reachable Marking Graph RMG): In *LGPN*, *RMG* is a three-tuple, $RMG(LGPN) = \{R(M_0), A, S\}$, $R(M_0)$ is the vertex set that consists of the reachable mark of net; A is a set of directed arcs; S is the side marker.

$S(M_i, M_j) = t_k, M_i, M_j$ are two vertices, (M_i, M_j) is the directed arc from M_i to M_j, and t_k is the side maker of (M_i, M_j).

Definition 23 (Leaf Mark M_e): In the *RMG*of*LGPN*, all the vertices without output arcs are leaf marks M_e, which are also called terminate marks.

Definition 24 (Trace): In the *RMG*of*LGPN*, all the parts from initial mark M_0 to any leaf mark M_e is called a trace.

2) LEAST SQUARE SOLVING UTILITY FUNCTION METHOD

In the process of solving the utility function by the least square method, the type of the utility function is divided into unitary linear utility function and multiple linear utility functions. The specific solution process is as follows.

(1) The least square method to solve unitary linear utility function.

Suppose that x is an independent variable of quantitative description, the dependent variable Y is a random variable, $E(Y) = \mu(x)$, function $y = \mu(x)$ is called the utility function and $\mu(x)$ is unknown. To facilitate the processing mathematically, suppose that $\mu(x)$ is a linear function, that is as follows:

$$y = \beta_0 + \beta_1 x \tag{1}$$

where β_0 and β_1 are to be determined, and β_1 is called the utility coefficient of the unitary linear utility function.

Use the least squares method to solve for β_0 and β_1 in the above equation. In the analysis of the unitary linear utility function, the least-squares estimators for β_0 and β_1 are as follows:

$$\hat{\beta}_0 = \bar{y} - \hat{\beta}_1 \bar{x}. \tag{2}$$

$$\hat{\beta}_1 = \frac{\sum_{i=1}^{n}(x_i - \tilde{x})(y_i - \tilde{y})}{\sum_{i=1}^{n}(x_i - \tilde{x})^2} \tag{3}$$

where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$.

Substituting β_0 and β_1 into formula (1), the corresponding unitary linear utility function can be solved.

(2) The least squares method to solve the multiple linear utility function.

Suppose there are p numbers of independent variable and a dependent variable, Y, $E(\mathrm{Y}) = \mu\left(x_p, \cdots, x_p\right)$. To facilitate the processing mathematically, suppose that $\mu\left(x_p, \cdots, x_p\right)$ is a linear function, that is as follows:

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p \tag{4}$$

where $\beta_0, \cdots, \beta_p$ is to be determined, and $\beta_0, \cdots, \beta_p$ is called the utility coefficient of the multiple linear utility function.

Use the least squares method to solve for $\beta_0, \cdots, \beta_p$ in the above equation. First, introduce some marks, as follows:

$$l_{jk} = \sum_{t=1}^{n}\left(x_{tj} - \bar{x}_j\right)\left(x_{tk} - \bar{x}_k\right), \quad j, k = 1, \cdots, p.$$

$$l_{jy} = \sum_{t=1}^{n}\left(x_{tj} - \bar{x}_j\right)\left(y_t - \bar{y}\right), \quad j, y = 1, \cdots, p.$$

TABLE 2. Mixed strategy utility metrics between gaming parties.

x \ y	$B_y^1(P_y)$	$B_y^2(1-P_y)$
$B_x^1(P_x)$	$U_x^{11}.\ U_y^{11}.$	$U_x^{12}.\ U_y^{12}.$
$B_x^2(1-P_x)$	$U_x^{21}.\ U_y^{21}.$	$U_x^{22}.\ U_y^{22}.$

And matrix

$$L = \begin{pmatrix} l_{11} & \cdots & l_{1p} \\ \vdots & \vdots & \vdots \\ l_{p1} & \cdots & l_{pp} \end{pmatrix}.$$

In the analysis of multiple linear utility function, the least-squares estimators for $\beta_0, \cdots, \beta_p$ are as follows:

$$\begin{pmatrix} \hat{\beta}_1 \\ \cdots \\ \hat{\beta}_p \end{pmatrix} = L^{-1} \begin{pmatrix} l_{1y} \\ \cdots \\ l_{py} \end{pmatrix}. \tag{5}$$

$$\hat{\beta}_0 = \bar{y} - \sum_{j=1}^{p} \hat{\beta}_j \bar{x}_j. \tag{6}$$

where, $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$.

Substituting $\beta_0, \cdots, \beta_p$ into formula (4), the corresponding multiple linear utility function can be solved.

3) UTILITY MATRIX ANALYSIS

The three steps of utility matrix analysis are as follows.

Step 1: Suppose that each game contains two rational participants, x and y, and each participant has two types of behavior, B^1 and B^2. The probability of occurrence of the two types of behavior is the mixed strategy of the game $(P_x, 1-P_x)$, and $(P_y, 1-P_y)$, the utility matrix is shown in the following table:

Step 2: Under the given mixed strategy $(P_x, 1-P_x)$ of x, the expected utility of y is as follows:

$$U_y = P_y\left[P_x U_y^{11} + (1-P_x)\, U_y^{21}\right] + (1-P_y)\left[P_x U_y^{12} + (1-P_x)\, U_y^{22}\right]$$

Under the given mixed strategy $(P_y, 1-P_y)$ of y, the expected utility of x is as follows:

$$U_x = P_x\left[P_y U_x^{11} + (1-P_y)\, U_x^{12}\right] + (1-P_x)\left[P_y U_x^{21} + (1-P_y)\, U_x^{22}\right]$$

Step 3: Find the partial derivatives of U_x, U_y and make them equal to zero, as shown below:

$$\frac{\partial U_x}{\partial P_x} = 0, \quad \frac{\partial U_y}{\partial P_y} = 0.$$

where P_x^* and P_y^* are the optimal decisions under the condition of mixed strategy between the two rational participants of the game.

V. B2C E - COMMERCE MODELING BASED ON LOGICAL GAME PETRI NETS

This chapter takes the B2C e-commerce mode as a case, uses the theory of Logical Game Petri nets, combines the Game theory and least squares estimation method, analyzes the credit risk in B2C e-commerce, and conducts research on the risk problem of the credit mechanism in enterprises competition module of B2C e-commerce.

First, transform the risk problem in the B2C e-commerce credit mechanism into the game behaviors among the four main bodies in the e-commerce mode credit mechanism, and construct the B2C e-commerce model based on the Logical Game Petri nets. Next, focus on the study of credit risk in the competition module between enterprises, establish the basic assumption, obtain the database set and segment it, solve the utility function in different business models, build the *LGPN* model and *RMG* of this module, obtain four traces that can describe the problem under the assumption by analysis; set up the utility matrix according to four traces and analyze it. Analysis of the *LGPN* model of the enterprise competition module from both the perspective of property and performance and discuss and verify the relationship between the business model and effectiveness.

A. B2C E - COMMERCE CREDIT MECHANISM RISK GAME BEHAVIOR MODELING

In the B2C e-commerce mode, the four main bodies are the consumer, enterprise, e-commerce platform and government, and the four main modules are the shopping module between the consumer and enterprise, the competition module between enterprises, the supervise module between the enterprise and e-commerce platform, and the reform module between the e-commerce platform and government. Transform the credit risk behaviors between the four main bodies in the four modules into game behaviors as shown below.

1) SHOPPING MODULE

In the shopping module between the consumer and enterprise, the two main bodies know each other's types of behaviors and corresponding probabilities, the process of the game is the process of shopping, and there is no order in the game process of decision making, so the game behavior between the consumer and enterprise is a complete information static game, both sides in the game want to obtain the optimal benefit and utility, so the game is a non-cooperative game.

2) COMPETITION MODULE

In the competition module between enterprises, the enterprises know each other's types of behaviors and corresponding probabilities, the decisions that they made seemed to be

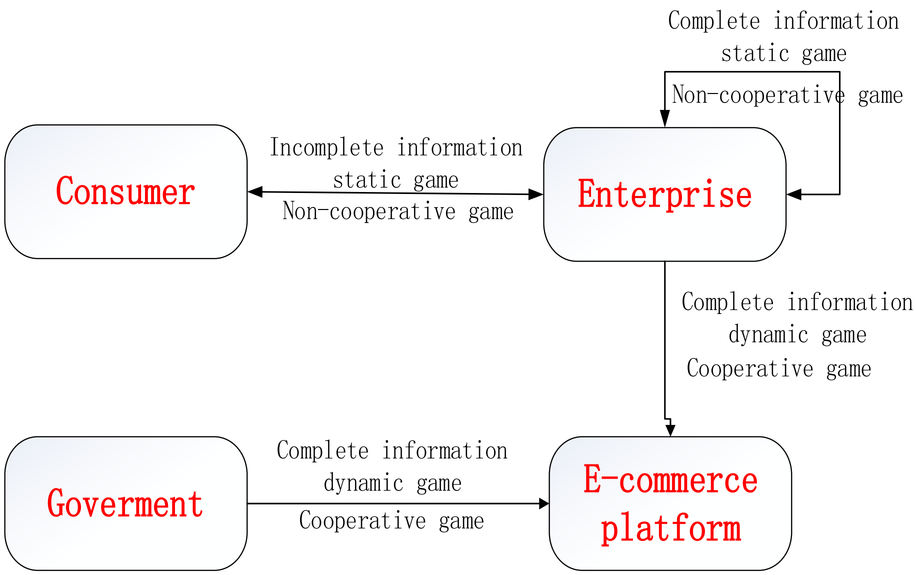


FIGURE 1. Relationship diagram of credit risk game behaviors among the four main bodies in B2C e-commerce.

conducted at the same time, and these two need to compete for the share in one market, so the game behavior between the enterprises is a non-cooperative complete information static game.

3) SUPERVISE MODULE

In the supervise module between the enterprise and e-commerce platform, the two main bodies know each other's types of behaviors and corresponding probabilities, but whether the e-commerce platform is chosen to conduct supervision is according to the business mode that the enterprise chooses, therefore the game behavior between the enterprise and e-commerce platform is a complete information dynamic game. At the same time, both sides in the game want more consumers in the market so that the enterprise and e-commerce platform can jointly obtain greater benefit and utility, so the game is a cooperative game.

4) REFORM MODULE

In the reform module between the e-commerce platform and government, the two main bodies know each other's types of behaviors and corresponding probabilities, but whether the government is chosen to support the program of the e-commerce platform is according to the credit mechanism and the current development of the e-commerce platform. Both sides in the game want the development of the market to be healthy and long-term, so the game behavior between the e-commerce platform and government is a cooperative complete information dynamic game.

According to above analytic, the relationship diagram of the credit risk game behaviors among the four main bodies in B2C e-commerce is as shown below in Fig. 1.

According to above analytic of the diagram of the relationship credit risk game behaviors among the four main bodies in B2C e-commerce in Fig. 1, and combined with the actual situation, the *LGPN* model of credit risk game behaviors among the four main bodies in B2C e-commerce is constructed as follows.

In the above *LGPN* model of credit risk game behaviors among the four main bodies in B2C e-commerce, the rational people include the government, e-commerce platform, enterprise X, enterprise Y and consumer, and the corresponding behavior set and state set of every rational person are as shown in Table 3 and Table 4.

In the next section, we focus on the analysis and study of the credit mechanism risk game behavior in the B2C e-commerce enterprise competition module.

B. SECURITY ANALYSIS OF B2C e - COMMERCE MODEL BASE ON LGPN

For the above LGPN model of credit risk game behaviors among the four main bodies in B2C e-commerce system, the security analysis is as follows.

E-commerce relies on network carriers and has the characteristics of transaction virtualization. The key to ensuring the security of the system depends on the security maintenance of the network information to a large extent. Since there are a certain amount of network information interaction between the four four main bodies in the system, such as whether the government supports the program of the E-commerce platform, whether the E-commerce platform needs to reform the current manage program, and whether the E-commerce platform needs to supervise the enterprise and so on. These information plays a decisive role in the operation of the entire system model. Therefore, the security protection of these information is the core of system model security.

TABLE 3. Representation of the element meanings of Behavior set in FIGURE 2.

Behavior set element	Element meaning
t1	government supports the program of the e-commerce platform
t2	government defaults the program of the e-commerce platform
t3	the program impacts both the government and e-commerce platform
t4	e-commerce platform chose to reform
t5	e-commerce platform chose not to reform
t6	e-commerce platform chose to supervise
t7	e-commerce platform chose not to supervise
t8	the policy impacts both the e-commerce platform and two enterprises
t9	enterprise chose to manage truthfully
t10	the short-term profit impacts both enterprises
t11	enterprise chose to manage in a fraudulant way
t12	the strategy impacts both enterprises
t13	consumer chose to buy product
t14	consumer chose not to buy product

TABLE 4. Representation of the element meanings of State set in FIGURE 2.

State set element	Element meaning
p1	government
p2	the reform program of the e-commerce platform
p3	the non-reform program of the e-commerce platform
p4	e-commerce platform
p5	the supervise policy of the e-commerce platform
p6	the non-supervise policy of the e-commerce platform
p7	the short-term profit of enterprise X
p8	the short-term profit of enterprise Y
p9	enterprise X
p10	enterprise Y
p11	the product of enterprise X
p12	the product of enterprise Y
p13	consumer

In the process of transmitting and storing information, network carriers not only have convenient and efficient features, but also have a certain degree of uncertainty. These uncertainties have given hackers an opportunity to attack the system for certain malicious reasons, such as information theft, maliciously disrupting the market, hindering the development of electronic platforms, etc. This requires us to verify and analyze the security of the model.

The attack-defense model based on Fig. 2 is shown in Fig. 3. On the basis of Figure 3, place p14, transition t15 and transition t16 are added. Place p14 represents the hacker. Transition t15 represents the hacker steals information from the government, e-commerce platform and enterprises. Transition t16 represents the hacker sells false information to enterprises and consumer.

1) SECURITY ANALYSIS OF INFORMATION THEFT

Suppose the current mark is $M_0 = (0, E_{\text{ref}}, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$, $M0$ means the e-commerce platform(p4) chose the reform program.

If the hacker(p14) wants to steal specific information about whether the government(p1) supports(t1) or defaults(t2) the e-commerce platform(p4) to implement the reform program at current mark $M_0.M_0[t1, t2 >_. \{t1, t2\}^\bullet = \{p2, p3\}$, $\{p2, p3\}$ contains the state information of both government(p1) and E-commerce platform(p4), according to the assumption, the hacker(p14) needs to steal specific information from place p2.

And suppose the government(p1) supports(t1) the reform program, $M_0[t1 > M_1$, $M_1 = (0, (E_{\text{ref}}, G_{su}), 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$.

If the hacker(p14) wants to successfully steal the information of the government(p1) supports(t1) the reform program of the e-commerce platform(p4) in p2, transition t15 needs to be enabled at current mark M_1, that is $M_1[t15 >$, then transition t15 needs to be fired, $M_1[t15 > M_1'$, $M_1' = (0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, (E_{\text{ref}}, G_{su}))$, M_1' means the hacker successfully steal the information that the government(p1) supports(t1) the reform program of the e-commerce platform(p4).

However, from the second point in definition 5, place mark r represents that the place can only hold the state set that rational person r can take, place mark not only just restricts the flow of tokens in the net, but also encrypts the information represented by the tokens, and place mark r is the key, this key means that only the subjects with the corresponding rights in the system can obtain the corresponding information.

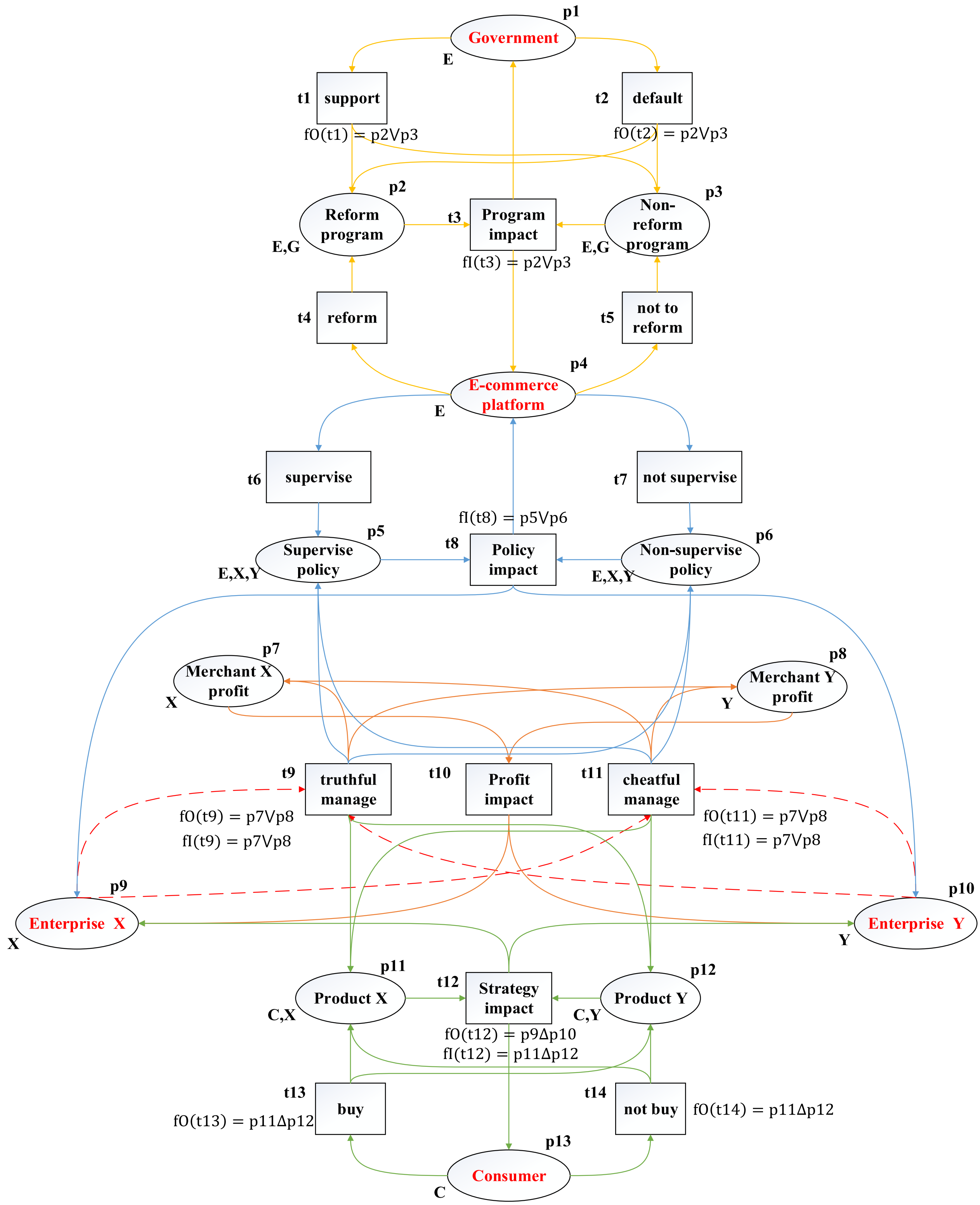


FIGURE 2. *LGPN* model of credit risk game behaviors among the four main bodies in B2C e-commerce.

Since the place mark of place p2 is marked as E,G, then only the E-commerce platform(E) and the government(G) can read and write information in place p2. And because the place mark of place p14 is H, so the hacker represented by place p14 cannot read or write information in any place without marked containing H. Therefor, $\neg M_1[t15>$, and $\neg M_1[t15 > M_1'$, insecure state M_1' is unreachable, the hacker cannot steal the information whether the

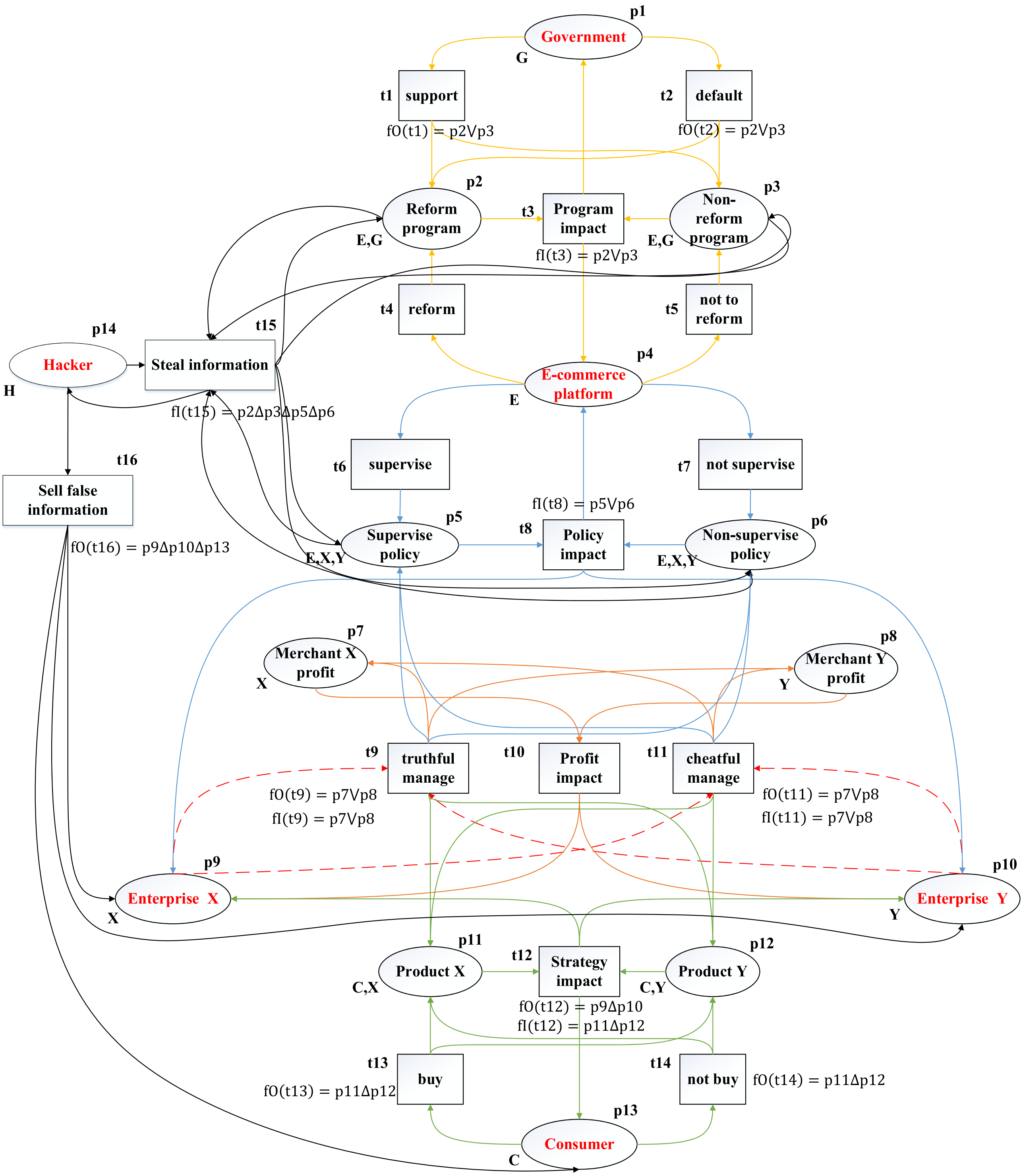


FIGURE 3. Attack-defense model based on *LGPN* model in B2C e-commerce.

government(p1) supports(t1) or defaults(t2) the e-commerce platform(p4) to implement the reform program in p2.

Similarly, the hacker cannot steal the information whether the government(p1) supports(t1) or defaults(t2) the e-commerce platform(p4) to implement the non-reform program in p3. Therefor, the hacker cannot steal the information of government encrypted by the *LGPN*. Moreover, the hacker cannot steal the information from any of the four main bodies in the B2C E-commerce model encrypted by the *LGPN*.

Because any insecure states related to the information theft is unreachable, so information theft type of attack is invalid in the B2C e-commerce model base on *LGPN*.

2) SECURITY ANALYSIS OF MALICIOUSLY DISTURBING THE MARKET

Suppose the hacker(p14) wants to maliciously disturbing the market by selling false information(t16) to the consumer(p13) and enterprise(p9,p10). The place mark of hacker(p14) is H, the place mark of consumer(p13) is C and the place mark of enterprise(p9,p10) are X,Y. Then the hacker(p14) will encounter the problem we have mentioned above, that is being unable to read and write information to subjects with different place mark. In another word, the transition t16 is unable to fire under any state, so the hacker cannot selling false information(t16) to the consumer(p13) and enterprise(p9,p10) under any condition.

Similarly, any insecure states related to maliciously disturbing the market by selling false information is unreachable, so maliciously disturbing the market type of attack is invalid in the B2C e-commerce model base on *LGPN*.

C. B2C e-COMMERCE ENTERPRISE COMPETITION MODULE CREDIT MECHANISM RISK GAME BEHAVIOR MODELING

In this section, we focus on the modeling construction and analysis of the credit mechanism risk game behavior in the B2C e-commerce enterprise competition module. First, give the basic hypothesis according to the actual situation, then, solve the utility function by using the least squares estimation method. On this basis, establish the *LGPN* model and the *RMG* of the competition module, and research the *RMG* to find four traces that can describe the game behavior. Next, use the utility matrix method to analyze the four traces.

1) BASIC HYPOTHESIS

In the process of studying the credit risk game behavior of the B2C e-commerce enterprise competition module, the basic hypotheses are as follows:

H1. In the process of trading in e-commerce, all the enterprises meet the characteristics of the rational-economic man, the purpose of which is to maximize utility;

H2. There are only two enterprises with the same type in the e-commerce market, which are enterprise X and enterprise Y, and there is only one type of product. The behavior types of the enterprises are either to ''manage truthfully'' or ''manage fraudulently'';

H3. The information between the two enterprises is completely open, and both sides know each other's behavior types and corresponding probability, but they do not know which choice the other one will make, so their decision making is considered to be conducted at the same time.

H4. The short-term utility of the enterprise is that the sales profit rate (*SPR*) of the enterprise is influenced by the loan overdue rate (*LOR*) and the rate of destroying the treaty (*DTR*), and the long-term utility of the enterprise is that the total capital growth rate (*TAG*) is not only influenced by its own *SPR* but is also influenced by the *SPR* of the other side.

H5. The capacity of market is certain, and the consumers of the market are basically divided equally by the two enterprises.

H6. The supervision of e-commerce and government for enterprises are not taken into consideration.

2) SOLUTION OF UTILITY FUNCTION

Under the basic hypotheses above, use the least squares utility function solution method in section 4.4.2 to solve the utility function of different business modes, obtain the data set from the literature [30, Ch. 5, Table 5.1], and take the four types of dates as date items 1, 15, 17 and 18 in the following calculation, which are X1 the sales profit rate (*SPR*), X15 the total capital growth rate (*TAG*), X17 the loan overdue rate (*LOR*) and X18 the rate of destroy the treaty (*DTR*).

First, use the *LOR*, *DTR* to calculate the credit index (*CI*) by segmenting the former 16 groups dates. The method for calculating the *CI* is as follows:

$$CI_i = (LOR_i - \frac{1}{n}\sum_{k=1}^{n} LOR_k) + (DTR_i - \frac{1}{n}\sum_{k=1}^{n} DTR_k) \quad (7)$$

The method of determining the type of enterprise data is shown below:

$$\begin{cases} r_i \in r_t, & CI_i < 0 \\ r_i \in r_c, & CI_i > 0 \end{cases}$$

where CI_i represents the credit index of enterprise i, LOR_i represents the loan overdue rate of enterprise *i*, DTR_i represents the rate of destroying the treaty of enterprise *i*, r_i represents the enterprise *i*, r_t represents the truthful enterprise, r_c represents the fraudulent enterprise.

According to above calculation method and the data set in the literature [30], the results are shown in Table 5.

According to Table 5, enterprises from 1 to 5 and 14 to 16 are the truthful enterprises, enterprises from 6 to 13 are the fraudulent enterprises, the corresponding four types of data, i.e., *SPR*, *LOR*, *DTR*, *TAG*, of these enterprises is divided into the data of truthful management and fraudulent management, using the Matlab language to achieve the least square method, solving the utility function under different business modes:

(1) Utility functions of truthful management:

$$\begin{cases} U^t_{SPR}\left(LOR^t, DTR^t\right) = -1.3228 + 2.5900LOR^t \\ \qquad\qquad + 9.2418DTR^t \\ U^{tt}_{TAG}\left(SPR^t\right) = 0.2177 + 0.2074SPR^t \\ U^{tc}_{TAG}\left(SPR^t, SPR^c\right) = 0.2726 + 0.0096SPR^t \\ \qquad\qquad - 0.1947SPR^c \end{cases} \quad (8)$$

TABLE 5. Credit index segmentation table of enterprises' data.

Enterprise number	Credit index *CI*	Type of rational
1	-0.09078	r_c
2	-0.11878	r_c
3	-0.20278	r_c
4	-0.29678	r_c
5	-0.07778	r_c
6	0.175222	r_t
7	0.307222	r_t
8	0.009222	r_t
9	0.444222	r_t
10	0.458222	r_t
11	0.151222	r_t
12	0.143222	r_t
13	0.006222	r_t
14	-0.14078	r_c
15	-0.19078	r_c
16	-0.20678	r_c

(2) Utility functions of fraudulent management:

$$\begin{cases} U_{SPR}^{c}\left(LOR^{c},DTR^{c}\right)=1.2914-2.9027LOR^{c} \\ \qquad\qquad\qquad\qquad +12.6597DTR^{c} \\ U_{TAG}^{ct}\left(SPR^{c},SPR^{t}\right)=0.2396+0.0903SPR^{c} \\ \qquad\qquad\qquad\qquad -0.1407SPR^{t} \\ U_{TAG}^{cc}\left(SPR^{c}\right)=0.1461+0.2098SPR^{c} \end{cases} \tag{9}$$

where U_{SPR}^{t} represents the sales profit utility of a truthful enterprise that is influenced by its own *LOR* and *DTR*, LOR^t represents the loan overdue rate of a truthful enterprise, DTR^t represents the rate of destroying the treaty of a truthful enterprise, U_{SPR}^{c} represents the sales profit utility of a fraudulent enterprise that is influenced by its own *LOR* and *DTR*, LOR^c represents the loan overdue rate of a fraudulent enterprise, DTR^c represents the rate of destroying the treaty of a fraudulent enterprise.

SPR^t represents the sales profit rate of s truthful enterprise. SPR^c represents the sales profit rate of a fraudulent enterprise. U_{TAG}^{tt} represents the total capital growth utility that is influenced by SPR^t when both enterprises are in the truthful management business mode. U_{TAG}^{tc} represents when there is one enterprise is in the truthful management business mode and the other enterprise is in the fraudulent manage business mode, the total capital growth utility of a truthful enterprise that is influenced by its own SPR^t and the SPR^c of the other enterprise. U_{TAG}^{ct} represents when there is one enterprise in the truthful management business mode and the other enterprise is in the fraudulent management business mode, the total capital growth utility of a fraudulent enterprise that is influenced by its own SPR^c and the SPR^t of the other enterprise. U_{TAG}^{cc} represents the total capital growth utility that is influenced by SPR^c when both enterprises are in the fraudulent management business mode.

X1 represents the sales profit rate (*SPR*), X15 represents the total capital growth rate (*TAG*), X17 represents the loan overdue rate (*LOR*) and X18 represents the rate of destroying the treaty (*DTR*).

For the above utility functions, the correctness verification is as follows.

Use the Matlab language to calculate the correlation coefficient and estimated error of the 6 utility functions in equations (8) and (9), which is shown as Table 6 and analyze the results.

The correlation coefficient represents the degree of correlation between the independent variables and dependent variables of the utility function, but it has a clear disadvantage. If the degree is close to 1, it is related to the size of data sets n. Currently, the sample size is n=16, which is small; therefore, we conclude that there is a linear relation between the independent variables and dependent variables according

TABLE 6. Parameter table of the correctness verification of the utility function.

Utility function	Correlation coefficient	Estimated error
U^{t}_{SPR}	0.5690	0.0401
U^{tt}_{TAG}	0.0615	0.0561
U^{tc}_{TAG}	0.1379	0.0618
U^{c}_{SPR}	0.7805	0.0551
U^{ct}_{TAG}	0.2587	0.0184
U^{cc}_{TAG}	0.3159	0.0162

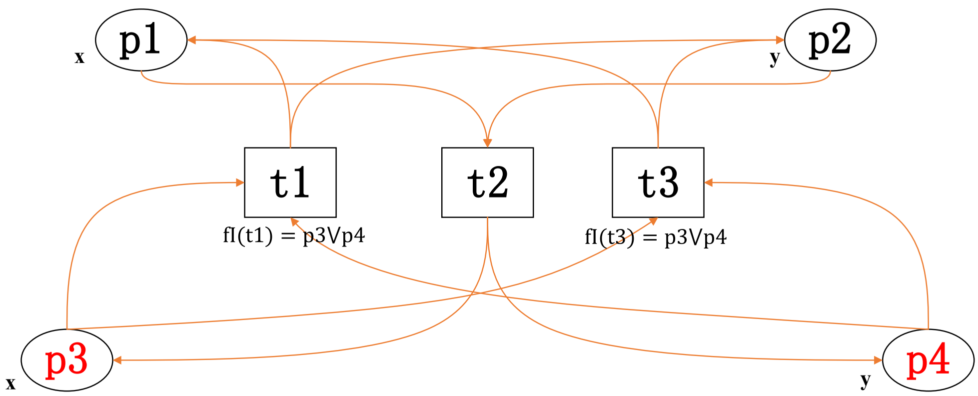


FIGURE 4. ***LGPN* model of enterprise competition module in B2C e-commerce.**

to the above data in Table 6. However, it is not sufficient to determine whether there is a close linear relation between the independent variables and dependent variables.

The estimated error represents the difference between the expectation of the estimator and the true value of the estimated parameter. If the difference is 0, then the estimator is unbiased, or else the estimator is biased. According to Table 6, the linear coefficient estimator is biased, as all the estimated errors of the 6 utility functions are less than 0.07, within our research acceptable range.

3) CONSTRUCTION OF ENTERPRISE COMPETITION MODULE MODEL BASED ON LOGICAL GAME PETRI NETS

According to above basic hypotheses and the utility functions of the two different business modes, construct the *LGPN* model of the enterprise competition module in B2C e-commerce, as shown in Figure 4.

In above *LGPN* model of the enterprise competition module in B2C e-commerce, the rational people include enterprise X and enterprise Y, and the corresponding behavior set and state set of both rational people are shown in Table 7 and Table 8.

According to above *LGPN* model of the enterprise competition module, construct the RMG as shown in Figure 4.

From Figure 5, the initial mark $M_0 = (0, 0, x, y)$, under the current mark M_0, the logical input function on

TABLE 7. Representation of the element meanings of behavior set in FIGURE 4.

Behavior set element	Element meaning
t1	enterprise chose to manage truthfully
t2	the short-term profit impacts both enterprises
t3	enterprise chose to manage in a fraudulent way

TABLE 8. Representation of the element meanings of state set in FIGURE 4.

State set element	Element meaning
p1	the short-term profit of enterprise X
p2	the short-term profit of enterprise Y
p3	enterprise X
p4	enterprise Y

transition t1 and t3 is satisfied, that is t1 and t3 are enabled. t1 represents the enterprise choosing the truthful management business mode, t3 represents the enterprise choosing the

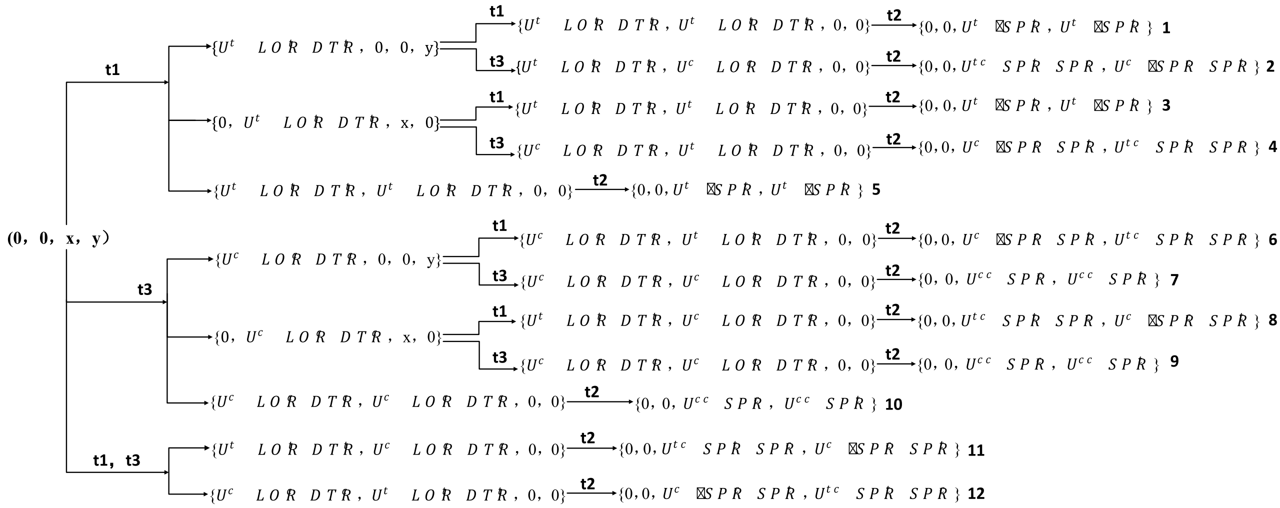


FIGURE 5. ***RMG*** **of** ***LGPN*** **model of the enterprise competition module in B2C e-commerce.**

fraudulent management business mode. Take trace 5 for example, transition t1 occurs, token x in place p3 and token y in place p4 are removed, both enterprises choose the truthful management business mode, token $U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right)$ is added to place p1 and token $U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right)$ is added to place p2, the mark of net is transformed from $M_0 = (0, 0, x, y)$ to $\{U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right), U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right), 0, 0\}$. In the new mark $\{U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right), U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right), 0, 0\}$, $U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right)$ and $U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right)$ represent the sales profit utility of enterprise X and enterprise Y, respectively, after they choose the truthful management business mode. Under current mark $\{U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right), U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right), 0, 0\}$, transition t2 is enabled, t2 represents the short-term profit, which is that the sales profit utility impacts both enterprises, transition t2 occurs, token $U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right)$ in place p1 and token $U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right)$ in place p2 are removed, token $U_{TAG}^{tt}\left(SPR_{x}^{t}\right)$ is added to place p3 and token $U_{TAG}^{tt}\left(SPR_{y}^{t}\right)$ is added to place p4, the mark of net is transformed from $\{U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right), U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right), 0, 0\}$ to $\{0, 0, U_{TAG}^{tt}\left(SPR_{x}^{t}\right), U_{TAG}^{tt}\left(SPR_{y}^{t}\right)\}$. In the new mark $\{0, 0, U_{TAG}^{tt}\left(SPR_{x}^{t}\right), U_{TAG}^{tt}\left(SPR_{y}^{t}\right)\}$, $U_{TAG}^{tt}\left(SPR_{x}^{t}\right)$ and $U_{TAG}^{tt}\left(SPR_{y}^{t}\right)$ represents the total capital growth utility of enterprise X and enterprise Y, respectively, which is the long-term utility, and they are influenced by short-term profit, which is the sales profit utility. The remaining transformation process of traces is similar, so no detailed description is included.

According to the basic hypotheses, the decision making of both enterprises is conducted at the same time; therefore, the 5, 10, 11, and 12 traces are the emphasis of this paper, and the specific transform process of these four traces are as follows:

(1) Both enterprises choose the truthful management business mode. (truthful manage, truthful manage)

The transform process of trace 5 is as follows:

$$(0, 0, x, y) \xrightarrow{t1} \{U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right), U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right), 0, 0\} \xrightarrow{t2} \{0, 0, U_{TAG}^{tt}\left(SPR_{x}^{t}\right), U_{TAG}^{tt}\left(SPR_{y}^{t}\right)\}$$

(2) Enterprise X chose the truthful management business mode and Enterprise Y chose the fraudulent management business mode. (truthful manage, fraudulent manage)

Transform process of trace 10:

$$(0, 0, x, y) \xrightarrow{t1,t3} \{U_{SPR}^{t}\left(LOR_{x}^{t}, DTR_{x}^{t}\right), U_{SPR}^{c}\left(LOR_{y}^{c}, DTR_{y}^{c}\right), 0, 0\} \xrightarrow{t2} \{0, 0, U_{TAG}^{tc}\left(SPR_{x}^{t}, SPR_{y}^{c}\right), U_{TAG}^{ct}\left(SPR_{y}^{c}, SPR_{x}^{t}\right)\}$$

(3) Enterprise X chose the fraudulent management business mode and Enterprise Y chose the truthful management business mode. (fraudulent manage, truthful manage)

The transform process of trace 11 is as follows:

$$(0, 0, x, y) \xrightarrow{t1,t3} \{U_{SPR}^{c}\left(LOR_{x}^{c}, DTR_{x}^{c}\right), U_{SPR}^{t}\left(LOR_{y}^{t}, DTR_{y}^{t}\right), 0, 0\} \xrightarrow{t2} \{0, 0, U_{TAG}^{ct}\left(SPR_{x}^{c}, SPR_{y}^{t}\right), U_{TAG}^{tc}\left(SPR_{y}^{t}, SPR_{x}^{c}\right)\}$$

(4) Both enterprises choose the fraudulent management business mode. (fraudulent manage, fraudulent manage)

The transform process of trace 12 is as follows:

$$(0, 0, x, y) \xrightarrow{t3} \{U_{SPR}^{c}\left(LOR_{x}^{c}, DTR_{x}^{c}\right), U_{SPR}^{c}\left(LOR_{y}^{c}, DTR_{y}^{c}\right), 0, 0\} \xrightarrow{t2} \{0, 0, U_{TAG}^{cc}\left(SPR_{x}^{c}\right), U_{TAG}^{cc}\left(SPR_{y}^{t}\right)\}$$

TABLE 9. Mixed strategy utility matrix between enterprise X and enterprise Y.

enterprise X \ enterprise Y	truthfully manage $B_y^1(P_y t)$	fraudulent manage $B_y^2(1 - P_y t)$
truthfully manage $B_x^1(P_x t)$	$U_{TAG}^{tt}\left(SPR_x^t\right)$, $U_{TAG}^{tt}\left(SPR_y^t\right)$	$U_{TAG}^{tc}\left(SPR_x^t, SPR_y^c\right)$, $U_{TAG}^{ct}\left(SPR_y^c, SPR_x^t\right)$
fraudulent manage $B_x^2(1 - P_x t)$	$U_{TAG}^{ct}\left(SPR_x^c, SPR_y^t\right)$, $U_{TAG}^{tc}\left(SPR_y^t, SPR_x^c\right)$	$U_{TAG}^{cc}\left(SPR_x^c\right)$, $U_{TAG}^{cc}\left(SPR_y^t\right)$

4) ANALYTIC OF THE UTILITY MATRIX

According to the above *LGPN* and *RMG* of the enterprise competition module in B2C e-commerce, construct the mixed strategy utility matrix of this competition module as shown below.

According to the mixed strategy utility matrix shown in Table 9, under the given management strategy of enterprise Y by using the probability $(P_{yt}, 1 - P_{yt})$ to choose (truthful manage, fraudulent manage), the expected utility of enterprise X is as follows:

$$\begin{aligned} U_x &= P_x t^* \{P_y t * U_{TAG}^{tt}\left(SPR_x^t\right) + (1 - P_{yt}) \\ &\quad * U_{TAG}^{tc}\left(SPR_x^t, SPR_y^c\right)\} + (1 - P_{xt}) \\ &\quad * \{P_y t * U_{TAG}^{ct}\left(SPR_x^c, SPR_y^t\right) + (1 - P_{yt}) * U_{TAG}^{cc}\left(SPR_x^c\right)\} \end{aligned}$$

Under the given mixed strategy of enterprise Y, let $\frac{\partial U_x}{\partial P_{xt}} = 0$, that is,

$$\begin{aligned} &P_{yt} * U_{TAG}^{tt}\left(SPR_x^t\right) + (1 - P_{yt}) * U_{TAG}^{tc}\left(SPR_x^t, SPR_y^c\right) \\ &\quad - P_{yt} * U_{TAG}^{ct}\left(SPR_x^c, SPR_y^t\right) - (1 - P_{yt}) * U_{TAG}^{cc}\left(SPR_x^c\right)\} \\ &\quad = 0 \end{aligned}$$

After simplifying, the P_{yt}^* can be obtained as P_{yt}^*, as shown at bottom of this page.

Bring the utility function (8), (9) to the above formula P_{yt}^*, as shown at the bottom of this page.

Let $\widehat{LOR^t} = \overline{LOR^t}$, $\widehat{DTR^t} = \overline{DTR^t}$, and let $\widehat{LOR^c} = \overline{LOR^c}$, $\widehat{DTR^c} = \overline{DTR^c}$, according to formula (8)-1, (9)-1, respectively obtain $\widehat{SPR^t}$ and $\widehat{SPR^c}$, among above:

$$\overline{LOR^t} = \frac{1}{n}\sum_{i=1}^{n} LOR_i^t, \quad \overline{DTR^t} = \frac{1}{n}\sum_{i=1}^{n} DTR_i^t, \quad n = 8$$
$$\overline{LOR^c} = \frac{1}{n}\sum_{i=1}^{n} LOR_i^c, \quad \overline{DTR^c} = \frac{1}{n}\sum_{i=1}^{n} DTR_i^c, \quad n = 8$$

According to the above formula:

$$\begin{aligned} \widehat{LOR^t} &= \overline{LOR^t} = 0.2823 \\ \widehat{DTR^t} &= \overline{DTR^t} = 0.6718 \\ \widehat{LOR^c} &= \overline{LOR^c} = 0.0789 \\ \widehat{DTR^c} &= \overline{DTR^c} = 0.0669 \end{aligned}$$

Bring the above four parameters to formulas (8)-1, (9)-1:

$$\widehat{SPR^t} = 0.1371, \widehat{SPR^c} = 0.1881$$

Bring the above two parameters $\widehat{SPR^t}$ and $\widehat{SPR^c}$ to P_{yt}^*:

$$P_{yt}^* \approx 0.5895.$$

Therefore, enterprise X can obtain the maximum expected utility when enterprise Y chooses the truthful management business mode by a probability of 58.95% and above. The analysis of the maximum expected utility of enterprise Y is the same.

Under the condition of a balanced mixed strategy, both enterprises chose the truthful manage business mode by a probability of 58.95% and above, and enterprise X and enterprise Y can have a relatively stable and good expected utility.

$$P_{yt}^* = \frac{U_{TAG}^{cc}\left(SPR_x^c\right) - U_{TAG}^{tc}\left(SPR_x^t, SPR_y^c\right)}{U_{TAG}^{tt}\left(SPR_x^t\right) - U_{TAG}^{tc}\left(SPR_x^t, SPR_y^c\right) - U_{TAG}^{ct}\left(SPR_x^c, SPR_y^t\right) + U_{TAG}^{cc}\left(SPR_x^c\right)}$$

$$P_{yt}^* = \frac{-0.1265 - 0.0096SPR_x^t + 0.2098SPR_x^c + 0.1947SPR_y^c}{-0.1484 + 0.1978SPR_x^t - 0.1195SPR_x^c + 0.1407SPR_y^t + 0.1947SPR_y^c}$$

D. PROPERTY ANALYSIS OF THE ENTERPRISE COMPETITION MODULE BASED ON THE LOGICAL GAME PETRI NETS

This section conducts the property analysis of the enterprise competition module based on the Logical Game Petri nets, which includes the properties in section 4.3.

1) LOCAL OPTIMALITY

Theorem 1: Decision with self-individual-local optimality may not have other-individual-local optimality, but the decision with other-individual-local optimality necessarily has self-individual-local optimality.

Proof: (1) Suppose in k group decision $D_M^{M\prime}, D_M^{M\prime\prime}, \ldots$ from mark M, rational person r_i has q choices, $q \leq k$, the utility of decision D_{ri}^m with self-individual-local optimality of r_i is greater than the utility of the other decision that r_i can make, $U\left(D_{ri}^m\right) > U\left(D_{ri}^{-m}\right)$, $m \in (1, \ldots, q)$, $r_i \in R$, $R = \{r_i, r_j\}$. Meanwhile, rational person r_j has t choices, $t \leq k$, the utility of decision $D_{r_j}^n$ with self-individual-local optimality of r_j is greater than the utility of the other decision that r_j can make, $U\left(D_{r_j}^n\right) > U\left(D_{r_j}^{-n}\right)$, $n \in (1, \ldots, t)$, $r_j \in R$.

If $\left(D_{ri}^m\right) > U\left(D_{r_j}^n\right)$, then rational person D_{ri}^m with the self-individual-local optimality of r_i has other-individual-local optimality, $D_{r_j}^n$ with self-individual-local optimality of r_j does not have other-individual-local optimality. If $U\left(D_{r_j}^n\right) > U\left(D_{ri}^m\right)$, then rational person $D_{r_j}^n$ with the self-individual-local optimality of r_j has other-individual-local optimality, D_{ri}^m with self-individual-local optimality of r_i does not have other-individual-local optimality.

According to the above proof, the decision with self-individual-local optimality may not have other-individual-local optimality.

(2) Suppose in the k group decision $D_M^{M\prime}, D_M^{M\prime\prime}, \ldots$ from mark M, rational person r_j has t choices, $t \leq k$, the utility of decision $D_{r_j}^n$ with other-individual-local optimality of r_j is greater than the utility of the other decisions that all rational people can make, $U\left(D_{r_j}^n\right) > U\left(-D_{r_j}^n\right)$, $n \in (1, \ldots, t)$, $r_j \in R$, $R = \{\mathrm{r}_1, \mathrm{r}_2, \ldots, \mathrm{r}_s\}$.

Because $U\left(D_{r_j}^n\right) > U\left(-D_{r_j}^n\right)$, the utility of decision $D_{r_j}^n$ is greater than the other decisions $-D_{r_j}^n$ that all rational people can make, also because $r_j \in R$, rational person r_j belongs to the set of all rational people R, $D_{rj}^{-n} \subset -D_{r_j}^n$, decisions D_{rj}^{-n} of rational person r_j except D_{rj}^n belongs to decisions $-D_{r_j}^n$ of all rational people except $D_{r_j}^n$, so $U\left(D_{r_j}^n\right) > U\left(-D_{r_j}^n\right)$, and decision $D_{r_j}^n$ with other-individual-local optimality of r_j also has self-individual-local optimality. ■

According to the above proof, a decision with other-individual-local optimality necessarily has self-individual-local optimality.

In the analytic of section 5.3.4, the SPR under the truthful business mode is $U_{SPR}^t = \widehat{SPR^t} = 0.1371$, the SPR under the fraudulent business mode is $U_{SPR}^c = \widehat{SPR^c} = 0.1881$, bring them to formulas (8), (9), and the TAG under different situations can be obtained as follows:

$$\begin{cases} U_{TAG}^{tt}\left(SPR^t\right) = 0.2461 \\ U_{TAG}^{tc}\left(SPR^t, SPR^c\right) = 0.1856 \\ U_{TAG}^{ct}\left(SPR^c, SPR^t\right) = 0.3105 \\ U_{TAG}^{cc}\left(SPR^c\right) = 0.2372 \end{cases}$$

Bring the above parameters to the four traces that describe the complete information static game behavior of the two enterprises, the specific transform process of these four traces are as follows:

(1) Both enterprises choose the truthful management business mode. (truthful manage, truthful manage)

The transform process of trace 5 is as follows:

$$M_0 = (0, 0, \mathrm{x,y}) \xrightarrow{\mathrm{t1}} M_1 = \{0.1371, 0.1371, 0, 0\}$$
$$\xrightarrow{\mathrm{t2}} M_2 = \{0, 0, 0.2461, 0.2461\}$$

(2) Enterprise X chose the truthful management business mode and Enterprise Y chose the fraudulent management business mode. (truthful manage, fraudulent manage)

The transform process of trace 10 is as follows:

$$M_0 = (0, 0, \mathrm{x,y}) \xrightarrow{\mathrm{t1,t3}} M_3 = \{0.1371, 0.1881, 0, 0\}$$
$$\xrightarrow{\mathrm{t2}} M_4 = \{0, 0, 0.3105, 0.2372\}$$

(3) Enterprise X chose the fraudulent management business mode and Enterprise Y chose the truthful management business mode. (fraudulent manage, truthful manage)

The transform process of trace 11 is as follows:

$$M_0 = (0, 0, \mathrm{x,y}) \xrightarrow{\mathrm{t1,t3}} M_5 = \{0.1881, 0.1371, 0, 0\}$$
$$\xrightarrow{\mathrm{t2}} M_6 = \{0, 0, 0.2372, 0.3105\}$$

(4) Both enterprises choose the fraudulent management business mode. (fraudulent manage, fraudulent manage)

The transform process of trace 12 is as follows:

$$M_0 = (0, 0, \mathrm{x,y}) \xrightarrow{\mathrm{t3}} M_7 = \{0.1881, 0.1881, 0, 0\}$$
$$\xrightarrow{\mathrm{t2}} M_8 = \{0, 0, 0.1856, 0.1856\}$$

Under mark M_0, the decision set of rational person x and rational person y are $D_x = \{\langle p_3, t_1\rangle, \langle p_3, t_3\rangle\}$ and $D_y = \{\langle p_4, t_1\rangle, \langle p_4, t_3\rangle\}$.

(1) When rational person x chooses the decision $D_x\langle p_3, t_1\rangle$ that represents the truthful management business mode, rational person y chooses the decision $D_y\langle p_4, t_1\rangle$ that represents the truthful management business mode, transition t1 occurs, the state of the net transformed from M_0 to M_1, the utility of rational person x and rational person y are both 0.1371.

(2) When rational person x chooses the decision $D_x\langle p_3, t_1\rangle$ that represents the truthful management business mode, rational person y chooses the decision $D_y\langle p_4, t_3\rangle$ that represents the fraudulent management business mode, transitions t1 and t3 occur at the same time, the state of net transformed from

M_0 to M_3, the utility of rational person x is 0.1371, and the utility of rational person y is 0.1881.

(3) When rational person x chooses the decision $D_x \langle p_3, t_3 \rangle$ that represents the fraudulent management business mode, rational person y chooses the decision $D_y \langle p_4, t_1 \rangle$ that represents the truthful management business mode, transitions t1 and t3 occur at the same time, the state of net transformed from M_0 to M_5, the utility of rational person x is 0.1881, and the utility of rational person y is 0.1371.

(4)When rational person x chooses the decision $D_x \langle p_3, t_3 \rangle$ that represents the fraudulent management business mode, rational person y chooses the decision $D_y \langle p_4, t_3 \rangle$ that represents fraudulent management business mode, transition t3 occurs at the same time, the state of net transformed from M_0 to M_7, and the utility of rational person x and rational person y both are 0.1881.

According to the above analytic and definition 17, the decision $D_x \langle p_3, t_3 \rangle$ that the rational person x made under mark M_0 has self-individual-local optimality, and according to inference 1, this decision is the optimal individual single step decision of rational person x under mark M_0. According to definition 18, this decision has other-individual-local optimality under the four global decisions, $D_{M_0}^{M_3}, D_{M_0}^{M_1}, D_{M_0}^{M_5}, D_{M_0}^{M_7}$. In addition, according to the above analytic, theorem 1 is verified by decision $D_x \langle p_3, t_3 \rangle$.

2) GLOBAL OPTIMALITY

Theorem 2: Decision with self-individual-global optimality may not have other-individual-global optimality, but a decision with other-individual-global optimality necessarily has self-individual-global optimality.

The process of the proof is similar to theorem 1.

Theorem 3: Decision in the decision set with other-individual-global optimality may not have other-individual-local optimality.

Inference 4: The coexistence of the other-individual-global optimality of the decision set and the other-individual-local optimality of decision cannot be guaranteed.

Under marks M_1, M_3, M_5 and M_7, the only enabled transition is t2, and the decision sets of rational person x and rational person y are $D_x = \{\langle p_1, t_2 \rangle\}$ and $D_y = \{\langle p_2, t_2 \rangle\}$.

(1) Under mark M_1, the decision set of rational person x is $D_x = \{\langle p_1, t_2 \rangle\}$, the decision set of rational person y is $D_y = \{\langle p_2, t_2 \rangle\}$, transition t2 occurs, the state of net transformed from M_1 to M_2, and the utility of rational person x and rational person y both are 0.2461

(2) Under mark M_3, the decision set of rational person x is $D_x = \{\langle p_1, t_2 \rangle\}$, the decision set of rational person y is $D_y = \{\langle p_2, t_2 \rangle\}$, transition t2 occurs, the state of net transformed from M_3 to M_4, the utility of rational person x is 0.3105, and the utility of rational person y is 0.2372.

(3) Under mark M_5, the decision set of rational person x is $D_x = \{\langle p_1, t_2 \rangle\}$, the decision set of rational person y is $D_y = \{\langle p_2, t_2 \rangle\}$, transition t2 occurs, the state of net transformed from M_5 to M_6, the utility of rational person x is 0.2372, and the utility of rational person y is 0.3105.

(4) Under mark M_7, the decision set of rational person x is $D_x = \{\langle p_1, t_2 \rangle\}$, the decision set of rational person y is $D_y = \{\langle p_2, t_2 \rangle\}$, transition t2 occurs, the state of net transformed from M_7 to M_8, and the utility of rational person x and rational person y are both 0.1856.

According to above analytic, the group multi-step decision set is $D^{Mu} = \{D^{Mu_1}, D^{Mu_2}, D^{Mu_3}, D^{Mu_4}\}$, the individual multi-step decision set of rational person x is $D_x^{Mu} = \left\{D_x^{Mu_1}, D_x^{Mu_2}, D_x^{Mu_3}, D_x^{Mu_4}\right\}$, the individual multi-step decision set of rational person y is $\left\{D_y^{Mu_1}, D_y^{Mu_2}, D_y^{Mu_3}, D_y^{Mu_4}\right\}$, and the specific content are as shown below:

$$D^{Mu_1}\begin{cases} D_x^{Mu_1} = \{\langle p_3, t_1 \rangle, \langle p_1, t_2 \rangle\}, \\ \qquad U\left(D_x^{Mu_1}\right) = (0.1371, 0.2461) \\ D_y^{Mu_1} = \{\langle p_3, t_1 \rangle, \langle p_2, t_2 \rangle\}, \\ \qquad U\left(D_y^{Mu_1}\right) = (0.1371, 0.2461) \end{cases}$$

$$D^{Mu_2}\begin{cases} D_x^{Mu_2} = \{\langle p_3, t_1 \rangle, \langle p_1, t_2 \rangle\}, \\ \qquad U\left(D_x^{Mu_1}\right) = (0.1371, 0.3105) \\ D_y^{Mu_2} = \{\langle p_3, t_3 \rangle, \langle p_2, t_2 \rangle\}, \\ \qquad U\left(D_y^{Mu_1}\right) = (0.1881, 0.2372) \end{cases}$$

$$D^{Mu_3}\begin{cases} D_x^{Mu_3} = \{\langle p_3, t_3 \rangle, \langle p_1, t_2 \rangle\}, \\ \qquad U\left(D_x^{Mu_1}\right) = (0.1881, 0.2372) \\ D_y^{Mu_3} = \{\langle p_3, t_1 \rangle, \langle p_2, t_2 \rangle\}, \\ \qquad U\left(D_y^{Mu_1}\right) = (0.1371, 0.3105) \end{cases}$$

$$D^{Mu_4}\begin{cases} D_x^{Mu_4} = \{\langle p_3, t_3 \rangle, \langle p_1, t_2 \rangle\}, \\ \qquad U\left(D_x^{Mu_1}\right) = (0.1881, 0.1856) \\ D_y^{Mu_4} = \{\langle p_3, t_3 \rangle, \langle p_2, t_2 \rangle\}, \\ \qquad U\left(D_y^{Mu_1}\right) = (0.1881, 0.1856) \end{cases}$$

Suppose that the utility is divided into short-term utility and long-term utility, take the maximum sum of short-term utility and long-term utility seen as the optimal utility, according to the above analytic and definition19, definition 20 and inference 2, it can be concluded that $D_x^{Mu_2}$, $D_y^{Mu_3}$ are each the optimal individual multi-step decision sets, they both have the self-individual-global optimality and the other-individual-global optimality. These two decision sets verified theorem 2.

According to definition 20 and inference 3, that $D_x^{Mu_2}$, $D_y^{Mu_3}$ both are the optimal Global Nash decisions, and they both have group-global optimality.

Group decisions $D_x^{Mu_2}$ and $D_y^{Mu_3}$ both represent that one of the two enterprises chose the truthful management business mode, and the other one chose the fraudulent management business mode. Their properties verified the analytic in section 5.3, which is that the enterprises chose the truthful manage business mode by a probability of 58.95% and above, then the enterprises can have a relatively stable and good expected utility.

$D_x^{Mu_2}$ has the other-individual-global optimality, $D_x^{Mu_2} = \{\langle p_3, t_1\rangle, \langle p_1, t_2\rangle\}$, and the utility of $D_x \langle p_3, t_1\rangle$ is 0.1371, and it does not have the other-individual-local optimality, which verified theorem 3.

According to theorem 3, the local optimality and the global optimality are impossible to equip at the same time, wnd similarly, the enterprise needs to make a balance between the short-term utility and long-term utility.

E. PERFORMANCE ANALYSIS OF ENTERPRISE COMPETITION MODULE BASED ON LOGICAL GAME PETRI NETS

This section conducts the performance analysis of the enterprise competition module based on Logical Game Petri nets.

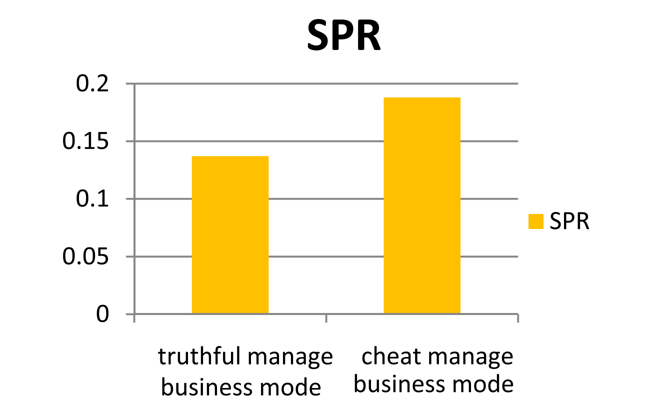


FIGURE 6. ***SPR*(short-term utility) of the *LGPN* model of the enterprise competition module in B2C e-commerce.**

The short-term utility that is represented by the *SPR*, and the specific content changes are shown in Figure 6.

The long-term utility that is represented by the *TAG*, and the specific content changes are shown in Figure 7.

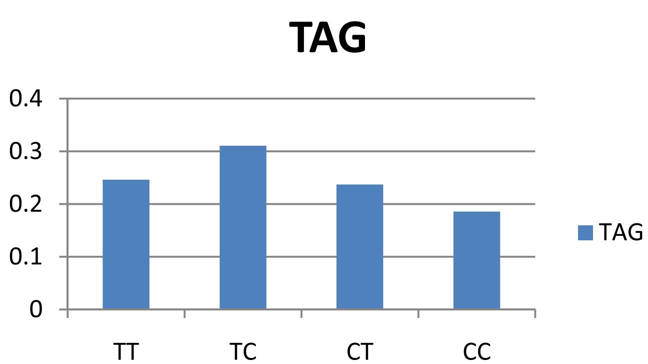


FIGURE 7. ***TAG*(long-term utility) of the *LGPN* model of the enterprise competition module in B2C e-commerce.**

In Figure 7, 'TT' represents the long-term utility(*TAG*) that is influenced by short-term utility(*SPR*) when both enterprises are in the truthful management business mode. 'TC' represents when there is one enterprise is in the truthful management business mode and the other enterprise is in the fraudulent manage business mode, the long-term utility of a truthful enterprise that is influenced by its own short-term utility and the short-term utility of the other enterprise. 'CT' represents when there is one enterprise in the truthful management business mode and the other enterprise is in the fraudulent management business mode, the long-term utility of a fraudulent enterprise that is influenced by its own short-term utility and the short-term utility of the other enterprise. 'CC' represents the long-term utility that is influenced by short-term utility when both enterprises are in the fraudulent management business mode.

For comparison, both specific content changes of short-term utility and long-term utility are shown in Figure 8.

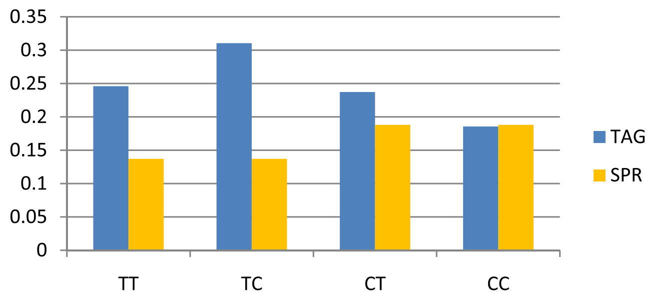


FIGURE 8. ***SPR*and *TAG* of *LGPN* model of enterprise competition module in B2C e-commerce.**

According to the four traces that describe the complete information static game behavior of the two enterprises, the *SPR* of the fraudulent management business mode is 0.1881, which is higher than the 0.1371 of the truthful management business mode; therefore, for obtaining higher short-term utility, which is the *SPR*, the enterprise has a reason to choose the fraudulent management business mode.

However, when both enterprises choose the fraudulent management business mode, the *TAG* values of the two enterprises are both 0.1856, which is the lowest of the four situations; therefore, it can be concluded that in this unhealthily developing market, both enterprises choose the fraudulent management business mode. If things continue this way, the vicious competition continues to cycle and has mutual influence on each other, and after a period of time, consumers will increase their knowledge and true value of the product, thereby failing to address any enterprises in this e-commerce platform, which will reduce the number of consumers in the whole market. Finally, the market will collapse, and the utility of the enterprises will plummet.

When both enterprises choose the truthful management business mode, the *TAG* values of the two enterprises are both 0.2461, which is higher than the situation of both enterprises choosing the fraudulent management business mode. In a truthfully managed, healthily developing market, the good environment for the entire market will encourage more consumers to spend on the e-commerce platform, and at the same time, the long-term utility of enterprises will be steadily improved.

For developing the e-commerce platform, the coexistence of an enterprises that chose the truthful management business mode and an enterprise that chose the fraudulent management mode is more common, that is, the market is partly successful. In this situation, the *TAG* of the enterprise that chose the truthful management business mode is 0.3105, the *TAG* of the enterprise that chose the fraudulent management is 0.2372. Because of the positive influence and the effect to the whole market of the truthful management enterprise, even for the enterprise that chose the fraudulent management, the long-term utility of it is still higher than the situation that both sides choose the fraudulent management business mode in the vicious market. After the consumers discover the fraudulent behavior of the cheat management enterprise, the enterprise that chose the truthful management business mode can obtain higher utility than the situation that both sides choose the truthful management business mode in the benign market. In this relatively neutral market of the long-term competitive relationship, the enterprise that chose the truthful management business mode dominates, and it can obtain much more long-term utility.

Regarding the long-term utility that is represented by *TAG*, the specific content changes are shown in Figure 7 and Figure 8. Situation TT represents the *TAG* of the enterprise that chose the truthful management business mode when both the enterprises choose the truthful management business mode. Situation TC represents the *TAG* of the enterprise that chose the truthful manage business mode when one of the two enterprises chose the truthful management business mode and the other one chose the fraudulent manage business mode. Situation CT represents the *TAG* of the enterprise that chose the fraudulent manage business mode when one of the two enterprises chose the truthful management business mode and the other one chose the cheat management business mode. Situation CC represents the *TAG* of the enterprise that chose the fraudulent management business mode when both enterprises choose the fraudulent management business mode.

According to Figure 8, it can be observed that no matter if the other enterprise chose the fraudulent or truthful manage business mode, the long-term utility of the enterprise that chose truthful management in situation TT and TC is always higher than that choosing fraudulent management in situations CT and CC. Under the four different situations, the highest long-term utility is possessed with the enterprise that chose the truthful management business mode in situation TC, and the long-term utility of the enterprise that chose the fraudulent management business mode is higher in situation CT than in situation CC, TC and CT both represent relatively neutral markets, which means the coexistence of fraudulent management and truthful management, and this relatively neutral market is clearly good for all types of enterprises.

According to Figure 9, it can be seen that the highest total utility is possessed with the enterprise that chose the truthful management business mode in situation TC, and no matter if the enterprise chose the truthful management business mode or the fraudulent manage business mode, the total

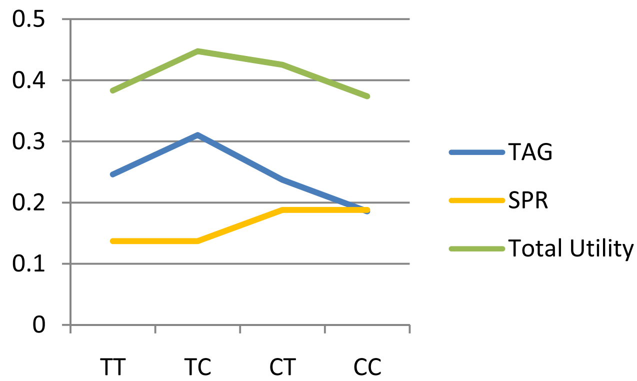


FIGURE 9. **Different utilities of the *LGPN* model of the enterprise competition module under different situations.**

utility of the enterprise is higher in relatively neutral markets, such as TC and CT, than in the purely benign market TT and the purely vicious market CC.

In the literature, [3], the author analyzed the game process of enterprises, and concluded the influence of the price on credit, that is with the improvement of credit, the advantage of the enterprise that accommodates the higher credit is decreasingly obvious, while low-credit enterprise will use their lower price advantage to make up for their lack of credibility. so the author has proposed some countermeasures for the enterprises that chose the truthful business mode to maintain the advantage.

In the literature, [1], the author analyzed the game behavior of enterprises and concluded that the reason for the competition between enterprises is to obtain the maximum profit for themselves, and when the B2C e-commerce market lacks a truthful management enterprise, the capacity of the market, which is the number of consumer, would decrease, and excessive dishonest enterprise hinder the further development of the platform. Therefore, choosing the strategy to guarantee their own profit and give consideration to the long-term development of the market is an important question that all of the enterprises should consider.

When the proportion of enterprises with good credit in the electronic platform is higher than x_3^*, poor credit enterprises can get higher profits. And when the proportion of enterprises with good credit in the electronic platform is lower than x_3^*, good credit enterprise can get higher profits. In our article, we use the credit index to distinguish the good credit or poor credit of the enterprise in the literature [1], good credit enterprise are those whose credit index is less than zero, that is $CI_i < 0$, and poor credit enterprise are those whose credit index is greater than zero, that is $CI_i > 0$.

x_3^* is the equilibrium point of the stable state of the market after the analysis of the literature [1]. Similarly, in our article, the critical point for whether the market can be healthy and long-term development is 0.5895, compared to literature [1], the data is relatively accurate and specific.

In this paper, the healthy competition between enterprises is good for the long-term development of the e-commerce market, and for most e-commerce markets, the common coexistence of both truthful and fraudulent management business modes is not as harmful to the enterprises and the market as people think. In the contrast, it can be said that this situation is in favor of the utility of the enterprises and the development of the market, and the above analytic is verified in section 5.3, that is, that when enterprises choose the truthful management business mode by a probability of 58.95% and above, enterprises can have a relatively stable and good expected utility, and the market can have relatively stable long-term development.

VI. CONCLUSIONS AND FURTHER RESEARCH

This chapter includes the study's conclusions and outlines further research.

A. CONCLUSIONS

In this paper, the logical Petri net theory and game theory are combined, and the theory of Logical Game Petri net is proposed. The related formal definition, graphical representation, dynamic property and analysis method are given. The study of credit risk in B2C e-commerce has been conducted, the credit risk problem has been transformed into the game behavior among four main bodies in B2C e-commerce, the enterprises competition module of B2C e-commerce have been analyzed, the LGPN model and RMG of this module are established, the utility function is solved by the least square method, the game matrix analysis method is used to analyze the four traces that can describe the game behavior, and the relation between enterprises was discussed. Next, the properties of Local Optimality and Global Optimality of individuals and groups in the model are analyzed and discussed, and the relationships between different business modes and the effectiveness of the enterprises is verified.

B. FURTHER RESEARCH

The LGPN can be combined with the theory of other high-level Petri nets, such as the time Petri net, colored Petri net and stochastic Petri net, to improve and perfect the model in different directions and performance.

There are more types and amounts of data sets of B2C e-commerce that need to be searched and obtained, which can be used to study B2C e-commerce based on the LGPN.

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