School-Choice Behavior and Game Based on Brain Cognition

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ABSTRACT

Brain stimulation experiment has revealed the association law between loss aversion tendency and brain-specific nervous system, providing a solid scientific basis for deep understanding of human behavioral preferences, as well as providing another research scheme for controversial school choice. There are many uncertain risks in the process of school choice, so asymmetry appears when the decision maker's brain processes gain and loss, which causes obvious school-choice preference reversal. Based on the inherent law of brain activity studied by fMRI and through analyzing the phenomenon of human choice behavior under the admission system in China, this study proves that applicants appear limited rationality or preference reversal when the emotional brain area is hyperactive. In addition, in the priority to the first applications (PTTFA) mechanism, applicants reveal that true preference is not a dominant strategy, which will lead to market imbalances and low inefficiency.

Key Words: Loss aversion, Irrational Choice, School-choice Behavior, Neuroeconomics.

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Introduction

In 2003, Sanfey *et al*. published "The Neural Basis of Economic Decision-Making in the Ultimatum Game" in Science. This behavioral science experiment has found that, in the face of unfairness, participant's neural mechanism is related to the anterior insular cortex and the dorsolateral prefrontal cortex. This reveals that human decision-making behavior is greatly related to emotion, providing an objective basis for "Ultimatum Game" of behavioral economics. In recent year, with the development of brain stimulation technology, it becomes possible to observe the change of behavioral preference in a specific brain area after receiving stimulation, and even to infer a certain causal association (Ruff *et al*., 2013). People usually react to the uncertainty with loss aversion emotion, which verifies the description of loss aversion in Tversky and Kahneman's (1992) prospect theory. Hessner *et al*., (2012) further found that loss aversion in people's risk decision-making is indeed highly correlated with the activity of the amygdale. Adaptive instinct affects people's risk decision-making behavior in a specific emotional form through the memory function of amygdala and limbic system (De *et al*., 2010) in addition to lowering the activity of certain nerve cells to cause loss aversion. When applicants (graduates or their parents) fill out their application forms, the intensity of their brain's neural responses to different admission risk assessments is asymmetric. When they feel nervous, panicky, and unfair, the order of preference will be adjusted. There is irrational differentiation in preferences, so it is necessary to include the emotional information of applicants in order to analyze school-choice behavioral game. Otherwise, the preference function has no significance. Before the widespread adoption of

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the DA mechanism in American public secondary schools, there were many defects in the traditional admission mechanism in Bostonian schools (Roth *et al.*, 2005). Applicants are required to fill out intention application forms during school choice, which is in fact equivalent to showing their preferences. The admission rule of "intention first, score follows" in China is similar to the Bostonian mechanism (Nie, 2007). An in-depth discussion of irrational behavior in school choice seems to abandon the expected utility theory, but actually provides richer empirical facts to enhance the explanatory power of behavioral science (He, 2005; Camerer *et al.*, 2005).

School-choice Behavior and Decision-making

There is a two-dimensional characteristic pattern in the operation mechanism of human nervous system, as shown in Table 1. According to the conclusions of neuroscience experts, there are two responses in the risk decision-making of human brain: on the one hand, the brain activity in quadrant I attempts to make objective risk assessment for different risk-taking behaviors, which is represented by rational actors; on the other hand, the brain activity in quadrant IV responds to risk by a certain emotion. These irrational emotions have a significant impact on the behavioral game result (Jia and Huang., 2015). The brain activity in quadrant IV is very intense in behavior decision-making. In the face of numerous school (or major) choice, applicants may imagine the possible results of admission. In particular, when sense of achievement, panic, security and other neurological delusion intertwine together, their order of preferences will be adjusted.

Table 1. Characteristic pattern of behavior process of nervous system

	Cognition process	Emotion process
Controlled process	Quadrant	Quadrant II
Unconscious process	Quadrant III	Quadrant IV

Behavioral preference reversal during school choice

For a long time, the admission in China has followed the rule of "intention first, score follow", and the higher-level schools will get the corresponding scores through a competitive exam. After that, graduates will rank their preferred schools (majors) and fill in the application form, which is called "filing the intention for school". The "PTTFA" is similar to the "Boston mechanism" in admission in American schools that schools give priority to first applicants. The admission principle of PTTFA is: schools will first consider the admission of the first applicants, and then consider other applicants, which in fact makes the first preference very important because if the applicant is not admitted to the first preference school and the second preference school has been filled, then he or she will miss the two schools; although applicants have a strong preference for a popular school, but they will not take too much risk in choosing the school for a low probability of admission. The response of the dorsolateral prefrontal cortex increases when there is a risk of rejection in applying for a preference school, and even it is more likely for them to be rejected by a relatively poor school. In face of the uncertainty risk, applicants will appear obvious "loss aversion" in filling out the application forms. Then they will naturally make some strategy behavior choice and the safest way is to choose those less popular schools in order to be accepted by the first preference school more likely. For applicants with loss aversion, their brain's asymmetry response to gains or losses is: when applicants have two schools α and β to choose and utility levels produced by the two schools are $u(\alpha)=30$ and $u(\beta)=40$, and if there are two choices: choice A is that they are accepted by α at a rate of 100%, and choice B is that they are not accepted by β at a rate of 80%, the overwhelming majority of applicants choose A; but if they have the following two choices, choice A is that they are rejected by α at a rate of 100%, and choice B is that they are rejected by β at a rate of 80%, most choose B according to China's admission data for many years. In general, if an applicant's preference is risk-averse, he or she will choose A in either choice; if an applicant's preference is risk-chasing, he or she will choose B in either choice. However, in the process of school choice, the decision maker of the same behavior shows the risk-averse preference in the first choice but the risk-chasing preference in the second choice. This preference reversal undoubtedly violates the preference consistency axiom of economics (Tversky and Kahneman, 1991), namely, violates the hypothesis of rational actors.

Applicants with a variety of emotions or loss aversion will naturally produce preference reversal. The problem is that to increase their chances of being admitted by the first preference school, some applicants will choose to distort their own preference ranking, thus creating a complex school-choice behavioral game. There are big differences in the bilateral behavioral game between the schools and the students due to the different admission mechanisms, and the final efficiency and fairness will change greatly (Wu and Zhong, 2012). The specific operation principle of the DA mechanism is:

Firstly, a student's application form of choosing schools is submitted in a non-public manner. According to the information of the first applicants (mainly the exam scores), the school will set up a priority list for admission. However, the school does not immediately admit the student but only retains him or her as an object to be considered.

Secondly, if there are remaining places, the school will put the first group of students to be considered together with the students who take the school as a second preference one, then the school will make a new ranking of the students according to the priority rule, and the students who fail to meet the criteria are rejected.

This rule goes on until no application for admission is rejected, and the process of choosing a school is over. According to this DA delay admission mechanism, applicants are likely to be accepted by their first preference schools. In addition, that school does not care its preference ranking for the applicants, but the risk of applicants' filling in the application forms is very low. That the DA mechanism enables all applicants to show their real preference is a dominant strategy, but the PTTFA mechanism often suffers from the complex game results of loss aversion and preference reversal.

School-choice Behavioral Game

Nash equilibrium of school-choice game

The process of choosing a school where students submit allocation forms and schools choose students who are outstanding constitutes the school-applicant bilateral game. The new definition of "Nash equilibrium" of the school-choice behavior is as follows: the set of the applicants is $M=(m_1, ..., m_n)$ and the set of schools is $W=(w_1, ..., w_k)$, and the bilateral behavior decision maker has ranking of preference which satisfies completeness and stringency. If $p(w_i)=m_4, m_2, ..., m_i$, it indicates that the school w_i's first choice is the applicant m_4, the second choice is the applicant m_2, which is set $m_4 > w_i m_2$, and the following is the other choices.

The school-choice behavioral game μ is expressed by mathematical mapping as $\mu: M \cup W \rightarrow M \cup W$; if $w=\mu(m)$ and only if $\mu(m)=w$, all w satisfies $\mu(w) \in M$ or $\mu(w)=w$; all m satisfies $\mu(m) \in W$ or $\mu(m)=m$. That is to say, the game result of behavioral choice either matches with the other decision maker (Shapley, 1962) or with the behavior decision maker himself (namely, the choice to give up the admission). If the applicant k is more likely to abandon the application than $\mu(k)$: $k > k\mu(k)$, the behavioral game mechanism μ is said to be blocked by the applicant k. If $w > m\mu(m)$ and $w > w\mu(m)$, it indicates that (m,w) is more willing to give up the current matching object and choose the other party, that is, the behavioral game mechanism μ is blocked by the bilateral decision makers (m, w). The behavioral game mechanism satisfies the "Nash equilibrium" if there is no blocked situation. In short, that Nash equilibrium of the behavioral game mechanism mean that the following two states do not exist: (1) school-applicants are more willing to give up the existing matching object and choose the other party; (2) an applicant refuses any school to give up the admission. For all the behavioral result sets, the behavioral game result initiated by the applicant is weak Pareto Optimality, that is, no matter how the admission result changes, it is impossible to appear the situation that "all admission candidates become better than the original strict situation". However, the PTTFA mechanism is faced with the phenomenon of loss aversion and preference reversal, so the behavioral game mechanism that decision maker's showing their true preference for school choice is the optimal strategy does not exist.

Behavioral game in preference reversal

The school-choice behavioral game with strict preference will produce many kinds of equilibrium results (Abdulkadiroglu *et al.*, 2009, Wei, 2010). In DA school-choice behavior initiated by applicants, applicants reveal that their real preference is a weak dominant strategy. The result of the optimal Nash equilibrium is a weak Pareto Optimality state, but not all applicants like μ_M. When faced with many schools (or majors) to choose, applicants may imagine the possible admission results after submitting the admission application forms. When the emotional information such as nervousness, excitement, panic and security is included, the nervous system in quadrant IV is active and the preference of applicant is readjusted. For example, loss aversion causes the applicant's brain activity to appear significant asymmetry, and the unconscious reversal of preference may make his or her situation better even if other applicants' preferences remain the same, that is, irrational behavior optimizes the Nash equilibrium result, as shown below:

If $M=\{m_1, m_2, m_3\}$, $W=\{w_1, w_2, w_3\}$, the order of preference is as follows:

$p(m_1)=w_2, w_1, w_3$ $p(w_1)=m_1, m_2, m_3$
$p(m_2)=w_1, w_2, w_3$ $p(w_1)=m_3, m_1, m_2$
$p(m_3)=w_1, w_2, w_3$ $p(w_1)=m_1, m_2, m_3$

One of the results of DA behavioral game mechanism is $\mu_M=[(m_1,w_1)(m_2,w_3)(m_3,w_2)]$ and there are also other forms of Nash equilibrium $\mu=[(m_1,w_2)(m_2,w_3)(m_3,w_1)]$ at the same time. m_1, m_3 cannot obtain his or her first choice in the first round due to the impact of competition of m_2. If m_2 does not show his or her true preference and assume that $p'(m_2)=w_3$, and none of the preferences of other applicants change, then μ is the best behavioral game result. Compared to their true preferences, their welfare situation does not get worse, but helps m_1, m_3 improve their welfare status.

In the school-choice behavioral game, applicants choose schools and they are also selected by schools. So the result of Nash equilibrium often appears so-called market blocked, which is most prominent in the PTTFA mechanism because the PTTFA mechanism gives the applicants a very large weight on the first choice. In the process of school choice, the application form filling will appear preference reversal, and the strategy of filling out the application form must not be strategy-proof. There will some situations that Nash equilibrium cannot predict in the final admission, such as loss of Pareto efficiency and lack of fairness (Qin, 2009). The first choice to take risk to fill in a highly competitive school may directly causes the second choice to fail, so applicants often use such a strategy: they take the school with the highest probability of admission as the first preference one, or allow a grade gradient between schools that they apply for. For example, they will choose their favorite school as the first preference one, but the second preference school must be different from the first school in grade, that is, there is a distortion of the true preference to withstand the risk phenomenon. In this way, the optimum efficiency of Nash equilibrium cannot be fully achieved in the school-choice behavioral game market, and the unfair phenomena such as "students with high scores are not admitted" also come into being.

Experimental Simulation

Understanding and analysis of loss aversion

According to some important conclusions of neuroeconomics in the early stage and starting from the perspective of non-rational actors, this school-choice decision-making model holds that when rational brain area is completely dominant, applicants will satisfy the characteristics of so-called rational actors in neoclassical economics. When emotional brain area is overactive, applicants present the characteristics of limit rational actors, and the loss aversion and preference reversal undoubtedly violate the hypothesis of rational actors, as well as do not satisfy the consistency axiom of classical economics preference (Tversky and Kahneman, 1991), that is, A>B and B>A, and A≠B. We can reduce it as: when x>0, U(x)<-U (-x). The aim of the experiment is to test two problems: first, through the reaction difference of different brain areas to the situation of choosing school, the study is to analyze the change of rational or irrational behavior preferences during choosing schools. Secondly, the core problems of school-choice game results are analyzed. In particular, the study discusses the Nash equilibrium state and efficiency of school-choice behavior based on "preference reversal" or "loss aversion". The simulation process uses 2×2 design, compares and analyzes the behavioral processes of 32 different types of applicants in the rational and irrational environments (Table 2).

Table 2. Experimental comparative design

Behavioral pattern	Environment	# Number of grouping objects	#Total number of objects
PTTFA(d)	rational	32	64
DA(d)	rational	32	64
PTTFA(s)	irrational	32	64
DA(s)	irrational	32	64

The decision-making behavior of applicants has two major characteristics: first, according to the admission information from the surrounding environment, they adjust their own strategic behavior to maximize their own interests; the brain activity in quadrant I attempts to make objective and rational estimates of different risk-taking behaviors. Second, applicants appear behavior preference reversal or loss aversion. For example, in the face of numerous school (or major) choice, nervousness, excitement, panic, security will emerge and the brain system in quadrant IV plays a leading role. Applicants will adjust their preference ranking, increase or reduce the gain of other decision makers. There are rational behaviors and irrational choices in the decision- making process of school-choice players. For example, they do not submit application forms according to strict preferences. Table 3 compares the utility of two kinds of school choices in rational and irrational situations. Applicants with high exam scores will choose high-quality schools and the utility will be greatly improved. For example, the utility value of applicant a with score of w for choosing the school r is $U_w^a(r) = 10$, while utility value of choosing other schools is $U_w^a(t) = 5$ or $U_w^a(b) = 4$. In addition, $U_s^a(j)$ indicates the utility level of applicant a in applying for the school j after preference reversal, which is mainly external contingency emotion or neurological delusion $-5 \le U_s^a(j) \le 5$. In accordance with the above principle, the total utility level $U_i^a(j)$ obtained by all applicants from the admitted school is expressed in similar monetary yield value, and utility level in the irrational environment is simulated by matlab software, as listed in Table 3. Boldface numerical values with underlines represent the total utility gained by applicants admitted in a rational environment by the schools, and other numbers represent the total utility of choosing other schools with loss aversion. In addition, this experimental simulation assume that applicants conduct a one-time incomplete information game under the PTTFA and DA mechanisms, and the admission number of schools is limited, and each applicant knows his or her own utility level obtained in different schools, but does not know the utility structure of other applicants.

Table 3. Utility value setting of decision-making maker

School applicants	Utility of school choice in a rational environment				Utility of school choice in an irrational environment			
	r	*t*	*b*	*f*	*r*	*B*	*C*	*D*
1	***29***	26	32	17	***28***	25	21	24
2	***27***	16	11	6	***28***	5	12	5
3	***17***	18	18	10	***5***	2	19	13
4	***17***	9	18	15	***17***	22	4	1
5	***12***	28	14	24	***19***	17	7	12
6	***22***	13	29	14	***11***	14	17	7
7	***12***	13	12	14	***14***	1	9	9
8	***29***	22	6	21	***23***	12	11	12
9	***15***	12	24	13	***21***	25	8	11
10	***21***	24	13	1	***13***	4	2	12
11	22	***26***	23	13	11	***14***	24	12
12	14	***21***	11	17	17	***19***	11	28
13	23	***12***	14	18	13	***21***	1	6
14	12	***19***	21	19	9	***10***	25	22
15	17	***25***	15	11	22	***24***	22	3
16	19	***10***	11	18	21	***22***	15	9
17	21	***18***	19	20	15	***9***	23	12
18	16	***2***	11	28	18	***15***	14	8
19	11	23	***6***	19	6	14	***23***	26
20	25	20	***11***	19	18	26	***8***	6
21	21	24	***8***	21	12	17	***35***	8
22	12	23	***17***	27	18	16	***14***	9
23	14	13	***7***	14	15	9	***13***	23
24	19	12	***8***	9	19	12	***18***	12
25	11	22	***19***	18	13	12	***8***	13
26	10	11	***26***	8	12	4	***6***	18
27	14	13	18	***9***	8	12	11	***24***
28	12	23	1	***17***	14	19	22	***33***
29	20	12	14	***7***	14	21	10	***5***
30	2	38	21	***17***	15	13	26	***23***
31	22	2	32	***16***	14	22	16	***11***
32	19	20	10	***22***	15	11	16	***18***

Equilibrium of behavioral game

School *j* with high reputation is willing to admit applicant *a*, and compared with the current school, *a* is more willing to go to the school *j*, then *(j,a)* is called blocking pair. If there is no blocking pair, school-choice behavioral game is in Nash equilibrium. Two kinds of simulation experiments are based on one-time game and incomplete information hypothesis. This part of the scheme combines the design ideas of Chen and Sonmez (2006). The experimental simulation starts with random selection of a applicant, simulates the rational and irrational behavior of brain activity in quadrant I and IV to different risk-taking events, and objectively estimates the school-choice decision-making behaviors. The simulation experiment is repeated for 1000 times, and the results of behavioral game and its blocking pair are recorded under rational and irrational environments. There are 64,000 task links in the process of decision-making behavior. If *Y(m,n,l)* indicates the l_{th} result of school choice of decision maker *n* in the environment *m*, then the average utility estimate is as follow:

$$\hat{\mu} = \frac{1}{64000}\sum_{m=1}^{2}\sum_{n=1}^{32}\sum_{l=1}^{1000} Y(m,n,l) \quad (1)$$

The estimate variance of utility result is:

$$\sigma^2 = \frac{1}{64000}\sum_{m=1}^{2}\sum_{n=1}^{32}\sum_{l=1}^{1000} [Y(m,n,l) - \hat{\mu}]^2 \quad (2)$$

In order to calculate the variance, 1000 mixed combinations are divided into two parts for 500 times, Namely,

$$\phi = \frac{1}{32000}\sum_{m=1}^{2}\sum_{n=1}^{32}\sum_{l=1}^{500} [Y(m,n,l) - \hat{\mu}] \times [Y(i,j,l+500) - \hat{\mu}] \quad (3)$$

The approximate result of variance is

$$\mathrm{var}(\hat{\mu}) \approx \frac{\sigma^2}{32 \times 1000 \times 2} + \frac{32\phi}{2} \quad (4)$$

The applicant's school-choice process is analyzed by an experiment. The statistical results of PTTFA and DA are shown in Table 4. The results show that DA (d) has the highest Pareto efficiency ($\hat{\mu} = 13.97$) of the behavioral game results in the rational environment, and the most stable equilibrium result appears, followed by PTTFA (d). This indicates that the preference reversal of applicants can influence the Nash equilibrium of the school-choice behavioral game whether they make decision-making based on DA mechanism or not. This also verifies that the neural reaction in quadrant IV affects human decision-making. PTTFA (s) is the most volatile ($\sigma^2=0.509$), representing the asymmetric response of the human brain in the face of gains or losses, which can well confirm the neural mechanism of loss aversion.

Table 4. Utility estimate result of school-choice behavior

Behavioral pattern	Mean value $\hat{\mu}$	Variance σ^2	Covariance ϕ	Variance Approx. Var ($\hat{\mu}$)	Standard deviation ε
PTTFA (d)	10.63	0.133	0.002	0.028	0.132
DA (d)	13.97	0.119	0.001	0.012	0.105
PTTFA (s)	13.88	0.509	0.003	0.003	0.062
DA (s)	13.91	0.234	0.034	0.022	0.183

Conclusions

Based on the latest research methods and conclusions of neuroeconomics, this study discusses the influence of bounded rationality on human psychological and behavioral process. The principle that brain neural mechanism is asymmetric to the information processing of risk gains and losses is verified through further analysis of school choice examples in China. When the gain is determined, the choice behavior of applicants is risk aversion, and when the loss is determined, the choice behavior is risk preference. In addition, under the admission rules in China, the "consistency preference" condition of applicants is not fully satisfied. Although the motivation of choosing a school is influenced by "utility maximization", most people have neither accurate compute ability nor time or information to fully consider the probability of various behavior choice results. Instead, they just experience intuition, perception, and external stimulation. When the emotional brain area becomes hyperactive, their irrational characteristic presents, and preference reversal to some extent increases the gain of applicants. Besides, under the PTTFA mechanism, applicants reveal that the true preference is not the dominant strategy nut will lead to market imbalance and low inefficiency. These analyses are helpful for us to understand the Pareto efficiency and Nash equilibrium in the behavioral game. The school-choice example and the rational and irrational characteristics of applicants in China have revealed the relationship between loss aversion and specific nervous system in the brain,

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providing a solid scientific basis for the deep understanding of human behavioral preference.

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