Online Appendix: Does Level-k Behavior Imply Level-k Thinking?

Ye Jin*

May 4, 2020

1 A Model of the Cognitive Space

In this section, I propose a model in which a player's type could be characterized by both his cognitive ability and his belief about the opponents' types. Similar assumptions could be found in Alaoui and Panta (2016), Choi (2012), Strzalecki (2014) and Georganas et al. (2015). Then the assumptions on the identification strategy will be discussed.

Lk Types in Simultaneous Ring Games

In a simultaneous ring game, Player i's cognitive type $t_i \in T_i$ is characterized by (a_i, b_i), where $a_i \in \{0, 1, 2, ...\}$ is the ability bound, and $b_i \in \Delta(T_{-i})$ represents the player's belief about his opponents' types. For simplicity, a player is assumed to hold the same belief about all 3 opponents. This study only considers degenerate beliefs, which restricts that $b_i \in T_{-i}$. Furthermore, the cognitively-constrained types are defined as the ones who have ability bound a_i, and hold the belief that their opponents are $(k-1)$th-order rational, but not ability-bounded.

Let's first define the cognitively-unbounded types with kth-order rationality, R_i^k, and then the observed Lk types with cognitive constraints could be defined based on the R_i^k types.

The irrational type is characterized by the set

$$R_i^0 = \{(a_i, b_i) | a_i = 0, b_i = \emptyset\}.$$

This type does not engage in any optimization and serves mainly as the anchoring point of analysis.

For any $k = 1, 2, 3, 4$, define the types whose behaviors depend only on their orders of rationality as

$$R_i^k = \{(a_i, b_i) | a_i > 4, b_i \in R_{-i}^{k-1}\}.$$

*Affiliation: NYU Shanghai. Email: wendyjin@nyu.edu. Address: 1555 Century Ave, Pudong, Shanghai, China, 200122.

The player's cognitive limit is assumed to be greater than 4, which is the maximum reasoning steps required to understand and solve the whole game. Therefore, cognitive limit never plays a role in determining the R_i^k type's behavior.

For a player with an ability bound that might be binding, exhibiting Lk behavior in the simultaneous games implies having kth-order rationality, and being able to perform k steps of reasoning. Therefore, the observed Lk types could be defined as

$$Lk_i = \{(a_i, b_i) | a_i \geq k, b_i \in R_{-i}^{k-1}\}.$$

Cognitive Types in Sequential Ring Games

In the sequential ring games, a player i's type is characterized by $t'_i = (a'_{i1}, a'_{i2}, b'_{i1}, b'_{i2}) \in T'_i$, where $a'_{i1} \in \{0, 1, 2, ...\}$ and $a'_{i2} \in \{0, 1\}$ are the player's ability bounds as first-movers and second-movers respectively, and $b'_{i1}, b'_{i2} \in T'^k_{-i}$ represents the player's belief about his opponents' types as first-movers and as second-movers[1]. Though I do not use the terms of sequential rationality, such as kth-order strong belief in rationality, b'_{i1} and b'_{i2} are capturing player i's belief about the opponents who are active in different information sets.

Again, let's first define the types, R'^k_i, whose ability bounds never bind and thus their behavior depends only on the orders of rationality:

$$R'^0_i = \{(a'_{i1}, a'_{i2}, b'_{i1}, b'_{i2}) | a'_{i1} = a'_{i2} = 0, b'_{i1}, b'_{i2} = \emptyset\},$$

and for $k = 1, 2, 3, ...,$

$$R'^k_i = \{(a'_{i1}, a'_{i2}, b'_{i1}, b'_{i2}) | a'_{i1} > 4, a'_{i2} = 1, b'_{i1} \in R'^{k-1}_{-i}, b'_{i2} \in R'^{\min\{k-1,1\}}_{-i}\}.$$

Then, for $k = 1, 2, 3, 4$, define the ability-bounded Lk types as

$$Lka_i = \{(a'_{i1}, a'_{i2}, b'_{i1}, b'_{i2}) | a'_{i1} = k, a'_{i2} = 1, b'_{i1} \in R'^{k-1}_{-i}, b'_{i2} \in R'^{\min\{k-1,1\}}_{-i}\},$$

and the belief-driven Lk types as

$$Lkb_i = \{(a'_{i1}, a'_{i2}, b'_{i1}, b'_{i2}) | a'_{i1} > k, a'_{i2} = 1, b'_{i1} \in R'^{k-1}_{-i}, b'_{i2} \in R'^{\min\{k-1,1\}}_{-i}\}.$$

Note that an Lka player is allowed to hold the belief that requires more reasoning steps than his ability bound a'_{i1} to respond. It is assumed that when a player faces a more sophisticated opponent, he would perform the maximum reasoning steps he possibly could. That is, he would

[1]Note that even when Player i is a first-mover position, an a'_{i2} is still assigned as a character to this player, and vice versa for the second-mover position. Therefore such a type characterization could be used on all player positions, which makes it more convenient to define higher-order beliefs.

reason up to a'_{i1} steps.

Assumptions on the Similarity of Simultaneous and Sequential Games

I now discuss the assumptions that are crucial to the identification of ability-bounded subjects.

A2: For each subject, $a_i = a'_{i1}$, and $a_i \geq 1$ implies $a'_{i2} = 1$, $\forall i$. That is, a subject's ability bound stays the same in simultaneous and sequential ring games.

As a first-mover, one needs to go through the same thought process to search for best responses in both the simultaneous and sequential games. It is assumed in $A2$ that a subject's ability bound should not change as a first-mover. As for the second-mover positions, it is assumed that if the subject behaves as at least $L1$ in the simultaneous games, he will be able to best respond as a second-mover in the sequential games.

Due to the same argument, a subject's belief in other first-movers' rationality should not change either.

A3: $b_i \in R_i^k$ if and only if $b'_{i1} \in R_i'^k$. That is, a subject's belief hierarchy about their opponents' rationality as first-movers stays the same in simultaneous and sequential ring games.

As for the second-movers in sequential games, although it also takes one step of reasoning to best respond, the task complexity is not exactly the same as the one step reasoning in the simultaneous game. Thus, I only assume that the task for the second-mover is easier, if not the same, than the task for one reasoning step in the simultaneous games.

A4: If $b_i \in R_i^k$ and $k \geq 1$, then it must be that $b'_{i2} \in R_i'^1$.

Combining $A3$ and $A4$, it implies that if a subject's kth-order belief says that the opponents are at least 1st-order rational in the simultaneous games, then in his kth-order belief the opponents are capable of best responding as the second-movers in the sequential games.

2 Response Time and Time Limit

2.1 Response Time and Types

Table 1 presents a regression of subjects' response times of a particular game on the their types, the feature of the game, and the order that the game is played.

$L0$'s response time is used as the reference group. Three types, $L1$, $L2b$, and the $Unidentified$ group are significantly quicker than $L0$. But the other types' response times do not significantly differ from $L0$'s.

	levels	$L0$	$L1$	$L2a$	$L2b$	$L3a$	$L3b$	$L4$	UI
		base	-6.485	-1.63	-3.706	-0.177	-1.342	1.773	-6.446
		-	(5.28)**	(1.37)	(3.09)**	(0.15)	(1.08)	(1.48)	(4.64)**
positions	SIMUL	P1	P2	P3	P4				
		11.604	9.301	3.905	base				
		(11.31)**	(9.01)**	(3.72)**	-				
	SEQ-P2	P1	P2	P3	P4				
		12.509	40.407	8.284	4.217				
		(12.21)**	(39.20)**	(8.03)**	(3.90)**				
	SEQ-P3	P1	P2	P3	P4				
		11.705	10.203	39.169	2.027				
		(11.45)**	(9.80)**	(39.17)**	(1.86)				
	order	-0.342							
		(11.47)**							
	Constant	34.242							
		(22.88)**							
	R^2	0.49							
	N	4296							

Note: This table shows the results from one regression. The dependent variable is response time (in seconds). * $p < 0.05$, ** $p < 0.01$. Standard errors are reported in the parentheses. Session fixed effects are included. UI refers to the Unidentified subjects.

Table 1: A Regression of Response Time on Types and Players Position

$L1$ and the Unidentified subjects are the fastest ones, using about 2.8 fewer seconds than $L2b$, and 6.5 fewer seconds than the rest groups. From Table 2, they are faster at almost all player positions, but a series of t-tests show that the difference are more likely to be significant at the players positions with higher reasoning level requirements, e.g. P1 and P2. It suggests that these subjects spend less effort on the games, which could be due to lack of sophistication, or lack of incentives for them to think hard. As a result, they exhibit lower reasoning levels.

It is hard to explain why *L2b* also play a bit faster than the other types. T-tests show that *L2b* subjects are significantly faster than *L2a* subjects in only 3 out of the 12 positions (P4 of SIMUL, P3 of SEQ-P2, and P2 of SEQ-P3).

The coefficients of the player positions show that subjects spend the least amount of time at the Player 4 positions, where they have dominant strategies. As the required reasoning steps increases, the response time becomes longer, which suggests that subjects' decision rules are in general consistent with iterated dominance.

The *order* variable takes the values from 1 to 24, representing the order of the games played by a particular subject. As a subject gets to every new game, on average, he spends 0.34 fewer seconds on the game. It implies that a subject spends about 7.8 fewer seconds on the last game than on the first game, all else equal, which suggests sort of learning effort when subjects are getting familiar with the operations on the matrices. Regressions treating the order variable as dummies generates similar results.

	SIMUL				SEQ-P2				SEQ-P3			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
L0	40.1	39.4	37.2	35.2	37.3	72.2	32.5	41.5	40.4	35.8	74.4	37.8
	(2.8)	(3.7)	(2.8)	(4.0)	(3.8)	(4.6)	(3.7)	(3.8)	(3.3)	(2.8)	(4.7)	(4.1)
L1	33.5	33	32.3	27	35.9	65.5	32	29	34.7	35.1	65.3	30.2
	(2.0)	(1.8)	(2.1)	(2.0)	(1.8)	(2.1)	(1.8)	(1.8)	(1.9)	(1.9)	(1.9)	(2.0)
L2a	41.6	39.9	30.9	29.5	40.5	68.3	38.1	32.8	41	43.8	68.5	31.6
	(1.7)	(1.8)	(1.7)	(1.7)	(1.7)	(1.5)	(1.6)	(1.9)	(1.8)	(1.6)	(1.3)	(2.0)
L2b	39.9	37.6	29.3	24.5	41	70.3	32.6	31.4	43.3	36.1	67.4	29.4
	(1.8)	(1.8)	(1.7)	(1.8)	(1.9)	(1.4)	(1.8)	(2.0)	(1.6)	(2.0)	(1.8)	(1.9)
L3a	45.7	43.6	35.2	32.8	46	71.9	36.3	34.7	44.5	41.2	67.6	30.5
	(1.8)	(1.5)	(2.0)	(2.2)	(1.6)	(1.4)	(2.2)	(2.2)	(1.6)	(1.8)	(1.8)	(2.2)
L3b	44.5	39.1	31.7	30.7	42.3	67.3	41.4	32.4	44.4	40.1	71.4	32.3
	(1.7)	(1.9)	(2.0)	(2.3)	(1.9)	(2.4)	(2.3)	(2.3)	(1.6)	(2.2)	(1.6)	(2.3)
L4	45	41.9	37.2	30.2	47.3	73.8	44.7	37.2	45.3	44.1	71.9	35.5
	(1.6)	(1.6)	(1.9)	(2.0)	(1.5)	(1.6)	(1.5)	(2.0)	(1.8)	(1.8)	(1.3)	(1.9)
UI	36	32.5	34.2	27.1	36.5	63	37.4	29.3	32.3	35.7	63.7	23.1
	(2.6)	(2.9)	(2.7)	(3.4)	(3.4)	(3.4)	(3.2)	(3.4)	(3.0)	(2.9)	(3.0)	(2.3)

Note: Standard errors are reported in the parentheses. *UI* refers to the Unidentified subjects.

Table 2: Response Time (in Seconds) by Types and Players Position

2.2 The Effect of the Time Limit

A time limit of 60 seconds was imposed on the decisions. Because of the random matching protocol and the dynamic feature of most of the games, the whole session needs to move at the same pace. In the pilot, it was found that, although most of the subject could finish their choices in one minute, there was always one subject who spends more than 5 minutes in each round, possibly due to inattention or being distracted, so that it would take more than 3 hours to finish a session[2].

To what extent are subjects constrained by the time limit? There are 12 out of the 184 subjects who failed to choose in one game (out of 184 $\times$ 24 games in total). For 7 out of the 12 subjects, missing one choice does not affect their type identification. Five subjects are affected and could not be identified due to the missing choice.

I next look at how many of the subjects submitted their decisions in the last 5 seconds of a round. These subjects might be the ones who are affected by the time limit. According to Table 3, 75.5% of the subjects had no more than 3 of such occasions, and over 90% of the subjects had no more than 6 of such occasions.

The subjects who are more likely to submit decisions in the last 5 seconds belong to different types (Table 4), suggesting that this time limit is not likely to affect type distribution. Very few $Unidentified$ subjects submitted late decisions. Therefore, it seems that the time limit is not the main cause for the large portion of $Unidentified$ subjects. Of course, there still exists the possibility that these subjects intentionally spent less effort and time due to the presence of a time limit.

[2]A possible solution to the problem is to have subjects finish all the first stage choices and then have them work on the second stages when the first stage choices have already been collected. In this way they could move at their own paces. However, to make salient the presence of the second movers as the first mover are making decisions, the design was not adopted.

N of responses in the last 5 seconds	N of subjects	percentage	accumulated percentage
0	51	27.7%	27.7%
1	43	23.4%	51.1%
2	28	15.2%	66.3%
3	17	9.2%	75.5%
4	7	3.8%	79.3%
5	12	6.5%	85.9%
6	10	5.4%	91.3%
7	7	3.8%	95.1%
8	1	0.5%	95.7%
9	1	0.5%	96.2%
11	2	1.1%	97.3%
12	1	0.5%	97.8%
13	1	0.5%	98.4%
14	1	0.5%	98.9%
18	1	0.5%	99.5%
22	1	0.5%	100.0%

Note: The summary includes the 5 subjects who cannot be identified due to missing choices.

Table 3: Subjects responding in the last 5 seconds of a round

	n: number of responses made in the last 5 seconds		
type	$n \geq 4$	$n \geq 6$	$n \geq 8$
missing	4	2	0
$L0$	3	1	0
$L1$	6	5	3
$L2a$	9	6	1
$L2b$	4	2	0
$L3a$	4	2	1
$L3b$	4	1	1
$L4$	10	6	2
UI	1	1	1

Note: *missing* refers to the 5 subjects who cannot be identified due to missing choices. UI refers to the Unidentified subjects.

Table 4: Type summary of subjects who made more than 4, 6, or 8 responses in the last 5 seconds

3 Type Classification with Alternative Cutoffs

3.1 Identification of Lk Behavior using Alternative Cutoffs

In type classification, a cutoff point is needed so that those subjects with $\min_k(x_{ik})$ larger than the cutoff will be assigned to $L0$ or the unidentified group. Table 5 reports the type assignment results with the cutoffs being 0, 1 or 2 deviations. In the first row, when a subject cannot be matched exactly to an Lk type, he is assigned to $L0$ or unidentifiable. This seems to be too strict as there are over 60% of the subjects left unidentified. When allowing for 1 deviation, the share of the unidentified subjects drops down to 15%, with more subjects being assigned to one of the four Lk types. If the 2-deviation cutoff is used, there is a further drop in the number of the unidentified subjects and an increase in $L1$ and $L2$. The numbers of higher types do not change.

Level	$L0$	$L1$	$L2$	$L3$	$L4$	UI
0 deviation	8	5	17	17	19	113
	4.5 %	2.8 %	9.5 %	9.5 %	10.6 %	63.1 %
random choice	89.0 %	0.4 %	0.1 %	0.1 %	0.0 %	10.4 %
1 deviation	7	26	50	39	30	27
	3.9 %	14.5 %	27.9 %	21.8 %	16.8 %	15.1 %
random choice	86.4 %	4.4 %	1.0 %	0.3 %	0.2 %	7.7 %
2 deviations	5	40	56	39	30	9
	2.8 %	22.3 %	31.3 %	21.8 %	16.8 %	5.0 %
random choice	72.5 %	18.9 %	4.2 %	1.5 %	0.7 %	2.2 %

Note: $N = 179$. Each subject is classified as $L1 - L4$ with no more than 0, 1 or 2 deviations from the predicted action profiles. Otherwise they are assigned to $L0$ or the unidentified group. The subjects classified as unidentified are able to choose dominant strategies as Player 4 but do not match any of the predicted patterns. They are at least rational, which makes them different from $L0$. The random choices are simulated with 10,000 randomly choosing subjects.

Table 5: Type assignment from SIMUL games

The choices of an appropriate cutoff is determined by simulation. In the simulation, the choice profiles of 10,000 robot agents are generated, assuming that they choose randomly among the three actions at all player positions. They are then analyzed through the type assignment process. This analysis examines the power of the type classification process by looking at how many of the randomly choosing agents could be correctly assigned to $L0$ and how many of them are assigned to one of the Lk types by mistake. When allowing for 1 deviation, over 86% of them are classified as $L0$, and around 5% go to the Lk types. It does not differ too much from the 0-deviation cutoff. However, when allowing for 2 deviations, over 25% of the random choosing subjects are assigned as Lk, which is too high to be acceptable. Therefore, the 1-deviation cutoff is chosen in the main analysis, for it gives reliable results and provides enough observations of the Lk types for the following analysis.

3.2 Identification of Lka and Lkb with alternative cutoffs

		Baseline + Sequential Types								
		$L0$	$L1$	$L2a$	$L2b$	$L3a$	$L3b$	$\geq L4$	UI	sum
	N	8	13	16	18	15	14	25	70	179
Baseline Types	L0	**6**	0	0	0	0	0	0	1	7
	L1	0	**13**	1	0	0	1	0	11	26
	L2	0	0	**15**	**18**	0	0	0	17	50
	L3	1	0	0	0	**15**	**13**	0	10	39
	L4	0	0	0	0	0	0	**25**	5	30
	UI	1	0	0	0	0	0	0	26	27

Note: $N = 179$. Subjects are assigned to a type with, at most, 2 deviations. Otherwise they are classified as $L0$ or unidentified. The subjects classified as unidentified are able to choose 5 out of 6 dominant strategies as player 4 but do not match any of the predicted patterns. The numbers in bold fonts represent the subjects who remain in the same Lk category in the two type classifications.

Table 6: Type assignment according to the observations from SIMUL, SEQ-P3 and SEQ-P2 (2 deviations)

		Baseline + Sequential Types								
		$L0$	$L1$	$L2a$	$L2b$	$L3a$	$L3b$	$\geq L4$	UI	sum
	N	8	34	31	27	22	19	26	12	179
Baseline Types	L0	**6**	1	0	0	0	0	0	0	7
	L1	0	**23**	1	1	0	1	0	0	26
	L2	0	4	**24**	**21**	0	1	0	0	50
	L3	1	0	1	0	**21**	**15**	0	1	39
	L4	0	0	1	1	1	0	**26**	1	30
	UI	1	6	4	4	0	2	0	10	27

Note: $N = 179$. Subjects are assigned to a type with, at most, 4 deviations. Otherwise they are classified as $L0$ or unidentified. The subjects classified as unidentified are able to choose 5 out of 6 dominant strategies as player 4 but do not match any of the predicted patterns. The numbers in bold fonts represent the subjects who remain in the same Lk category in the two type classifications.

Table 7: Type assignment according to the observations from SIMUL, SEQ-P3 and SEQ-P2 (4 deviations)

3.3 Subjects with non-unique minimum deviations from a predicted strategy profile

A subject is assigned to the type k with the highest likelihood d_{ik}, which is equivalent to finding the lowest number of deviations x_{ik}. If a subject's action profile matches exactly with a type's predicted profile, he will be assigned to this type. However, if $\min_k(x_{ik}) > 0$, there might be more than one minimum x_{ik}. Following Kneeland (2015), this subject will be assigned to the lowest type that has the minimum number of deviations.

A caveat of this type assignment method is that a subject categorized as $L2$ or $L3$ but has multiple minimum x_{ik}'s might actually belong to a higher type. The misidentification might lead to an overestimation of the belief-bounded subjects. In Table 8, the $L2$ and $L3$ subjects are analyzed separately based on whether the subject's action profile has more than one minimum deviations in the type classification using the 8 simultaneous games. It shows that indeed the ones without a unique minimum are more likely to be identified as a belief-bounded type.

	N	$L0$	$L1$	$L2a$	$L2b$	$L3a$	$L3b$	$L4$	UI
$L2$ Unique	31	0	1	15	12	0	0	0	3
$L2$ Not Unique	19	0	2	6	9	0	1	0	1
$L3$ Unique	27	1	0	0	0	16	7	0	3
$L3$ Not Unique	12	0	0	0	0	4	8	0	0

Note: $L2$ and $L3$ Unique are the subjects who are categorized as $L2$ or $L3$ from the 8 simultaneous games and has unique minimum deviations x_{ik}. $L2$ and $L3$ Not Unique are the subjects who are categorized as $L2$ or $L3$ but also has more than one minimum deviations.
The $L2a$, $L2b$, $L3a$, and $L3b$ types are from the 20 games and could have non-unique minimum deviations.

Table 8: Type classification of $L2$ and $L3$ with or without unique minimum deviations

Since the classification of Lka and Lkb is also subject to the same problem, Table 9 shows the type distribution of only the subjects who have unique minimums in the type classifications of both the 8 games and the 20 games. There are similar numbers of ability-bounded and belief-driven $L2$ subjects, but among the $L3$ subjects, many more of them appear to be ability-bounded. This pattern is similar to the findings in the main results section.

	N	$L0$	$L1$	$L2a$	$L2b$	$L3a$	$L3b$	$L4$	UI
$L2$	25	0	0	10	12	0	0	0	3
$L2$	27	1	0	0	0	16	7	0	3

Note: All subjects presented in this table have unique minimums in type classifications of both the 8 games and the 20 games.

Table 9: $L2$ and $L3$ subjects with unique minimum deviations

4 Additional Analysis on Learning Effects

In this section, I first provide the analysis of learning effects with some alternative cutoffs. As suggested by a referee, playing P4 positions at the very beginning of the experiment might have the highest effect on learning. Therefore, I look at the subjects who played as P4 in the very first round ($n = 46$), who played P4 at least once in the first two rounds ($n = 89$), and those who played P4 at least twice in the first 4 rounds. As shown in Figure 1 there is no evidence that these subjects are more likely to be higher types. Goodness-of-fit tests show that their distributions are not statistically different from the distribution of the full sample.

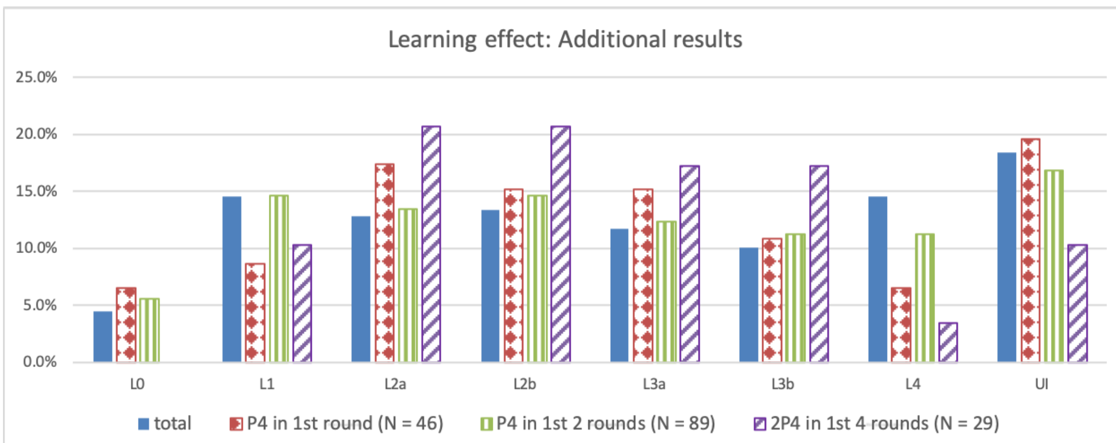


Figure 1: Type distributions of the subjects who have an advantage in learning (Alternative cutoffs)

Next, let's look at whether there exist systematic type shifts in the data. That is, whether subjects are more likely to shift to a higher (lower) type in the later (earlier) period of the experiment. Since the choices in all 20 first-mover positions are needed to pin down a subject's type, it is not possible to estimate one's type in the early and late parts of the experiment separately. Instead, I look at the deviations from the choice pattern of one's assigned type. The deviation observed in the type assignment process could be sorted into one of three cases: (1) a non-equilibrium strategy is chosen at a position where the type should have chosen an equilibrium strategy. (2) two different strategies are chosen at the same position of the two paired rings where the type should be on off-equilibrium path and choose the same strategy, and at least one of the two strategies chosen is an equilibrium strategy. (3) two different strategies are chosen at the same position of the two paired rings where the type should be on off-equilibrium path and choose the same strategy, and neither of the two strategies chosen is an equilibrium strategy.

Case (1) implies that the subject might shift to a lower level when playing that game and Case (2) corresponds to the shift to a higher level. If learning affects subjects' behavior, they should be more likely to deviate to a higher level in the later half of the experiment and more likely to a lower level in the earlier half. If, however, the growth of fatigue plays a more important role, it should be opposite. Of course it could not be ruled out that some deviations in Case (1) and (2) are caused by preference shifts or mistakes. But if the occurrences of preference shifts or mistakes are assumed to be time-invariant, then they could be canceled out when only the differences of the earlier and later halves are examined.

	8 Baseline Games			20 first-mover Games		
	Case (1)	Case (2)	Case (3)	Case (1)	Case (2)	Case (3)
Shifts	downward	upward	-	downward	upward	-
Earlier	12	26	25	42	80	53
Later	2	27		24	79	

Note: the first two cases are counted in the earlier and later 12 games respectively. $L0$ and unidentifiable subjects are excluded.

Table 10: Deviations sorted into three cases

Table 10 reports the deviations of the classified subjects, from both the 8 SIMUL games and the 20 first-mover games type assignments. $L0$ and unidentifiable subjects are excluded from this analysis, because according to the definition $L0$s could be using any combination of strategies, and since I could not identify the decision rules of the unidentifiable it would be hard to determine which choices are deviations from their rules. The 24 games were played in a random order and the orders of play were different for each subject. Cases (1) and (2) could therefore be put into two categories, that is whether these deviations occur in the first or later 12 games. In Case (3) it could only be observed that subjects are choosing two different strategies at the same position, but it is impossible to tell which one is the deviation (or both could be deviations). So only the total numbers of deviations in Case (3) are reported.

In Case (1), players deviate to a lower type. This kind of deviation is more likely to happen in the first half of the experiment, suggesting some sort of learning effects. However, the occurrences of Case (2) deviations, which imply a shift to a higher level, are quite close between earlier and later periods of the experiment.

I next run a probit regression to determine the learning effect specifically at each position.

$$\text{Probit}(Y_i) = \alpha + \beta_1 \text{L12}_i + \beta_2 \text{POS}_i + \beta_{3j} \text{POS}_{ij} \times \text{L12}_i + \epsilon_i, \tag{1}$$

where $Y_i = 1$ when an equilibrium strategy is chosen, and $Y_i = 0$ otherwise; $L12_i = 1$ if that choice is made in the later 12 games, and $L12_i = 0$ otherwise; POS_{ij} denotes the position dummy at position j. The session fixed effects are also controlled.

Table 11 reports the coefficients $\beta_1 + \beta_{3j}$ of each position j. One position dummy, player 4 of G5, is dropped because of collinearity. Significant positive learning effects are found at only 3 of

		player 1	player 2	player 3	player 4
Baseline	G1	0.215	0.009	0.287	0.127
		(0.193)	(0.189)	(0.210)	(0.389)
	G2	0.267	0.055	0.235	0.010
		(0.190)	(0.188)	(0.211)	(0.417)
		player 1	player 2 (2nd)	player 3	player 4
Seq-P2	G3	0.210	0.108	0.570**	-0.226
		(0.193)	(0.331)	(0.234)	(0.365)
	G4	0.232	-0.683	-0.103	0.272
		(0.199)	(0.427)	(0.227)	(0.315)
		player 1	player 2	player 3 (2nd)	player 4
Seq-P3	G5	0.028	0.492**	0.142	-
		(0.187)	(0.200)	(0.344)	-
	G6	0.393**	-0.144	0.237	0.010
		(0.193)	(0.197)	(0.369)	(0.395)

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are reported in the parentheses. (2nd) denotes second stage movers. Player 4 of G5 is dropped due to collinearity.

Table 11: Experience effect at each position ($\beta_1 + \beta_{3j}$)

the 23 positions.

Since the identification uses at least a pair of ring games, the learning effects at three positions is unlikely to affect the type distribution. It is reported in **??** that the performance of the subjects who could have better opportunities to learn is not different from the whole sample. Here I further show with multilogit regressions that playing more player 4 positions or second-mover positions in the earlier periods does not affect the probability of being assigned to a high type (Table 12 and Table 13).

Independent Variable: $I(n(P4) > 4$ in earlier 12 games)							
base outcome	$L0$	$L1$	$L2a$	$L2b$	$L3a$	$L3b$	$L4$
vs $L0$		-0.398	-0.713	-0.770	-0.843	0.182	-1.713*
		(0.883)	(0.897)	(0.887)	(0.893)	(0.884)	(0.999)
vs $L1$	0.398		-0.315	-0.372	-0.445	0.581	-1.315
	(0.883)		(0.720)	(0.670)	(0.715)	(0.656)	(0.823)
vs $L2a$	0.713	0.315		-0.0564	-0.129	0.896	-1.000
	(0.897)	(0.720)		(0.682)	(0.703)	(0.713)	(0.832)
vs $L2b$	0.770	0.372	0.0564		-0.0730	0.952	-0.943
	(0.887)	(0.670)	(0.682)		(0.697)	(0.676)	(0.811)
vs $L3a$	0.843	0.445	0.129	0.0730		1.025	-0.870
	(0.893)	(0.715)	(0.703)	(0.697)		(0.723)	(0.835)
vs $L3b$	-0.182	-0.581	-0.896	-0.952	-1.025		-1.895**
	(0.884)	(0.656)	(0.713)	(0.676)	(0.723)		(0.801)
vs $L4$	1.713*	1.315	1.000	0.943	0.870	1.895**	
	(0.999)	(0.823)	(0.832)	(0.811)	(0.835)	(0.801)	

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are reported in the parentheses. Each row shows a regression with a different type being the base outcome. Session fixed effects are included in the multilogit regressions. Unidentifiable subjects are excluded.

Table 12: Multilogit regression of types on Learning Effects (1)

Independent Variable: $I(n(P4) + N(PSM) > 6$ in earlier 12 games)							
base outcome	*L*0	*L*1	*L*2*a*	*L*2*b*	*L*3*a*	*Lb*3	*L*4
vs *L*0		0.381	-0.320	-0.633	-0.740	0.689	-0.761
		(0.893)	(0.907)	(0.926)	(0.948)	(0.951)	(0.922)
vs *L*1	-0.381		-0.700	-1.014	-1.121	0.308	-1.142*
	(0.893)		(0.690)	(0.681)	(0.746)	(0.704)	(0.674)
vs *L*2*a*	0.320	0.700		-0.314	-0.420	1.009	-0.441
	(0.907)	(0.690)		(0.699)	(0.740)	(0.758)	(0.697)
vs *L*2*b*	0.633	1.014	0.314		-0.107	1.322*	-0.128
	(0.926)	(0.681)	(0.699)		(0.758)	(0.757)	(0.696)
vs *L*3*a*	0.740	1.121	0.420	0.107		1.429*	-0.0208
	(0.948)	(0.746)	(0.740)	(0.758)		(0.819)	(0.741)
vs *L*3*b*	-0.689	-0.308	-1.009	-1.322*	-1.429*		-1.450*
	(0.951)	(0.704)	(0.758)	(0.757)	(0.819)		(0.742)
vs *L*4	0.761	1.142*	0.441	0.128	0.0208	1.450*	
	(0.922)	(0.674)	(0.697)	(0.696)	(0.741)	(0.742)	

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are reported in the parentheses. Each row shows a regression with a different type being the base outcome. Session fixed effects are included in the multilogit regressions. Unidentifiable subjects are excluded.

Table 13: Multilogit regression of types on Learning Effects (2)

5 Other Results

5.1 Consistency of Behavior across Simultaneous and Dynamic Games

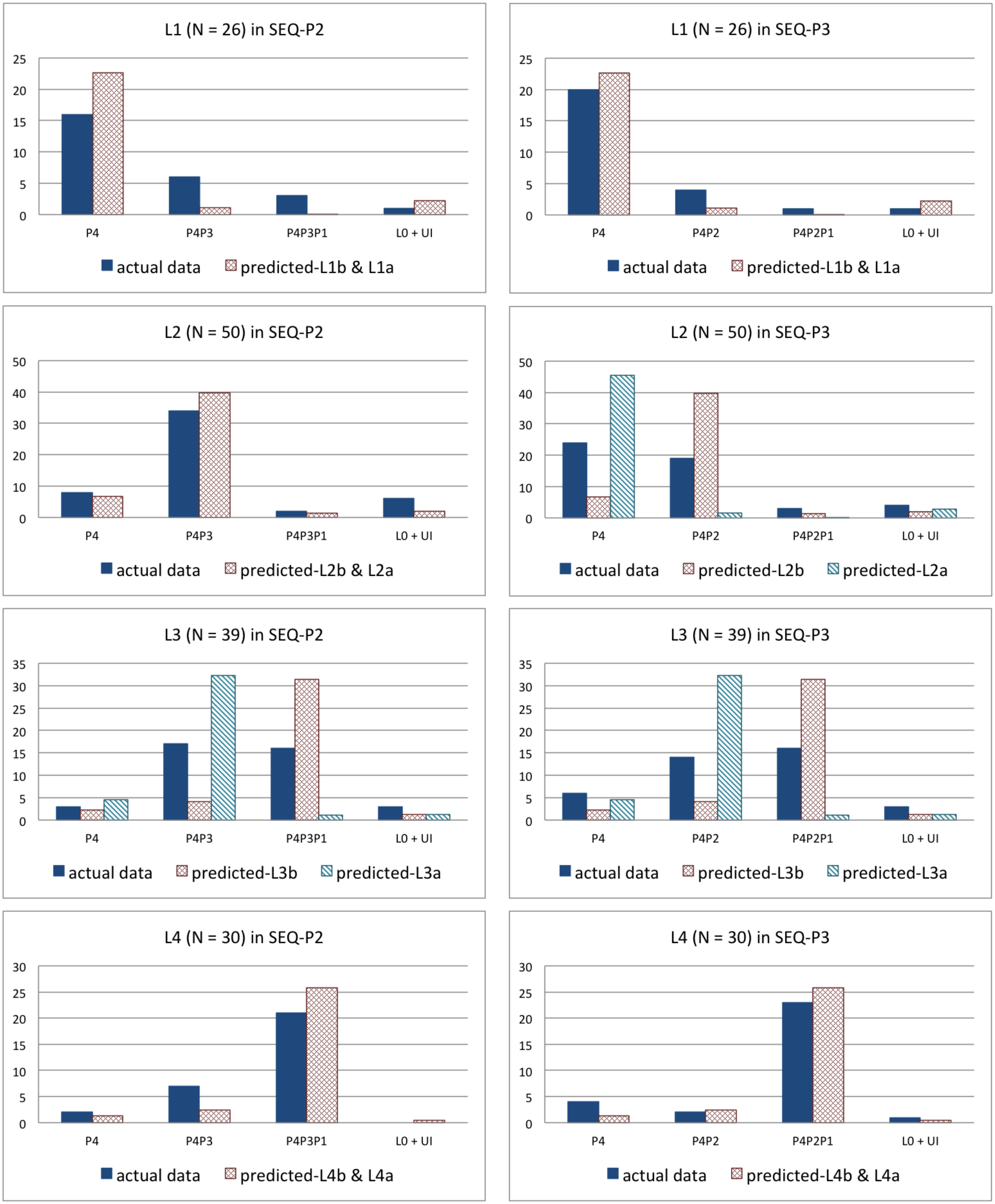
This section shows that subjects' behavioral patterns in the sequential games are close to the theoretical predictions assuming that their rationality levels and ability bounds are consistent across simultaneous and sequential games. Most subjects fall into the predicted categories.

Figure 2 gives the actual type switch patterns of the identified Lk type from SIMUL. In each diagram, the solid bar describes the behavior of these Lk types in SEQ-P2 or SEQ-P3. According to **??**, subjects' behavior could be sorted into three categories based on their choices as first-movers in the sequential games. In SEQ-P2, the subjects could be playing the (iterated) dominant strategies only at P4 position, at P4 and P3 positions, or at all of the P4, P3 and P1 positions. In SEQ-P3, the three categories are playing the (iterated) dominant strategies at P4 position, at P4 and P2 positions, or at P4, P2 and P1 positions. The three categories correspond to the subjects best responding to 1st-, 2nd-, and 3rd-order rational belief in the sequential games. Each subject could be assigned to one of the categories by the method in **??** and the 1-deviation cutoff[3].

In theory, these subjects' behavior should follow **??** if their belief levels and ability levels remain the same in both simultaneous and sequential games. However, one could be misidentified to a different type if he deviates too much from his own type. In order to determine how many misidentifications from the predicted categories could occur, for each of the $L1$-$L4$ types, I simulate the choices of 10,000 pseudo-subjects in sequential games, assuming that all of them are either Lka or Lkb. The average deviation rate of each type used in the simulation is from the type classification results of the simultaneous games in **??**. In Figure 2, the patterned bars of each category give the predicted behavior pattern of Lka or Lkb obtained from simulation. According to the simulation, around 85% of the subjects should fall into the predicted categories if their belief and ability bound do not change.

Let's first take a look at the $L1$ and $L4$ types, and $L2$ in SEQ-P2. The predictions of Lka or Lkb behavior are the same for these subjects. Their actual choices in SEQ-P2 and SEQ-P3 share similar patterns with the simulated distributions, though less concentrated on the theoretically predicted categories, possibly due to the presence of inconsistent subjects. According to Table 14, exact tests of goodness-of-fit show that in three of these five cases ($L1$ in SEQ-P3, $L2$ in SEQ-P2

[3]According to $A1$, a subject best responding to 1st-order rational belief in SEQ-P2 plays dominant strategies as Player 4, but chooses the same actions as Players 1 and 3. This gives the predicted action profile for the "P4" category in SEQ-P2, which includes $L1b$ and $L1a$. Similarly, a subject responding to 2nd-order rational belief in SEQ-P2 should play the (iterated) dominant strategies as Players 3 and 4 and choose the same action as Player 1, which gives the action profile for the "P4P3" category in SEQ-P2, including $L2a$, $L2b$ and $L3a$. A subject responding to 3rd-order rational belief in SEQ-P2 should play the (iterated) dominant strategies as Players 1, 3 and 4, which is the "P4P3P1", including $L3b$, $L4a$ and $L4b$. The actions of the three categories in SEQ-P3 could be predicted in the same way.



Note: In SEQ-P2, subjects are sorted into three categories: choosing the (iterative) dominant strategies at P4 ("P4"), at P4 and P3 ("P4P3"), and at P4, P3 and P1 ("P4P3P1"). In SEQ-P3, subjects are sorted into three categories: choosing the (iterative) dominant strategies at P4 ("P4"), at P4 and P2 ("P4P2"), and at P4, P2 and P1 ("P4P2P1"). Each subject is assigned to a category with ER and 1-deviation cutoff. The solid bars give the actual type distribution. The checked and stripe bars give the simulated type distribution assuming that these subjects are Lkb or Lka. In certain cases the behaviors of Lkb and Lka are not distinguishable, and they are represented by the same checked bar.

Figure 2: Behavior pattern of each Lk type in sequential games

and $L4$ in SEQ-P3) the actual type distributions are not different statistically from the predicted ones at the significance level of 0.05 (Table 14). In the case of $L4$ subjects in SEQ-P2, the difference is at the 0.05 level but not the 0.01 level.

	SEQ-P2	all categories	each category vs. the rest			
			(1)	(2)	(3)	(4)
			P4	P4P3	P4P3P1	$L0$ + UI
$L1$	vs. predicted-$L1b$ & $L1a$	**0.0012**	**0.0040**	**0.0121**	0.0485	0.6249
$L2$	vs. predicted-$L2b$ & $L2a$	0.1702	0.7124	0.0704	0.5396	0.0648
$L3$	vs. predicted-$L3b$	**0.0000**	0.7669	**0.0000**	**0.0000**	0.2674
	vs. predicted-$L3a$	**0.0000**	0.5337	**0.0000**	**0.0000**	0.2674
$L4$	vs. predicted-$L4b$ & $L4a$	**0.0320**	0.7208	0.0329	**0.0093**	0.4522
	SEQ-P3	all categories	each category vs. the rest			
			P4	P4P2	P4P2P1	$L0$ + UI
$L1$	vs. predicted-$L1b$ & $L1a$	0.0824	0.1752	0.1111	0.4373	0.6249
$L2$	vs. predicted-$L2b$	**0.0000**	**0.0000**	**0.0000**	0.2676	0.3278
	vs. predicted-$L2a$	**0.0000**	**0.0000**	**0.0000**	0.0547	0.6334
$L3$	vs. predicted-$L3b$	**0.0000**	0.0791	**0.0006**	**0.0000**	0.2674
	vs. predicted-$L3a$	**0.0000**	0.5058	**0.0000**	**0.0000**	0.2674
$L4$	vs. predicted-$L4b$ & $L4a$	0.1842	0.1181	1.0000	0.0913	0.4453

Note: the numbers in bold fonts represents the 0.05 significance level test result, with the null hypothesis that the actual data and simulated data are drawn from the same distribution. The first column shows the original tests including all four categories. Columns (2)-(5) show the follow-up tests of each category vs. the sum of all the other categories. For the four follow-up tests, the significance level is corrected by $0.05/4 = 0.0125$.

Table 14: p-values of the exact tests of goodness-of-fit: actual vs. predicted distributions

Since there might exist both $L2a$ and $L2b$ in SEQ-P3, and both $L3a$ and $L3b$ in SEQ-P2 and SEQ-P3, the type distributions of the $L2$ and $L3$ subjects could be different from the simulated ones. However, the difference should only be reflected in the predicted categories. Specifically, for $L2$'s behavior in SEQ-P3, the difference from the simulated distribution should only be found in the best response rates at Player 2 position. Therefore small p-values should only occur in the "P4" and "P4P2" categories and the proportions of the other categories should not differ too much from the simulated ones. Similarly, for $L3$'s behavior in SEQ-P2 and SEQ-P3, the difference should only be reflected in the best response rates at Player 1 position (reflected in Categories (2) and (3)). The follow-up test of each of the four categories confirms that very few subjects fall outside of the predicted categories.

Thus it could be concluded that the simulated type distributions are good predictions of the aggregate pattern, which provides strong evidence that most subjects are consistent in belief and ability bounds.

5.2 Do *L3b* subjects believe that their opponents are ability-bounded or belief-driven?

In the theoretical framework, a simplifying assumption was made that a player holds belief only in the opponents' rationality but not in their ability bounds. This assumption only affects the behavioral implications for *L*3 subjects. It remains to check the validity of this assumption. In SEQ-P2, in order to play the iteratedly dominant strategy as Player 1, *L3b* needs to believe that the opponents reason two steps, while in SEQ-P3 *L3b* needs to believe that the opponents reason three steps. If all *L3b* subjects hold the belief that their opponents are 2nd-order rational and not ability-bounded, then SEQ-P3 and SEQ-P2 should make no difference for them, which serves as the null hypothesis in this test.

Under the null hypothesis, there should be the same proportion of *L*3 subjects identified as *L3b* in SEQ-P2 and SEQ-P3. Otherwise, if a subject believes that the opponents are *L2a*, he will not comply with iterated dominance as Player 1 in SEQ-P3. In this case, fewer *L*3 subjects would be identified as *L3b* in SEQ-P3 than in SEQ-P2.

In the actual data, no difference could be found statistically in the type distributions from the two sets of sequential games (see Figure 2). A closer look at the behavior patterns of the *L*3 subjects (Table 15) has confirmed that most of these subjects behave consistently as *L3b* or *L3a* in both SEQ-P3 and SEQ-P2. No evidence is found to reject the hypothesis that *L3b* believes that their opponents are always best responding to the 2nd-order rational belief[4].

		behavior in SEQ-P2			
		P4	P4P3	P4P3P1	UI
in SEQ-P3	P4	3	2	1	0
	P4P2	0	9	4	1
	P4P2P1	0	5	10	1
	UI	0	1	1	1

Table 15: Behavioral patterns of the 39 *L*3 subjects in the two sequential games

[4]It should be noted that with a sample size of 39 *L*3 subjects, to get a power higher than 0.8, it requires at least 25% of them responding to the belief that the opponents are bounded by two steps of thinking (Faul et al., 2007). So there may very well exist a small number of such subjects, who could not be detected in this experiment due to lack of power.

5.3 Type Assignment with the Assumption of Uniform Randomizing $L0$

The assumption used to predict Lk behavior in the ring games is that an Lk player does not respond to the changes in $(k+1)$- or higher direct opponents' payoffs (**A1**). An alternative assumption, which is widely used in Lk experiments, is that the irrational $L0$ type uniformly randomize on all the possible actions (**UP**: uniform prior on $L0$).

		$L0$	$L1$	$L2$	$L3$	$L4$	UI
SIMUL	ER	7	26	50	39	30	27
		3.9%	14.5%	27.9%	21.8%	16.8%	15.1%
	UP	6	10	43	39	53	28
		3.4%	5.6%	24.0%	21.8%	29.6%	15.6%
		$L0$	P4	P4P3	P4P3P1	-	UI
SEQ-P2	ER	7	43	69	46	-	14
		3.9%	24.0%	38.5%	25.7%	-	7.8%
	UP	7	32	60	78	-	2
		3.9%	17.9%	33.5%	43.6%	-	1.1%
		$L0$	P4	P4P2	P4P2P1	-	UI
SEQ-P3	ER	5	68	46	45	-	15
		2.8%	38.0%	25.7%	25.1%	-	8.4%
	UP	5	22	46	94	-	12
		2.8%	12.3%	25.7%	52.5%	-	6.7%

Note: $N = 179$. Subjects are assigned to a type with no more than 1 deviation when using $A1$, with no more than 2 deviations when using UP. Otherwise they are assigned to $L0$ or the unidentified group. The subjects classified as unidentified play dominant strategies as Player 4 but do not match any of the predicted patterns.

Table 16: Type assignment using the two assumptions ER and UP

The distribution of assigned types using the predicted Lk behavior of UP is given in Table 16. The 2-deviation cutoff is used here, so a random choosing subject only has a probability of less than 5% of being assigned to one of the Lk types, which is comparable to the main results. The distributions shift to the right in all three sets of games. In the simultaneous games, the number of $L4$ subjects almost doubles, and the number of $L1$ drops by more than a half. The shift is even larger in SEQ-P3. The number of subjects assigned to "P4" category under UP is less than a third of the number under $A1$. And the number in "P4P2P1" category increases by more than 100%. A closer look at the type changes confirms that everyone's level rises or at least stays the same. Nobody goes to a lower level under UP. Nevertheless, the numbers of $L0$ and the unidentified are quite close. There are 6 subjects classified as $L0$ and 14 classified as unidentified under both assumptions.

Type classification with UP tends to overestimate the lower types. This is because the predicted action profile of each type on the off-equilibrium path using UP is a special case of that using $A1$. Since UP puts stronger restrictions on the off-equilibrium path, any subject has a smaller chance to be assigned to a low type. The overestimation would be more severe if fewer subjects follow the prediction of UP, as observed in SEQ-P3. Hence I use $A1$ in the main analysis, which I believe provides more robust and reliable results.

6 Instructions

You are about to participate in an experiment in decision making. The experiment includes 24 decision problems and 9 short questions. You will get separate instructions for the short questions after the decision making part. If you follow the instructions and make good decisions, you may earn a considerable amount of money. Besides that, you will also get a $5 participation fee. All the money that you earn will be paid to you in private after today's session.

You may not write during the experiment. It is also important to remain silent throughout the experiment and not to look at other people's work. If you have any questions or need assistance of any kind, please raise your hand, and the experimenter will come to you. Otherwise, if you write, laugh, talk with other participants, exclaim out loud, etc., YOU WILL BE ASKED TO LEAVE. Thank you.

Your earnings will be determined by your decisions and the decisions of other participants in the experiment. Before making your decisions, you will be able to gather information about how your earnings and other participants' earnings depend on your and their decisions. Then you need to take an understanding test and have the opportunity to practice on 4 problems. You will NOT be paid for the practice rounds.

The experiment has 24 rounds. In each round, you will be matched with a RANDOMLY selected group of the other participants. A new group will be formed and matched with you in each round. You will not know which ones of the other participants you are matched with, and your identity and the identities of the other participants will never be revealed.

Each round concerns a DECISION SITUATION in which you and the other participants in your group separately and independently make decisions called CHOICES. Together, your and their choices determine your and their earnings in this round, which may be different for each member in the group.

Neither your nor their choices in a round will affect how you or the other participants are matched or the decision situations you and they face in the rest of the experiment.

In each round, you will choose among three alternatives. The other members in your group will also have three alternatives to choose from. Your earnings will depend on the combination of your choice and one of the other group member's choice. These earnings possibilities will be represented in a table like the one below. Your choices will determine the row of the table. The choice of one of the other members in your group, whom we call Participant X, will determine the column of the table. You may choose from "a, b, c" and Participant X may choose from "d, e, f". The cell corresponding to this combination of choices will determine your earnings.

Time left: 26 seconds

Your Earnings

		X's Choices		
		d	e	f
Your Choices	a	14	8	4
	b	20	8	14
	c	0	16	18

Participant X's Earnings

		Y's Choices		
		g	h	i
X's Choices	d	20	14	8
	e	16	2	18
	f	0	16	16

Participant Y's Earnings

		Z's Choices		
		j	k	l
Y's Choices	g	4	16	14
	h	14	12	10
	i	6	10	8

Participant Z's Earnings

		Your Choices		
		a	b	c
Z's Choices	j	8	20	12
	k	0	8	6
	l	18	12	6

Your earnings are given by the blue numbers. You can highlight any cell by clicking on them.

Participant Z is the observer in this group.

Your earnings depend on your and Participant X's choices.

Participant X's earnings depend on Participant X's and Participant Y's choices.

Participant Y's earnings depend on Participant Y's and Participant Z's choices.

Participant Z's earnings depend on Participant Z's and your choices.

Please choose: a b c

You will not be able to change your choice after you have confirmed it.

CONFIRM

For example, given the above earnings tables, if you choose b and Participant X chooses e, then you will earn 8 dollars for this round. If instead Participant X chooses f, you will earn 14 dollars.

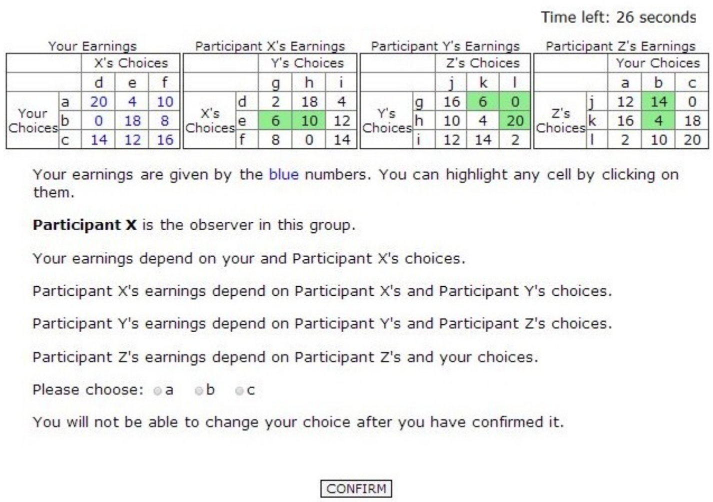
Your earnings will always be listed in the FIRST table. Participants X, Y and Z's earnings are listed in the other three tables. X's earnings depend upon his/her choice and Y's choice. Y's earnings depend upon his/her choice and Z's choice. Z's earnings depend upon his/her choice and your choice.

For example, if you choose a, Participant X chooses e, Participant Y chooses h, Participant Z chooses l, then you will earn 8 dollars, X will earn 2 dollars, Y will earn 10 dollars and Z will earn 18 dollars.

The earnings tables will be given to every member of the group. After you have made the decision in that round, you need to click the button to confirm you choice and wait to proceed to the next problem after all the other group members have finished their choices. The earnings tables may change from round to round, so you should always look at the earnings carefully at the beginning of each round.

Besides, you may highlight any cell by clicking on it to help you making the decisions (see screenshot below).

There is a time limit of 60 seconds for you to make choice in each round. There will be a counting down clock showing how much time is left for this round. The clock is located on the upper right corner, as shown in the screenshot below. If you fail to make a decision within the time limit, you will earn \$0 in this round. If any group member fails to make a choice within the time limit, the system will randomly pick a choice out of his three alternatives when calculating the earnings of other group members. For example, given the earnings tables below, if you choose b, X chooses f, Y fails to choose, Z chooses l, and the system chooses g for Y, then you will earn \$8, X will earn \$8, Y will earn \$0 and Z will earn \$10.


Time left: 26 seconds

Your Earnings		X's Choices		
		d	e	f
Your Choices	a	20	4	10
	b	0	18	8
	c	14	12	16

Participant X's Earnings		Y's Choices		
		g	h	i
X's Choices	d	2	18	4
	e	6	10	12
	f	8	0	14

Participant Y's Earnings		Z's Choices		
		j	k	l
Y's Choices	g	16	6	0
	h	10	4	20
	i	12	14	2

Participant Z's Earnings		Your Choices		
		a	b	c
Z's Choices	j	12	14	0
	k	16	4	18
	l	2	10	20

Your earnings are given by the blue numbers. You can highlight any cell by clicking on them.

Participant X is the observer in this group.

Your earnings depend on your and Participant X's choices.

Participant X's earnings depend on Participant X's and Participant Y's choices.

Participant Y's earnings depend on Participant Y's and Participant Z's choices.

Participant Z's earnings depend on Participant Z's and your choices.

Please choose: a b c

You will not be able to change your choice after you have confirmed it.

CONFIRM

In certain rounds, one of the group members will be RANDOMLY selected to be the OBSERVER. An observer will be able to look at the other group members' choices before making his/her choice. At the beginning of each round, We will inform every member in the group which member has been assigned to be the observer. (But, of course, his/her true identify will always remain anonymous.)

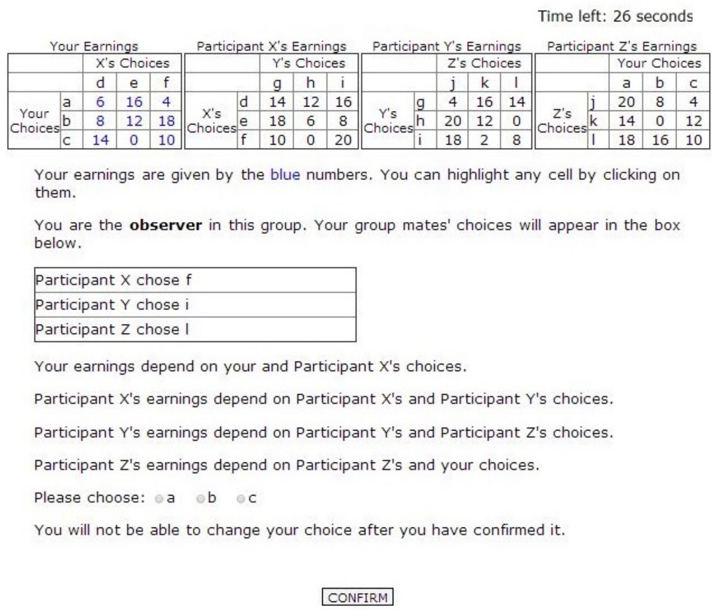
For example, if Participant X is selected to be the observer, you and Participants Y and Z will see this sentence on the screen:

"Participant X is the observer."

And participant X will see this on the screen:

"You are the observer."

Below is a screenshot of the interface for an observer. After the other participants have made their choices, these choices will appear in the box.



Time left: 26 seconds

Your Earnings

		X's Choices		
		d	e	f
Your Choices	a	6	16	4
	b	8	12	18
	c	14	0	10

Participant X's Earnings

		Y's Choices		
		g	h	i
X's Choices	d	14	12	16
	e	18	6	8
	f	10	0	20

Participant Y's Earnings

		Z's Choices		
		j	k	l
Y's Choices	g	4	16	14
	h	20	12	0
	i	18	2	8

Participant Z's Earnings

		Your Choices		
		a	b	c
Z's Choices	j	20	8	4
	k	14	0	12
	l	18	16	10

Your earnings are given by the blue numbers. You can highlight any cell by clicking on them.

You are the **observer** in this group. Your group mates' choices will appear in the box below.

Participant X chose f
Participant Y chose i
Participant Z chose l

Your earnings depend on your and Participant X's choices.

Participant X's earnings depend on Participant X's and Participant Y's choices.

Participant Y's earnings depend on Participant Y's and Participant Z's choices.

Participant Z's earnings depend on Participant Z's and your choices.

Please choose: a b c

You will not be able to change your choice after you have confirmed it.

CONFIRM

The observer will be given an extra of 30 seconds to make his/her choice, which means the observer will have 90 seconds in that round. If you are the observer, please wait patiently until your group-mates' choices show up in the boxes.

Whether you or the other members will be selected as the observer does NOT depend on your or their previous choices nor the group formation. You will be randomly matched with a new group in each round and the identities of all the group members will always remain anonymous.

Once you have confirmed your choice for a round, you will not be able to change your choice for that round. After you have made your choices for all of the 24 rounds, one round will be randomly selected for payment at the end of the experiment. Every participant in this room will be paid based on his/her choices and the choices of his/her randomly selected group-mates in this round. Any of the rounds could be selected. So you should treat each round like it will be the one determining your payment.

You will be informed of your total earnings, the round chosen for payment, what choice you made in that round and the action of your randomly matched group-mates only at the end of the experiment. You will not learn any other information about the actions of other participants' in the experiment. You final payment will be the earnings calculated by the system plus the $5 participation fee. All the money that you earn will be paid to you in private after today's session.

References

[1] Alaoui, Larbi and Antonio Panta. 2016. “Endogenous Depth of Reasoning.” *The Review of Economic Studies* 83(4): 1297-333.

[2] Choi, Syngjoo. 2012. “A Cognitive Hierarchy Model of Learning in Networks.” *Review of Economic Design*, 16, 215-250.

[3] Georganas, Sotiris, Paul J. Healy and Roberto A. Weber. 2015. “On the Persistence of Strategic Sophistication.” *Journal of Economic Theory* 159: 369-400.

[4] Strzalecki, Tomasz. 2014. “Depth of Reasoning and Higher Order Beliefs”. *Journal of Economic Behavior and Organization* 108: 108-22.