Background

Guessing Games and Non-Standard Data

One question that has guided research on the guessing game is whether choice (say) of 33 is a sophisticated response to a fully reasoned belief that others will average 50 or a reflection of bounds on rationality.[1] In trying to understand this, various researchers have begun to explore non-standard data that may aid in the interpretation of choices. For example, Costa-Gomes, Crawford and Broseta (2001) and Costa-Gomes and Crawford (2006) examined data on information search behavior recorded using MouseLab. Costa-Gomes and Crawford (2006) used MouseLab to study cognition via information search in a rich class of two-person guessing games. They provide compelling evidence that patterns of search as well as of choice can be well explained by Lk and cognitive hierarchy models.

A second line of research involves estimating subjects' levels of reasoning by analyzing verbal data associated with their choices (e.g. Sbriglia (2008), Bosch-Domenech, Montalvo, Nagel and Satorra (2002) and Arad (2012)). Burchardi and Penczynski (2014), for example, analyzed subjects' arguments while attempting to convince their "teammates" to follow their advice.

A separate line of work uses physiological and neurological measurements to gain insight into play in the guessing game. Dickinson and McElroy (2010) find that subjects apply higher levels of reasoning when well-rested rather than sleep-deprived, and when at their peak time of day rather than at their off-peak times. Coricelli and Nagel (2009) use fMRI techniques to explore levels of reasoning in a game in which subjects play against computers. They uncover systematic differences in the neurological responses of the players at different levels of strategic sophistication. Chen, Huang and Wang (2013) used eye-tracking data to complement choice data in a modified 2/3 guessing game played spatially on a two-dimensional plane. Taken together, the above research makes it clear that bounds on rationality play an important role in explaining the behavioral patterns in guessing games.

Choice Process Data

The recent expansion of the evidentiary base in studies of the guessing game mirrors a similar movement in decision theory. The desire to enrich standard choice data while retaining strong links to standard theory led Caplin and Dean (2011) to introduce "choice process" data in the search theoretic context. These data identify the evolution of perceived optimal choices during the period of search. Caplin, Dean, and Martin (2011) develop an experimental interface to capture these data, and use it to get new insights into the nature of the search process and the rules for stopping search.

Unlike in the search theoretic context, in the case in this paper there is no external information to gather that would motivate changing one's mind in the pre-decision period. Hence the question our CP experiment addresses is the extent to which subjects learn to play the guessing game by turning it over in their mind. As they do this, they may

[1] See Crawford (2008), Grosskopf and Nagel (2008) and Coricelli and Nagel (2009).

reflect both on the structure of the game itself and on their own earlier thoughts (as in the Goeree and Holt (2004) model of "noisy introspection"). Do they gradually move to higher levels of sophistication as they internalize the structure of the game? Do they use their own earlier thoughts to model the thoughts of others, as suggested by various models in social psychology (see Dawes (1990))? The CP experiment gathers data on this process of learning while hewing closely to the decision theoretic tradition.

Learning by Thinking and Time To Decide

Economists have studied many forms of learning, such as Bayesian updating, learning by doing, and reinforcement learning. Our focus is on a quite distinct form of learning that involves no new external stimulus: "learning by thinking." This raises the question of how long a period of time players have been given to contemplate their strategy in prior versions of the guessing game. Unfortunately there is little pattern in this respect. Ho, Camerer and Weigelt (1998) set an experimental time limit of 2 minutes. However this was the maximum allowed time and not the time it took for subjects to actually respond. Bosch-Domenech, Montalvo, Nagel and Satorra (2002) report results of a five minute laboratory experiment, and of other experiments conducted more remotely (e.g. via newspaper) with response times of up to two weeks.

We are aware of only one paper in which the time constraint in a 2/3 guessing game was manipulated. Kocher and Sutter (2006) examined the effects of time pressure and incentive schemes on choices in repeated plays of the guessing game. Surprisingly, they did not find much difference in first round play for different time constraints.[2]

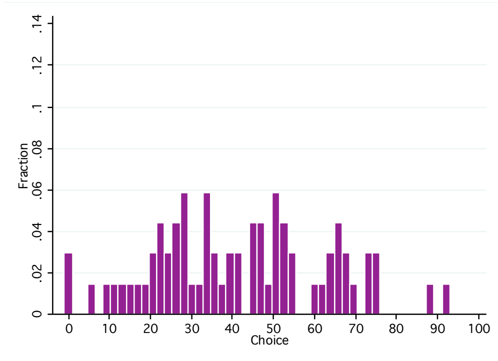
Using a different design, Rubinstein (2007) explored the connection between contemplation time and choice in the context of an online version of the guessing game. There was no maximum time, but a server recorded the time a subject took to submit the answer. He found that the focal L1 and L2 responses of 33 and 22 respectively took longer on average than other choices.

In a particularly relevant precursor to the CP design, Weber (2003) also explored the connection between contemplation time and choices in the guessing game. He had subjects play the guessing game ten times in a row, providing them with no feedback on their performance until all ten trials had been completed. What he found was that, while choice in the first round was entirely as in the standard game, by round ten the average choice had fallen significantly. This suggests that further reflection on the structure of the game led many to change their minds, without any feedback from outcomes and without new external information of any kind. However, in Weber's (2003) setting, subjects may change their decisions over time not only due to continued reflection on the structure of the game, but also because they expect others to change. In contrast, our CP experiment is designed exclusively to focus on the impact of internal reflection.[3]

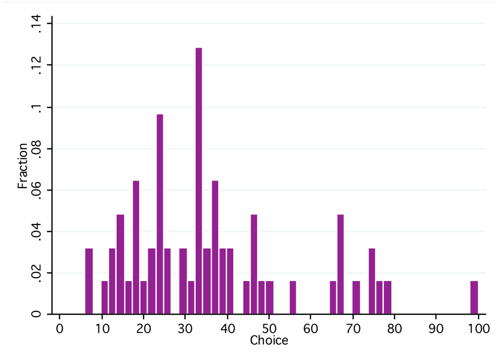
[2]This may be due to the fact that their subjects knew that they would repeat the game several times, and so would be able to change their decisions in later plays of the game. In our design, subjects play one and only one time, and may therefore more rapidly internalize the structure of the game.

[3]This is because the other payoff-relevant actions were settled in a prior interaction as we will describe in the next section.

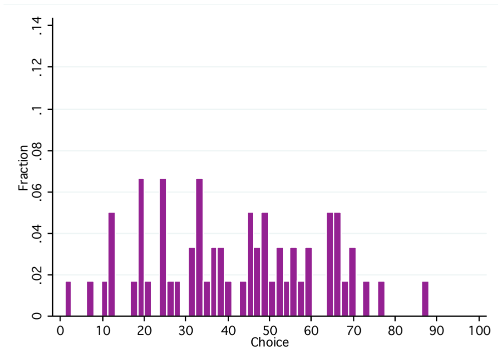
1 Equivalence of Choice Process and Standard Experiments of Equivalent Time Horizon - Additional Evidence



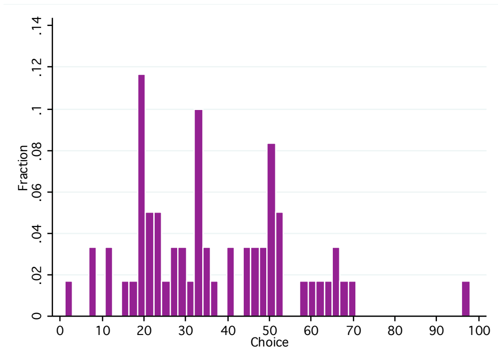
(a) Standard - Choice at 30 sec



(b) Standard - Choice at 180 sec



(c) CP - Choice at 30 sec



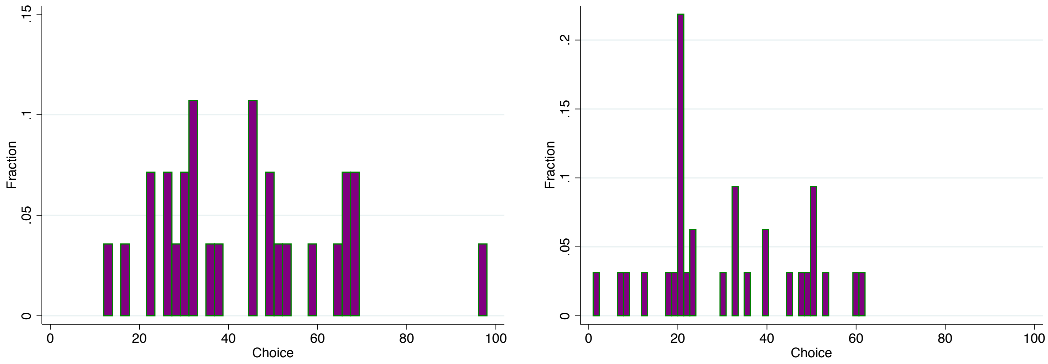
(d) CP - Choice at 180 sec

Figure 1: Histogram of Final Choices in the Standard and CP Experiments

Figure 1 presents the histograms of choices in Standard 30 second and 180 second treatments and CP experiments at 30 and 180 seconds. Kolmogorov-Smirnov tests show no difference between the distribution of choices elicited under the CP protocol and the standard experiments of equivalent time horizon ($p > .10$).

Final Choice of Naive and Sophiticated Types

Figure 2 shows the distributions of final choices for naive and sophisticated types. A Kolmogorov Smirnov test shows that these distributions are statistically different ($p < 0.05$).



(a) Naive players. (b) Sophisticated players

Figure 2: Distribution of choices of naive and sophisticated players at the end of the game.

Instructions for the Choice Process Experiment

We will start with a brief instruction period. If you have any questions during this period, raise your hand. Experiment consists of two parts. You will be given instructions for the next part of the experiment once you finished this part. Anything you earn in the experiment will be added to your show-up fee of $7.

PART I

We will start by describing what kinds of decisions you will be making in this game. We will then describe the rules of the game and the payments in this game.

Your task in this game is to choose a number from those presented on the screen.

The game lasts 180 seconds. At the top right corner of the screen you can see how many seconds are left. At the bottom right corner of the screen there is a "Finished" button. The rest of the screen is filled with buttons representing integer numbers between 1 and 100. They are arranged in decreasing order.

When the game starts, you can select the number by clicking on the button displaying the number that you want. You may click when you want, however many times you want.

The computer will record all the numbers you click on, as well as when you clicked on them.

After 180 seconds, or when you click the finish button, the round will come to an end and you won't be able to change your choice anymore. Just to make clear, if you choose a number and then stay with that number until the end, or instead decide to click on the "Finish" button, it will make no difference.

Only one of the numbers you selected will matter for payment. To determine which one, the computer will randomly choose a second between 0 and 180, each second is equally likely to be chosen. The number you selected at that time will be the one that matters. We will call this number **"Your Number."** Below are two examples.

Example 1

Suppose you chose the button 100 for seconds 0 to 180. Suppose the computer randomly selects second 13 to be the random second.

Since at second 13 you were at button 100, 100 is "Your Number".

Example 2

Suppose that after 10 seconds you selected the button 62. Suppose then that at second 55 you switched to button 40. Suppose that then at second 90 you switched to button 89 and then clicked on the Finish button.

In this case "Your Number" would be:

- if the computer randomly chooses a number between 0 and 9 seconds: none.
- if the computer randomly chooses a number between 10 and 54 seconds: 62
- if the computer randomly chooses a number between 55 and 89 seconds: 50
- if the computer randomly chooses a number between 90 and 180 seconds: 89

These examples are completely random and do not represent a hint at what you ought to do in this experiment. Note: once a button is clicked on, it becomes highlighted and you do not need to click on it again as it is already selected.

If you have not yet made a selection at the random second the computer chooses, then you cannot win this game.

Also, understand that if at any point you prefer a different number to the one you currently have selected, you should change the button you selected as this would reduce the chances of the less preferred number being recorded as "Your Number."

The Structure of the Game

A few days ago 8 undergraduate students like yourselves played a game. Your payoff is tied to the choices made by those 8 students, so you need to understand the game they played. We will now distribute the rules of the game these 8 students played and the rules of the game you will be playing.

Your payoff will not depend on the choices made by the people in this room. It depends only on your choice and the choices these 8 students made a few days ago.

[**Distribute the second set of instructions face down now. Wait for all to receive a copy. Read it out loud.**]

The PAST game the 8 people played:

Each of the 8 students had 180 seconds to choose an integer between 1 and 100 inclusive, which they wrote on a piece of paper. After 180 seconds, we collected the papers. The winner was the person whose number was closest to two thirds of the average of everyone's numbers. That is, the 8 students played among themselves and their goal was to guess two thirds of the average of everyone's numbers.

The winner won $10 and in case of a tie the prize was split.

The game YOU will be playing now:

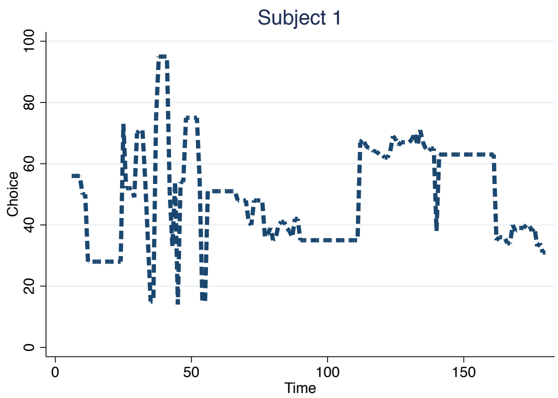
You will have 180 seconds to choose an integer between 1 and 100 inclusive. You win $10 if you are "better than" those 8 students at determining two thirds of the average of their numbers. That is, you win $10 if **Your Number** is the **closest** to two thirds of the average of the numbers in the past game.

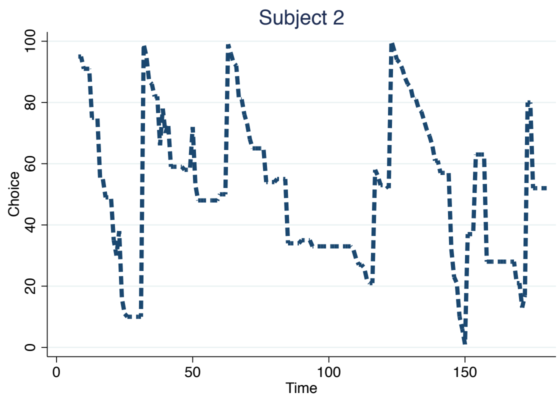
At any point, it is in your best interest to select the button corresponding to what you think is two thirds of the average of the numbers in the past game.

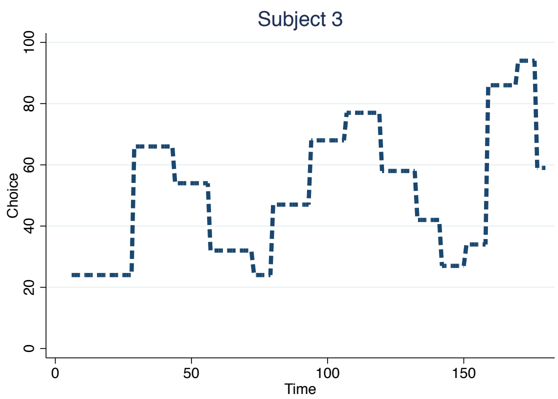
[Game starts right away.]

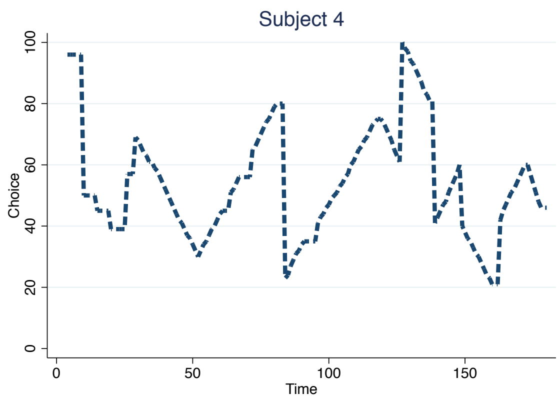
Individual Paths

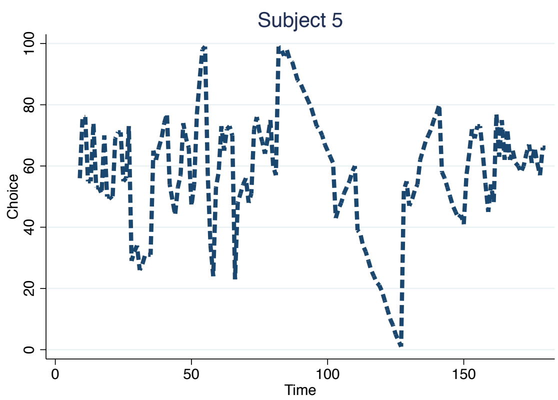
Subjects 1 through 28 are classified as naive. Subjects 29 through 60 are classified as sophisticated.

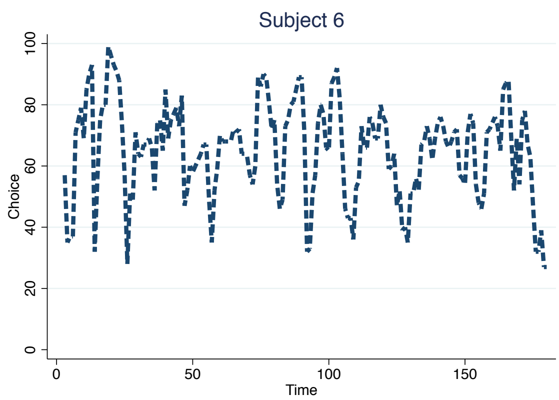


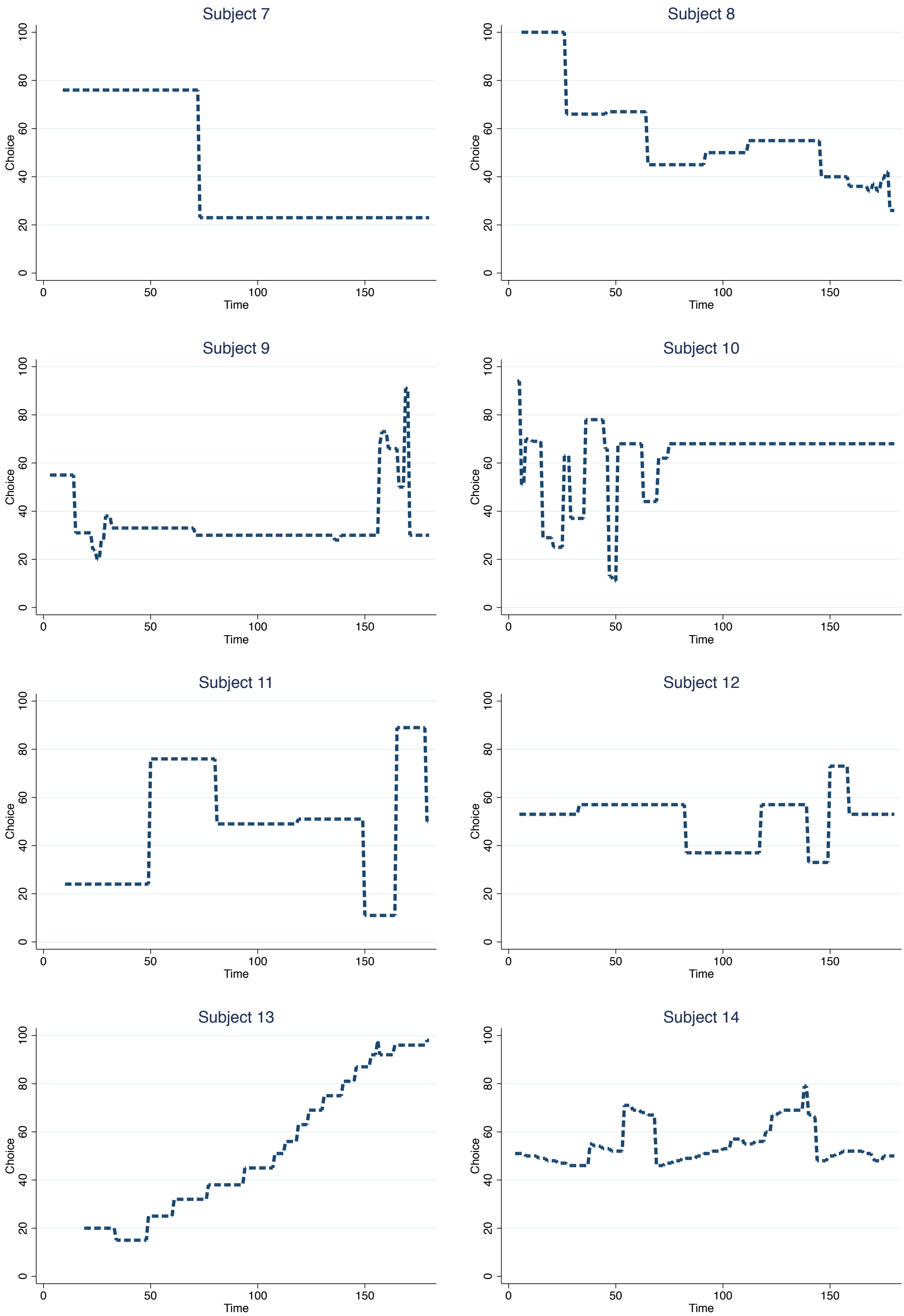








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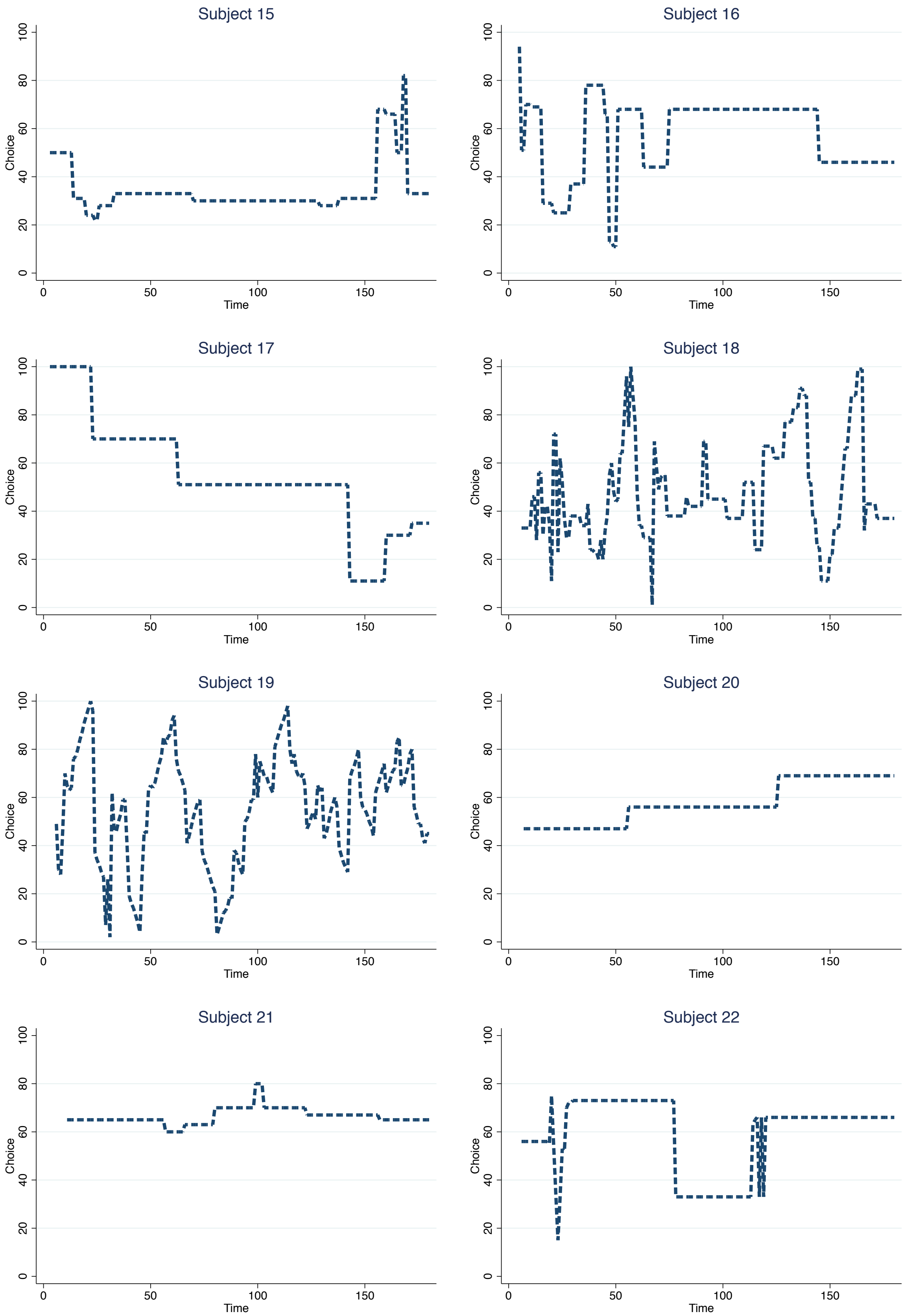
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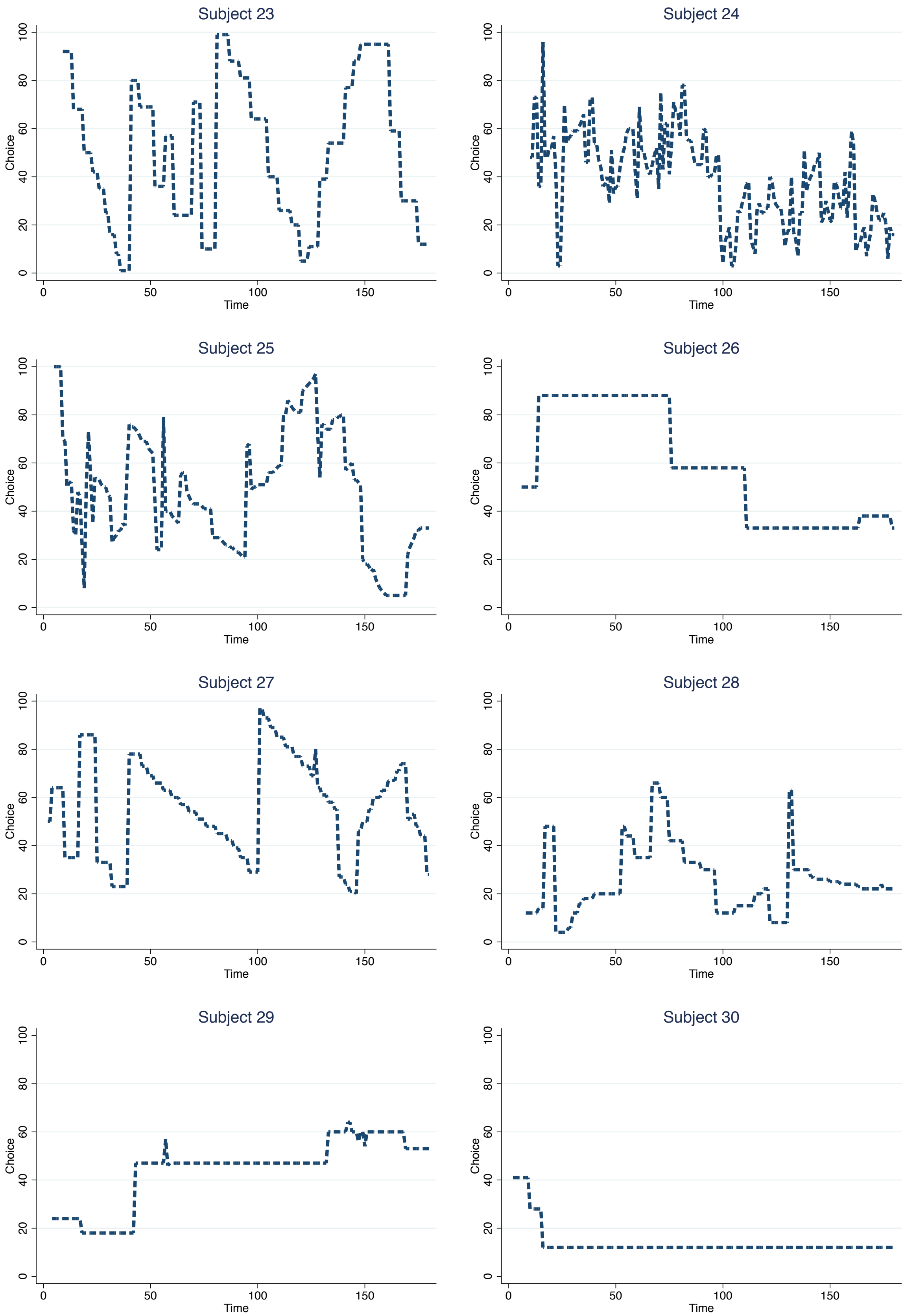
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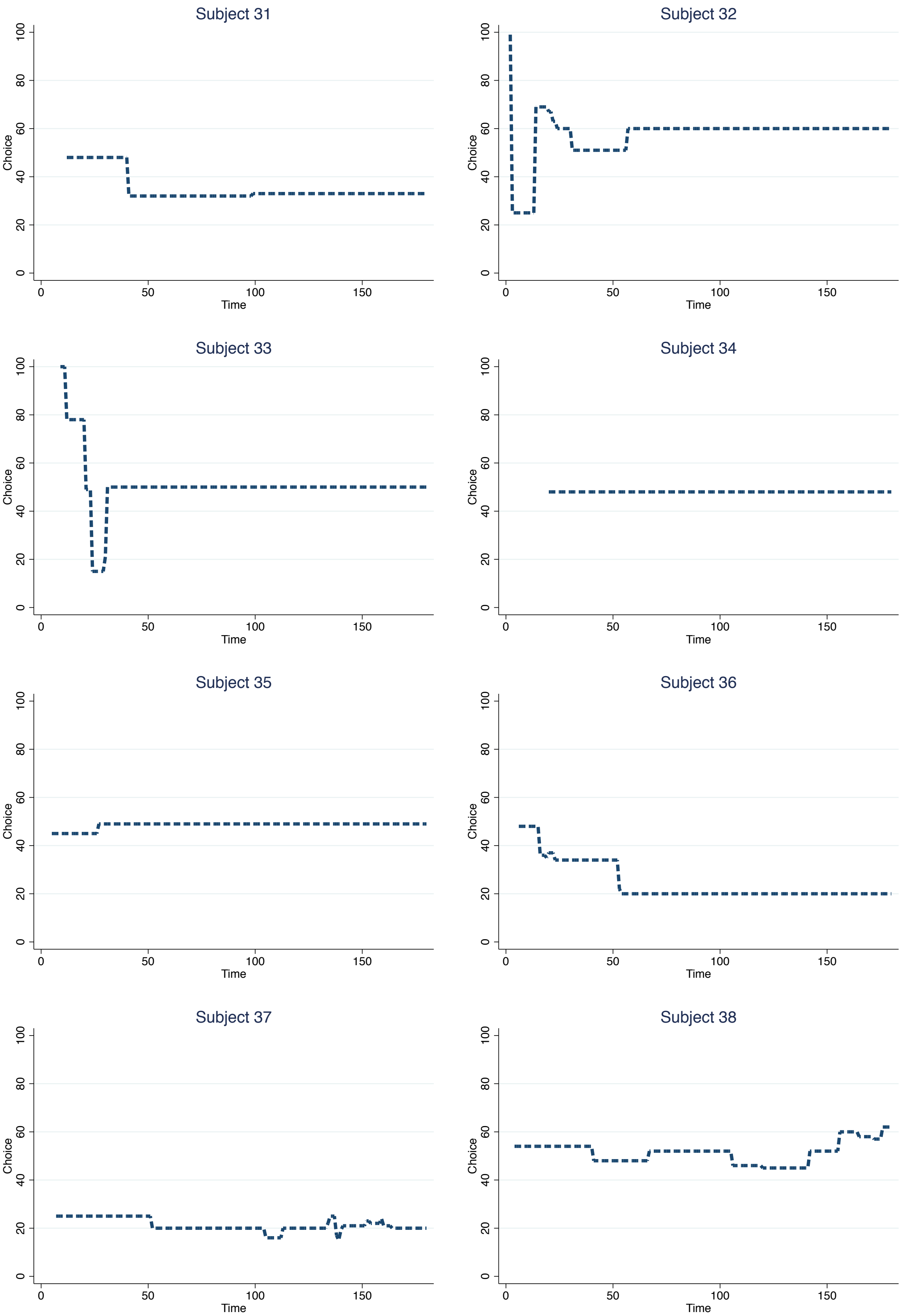
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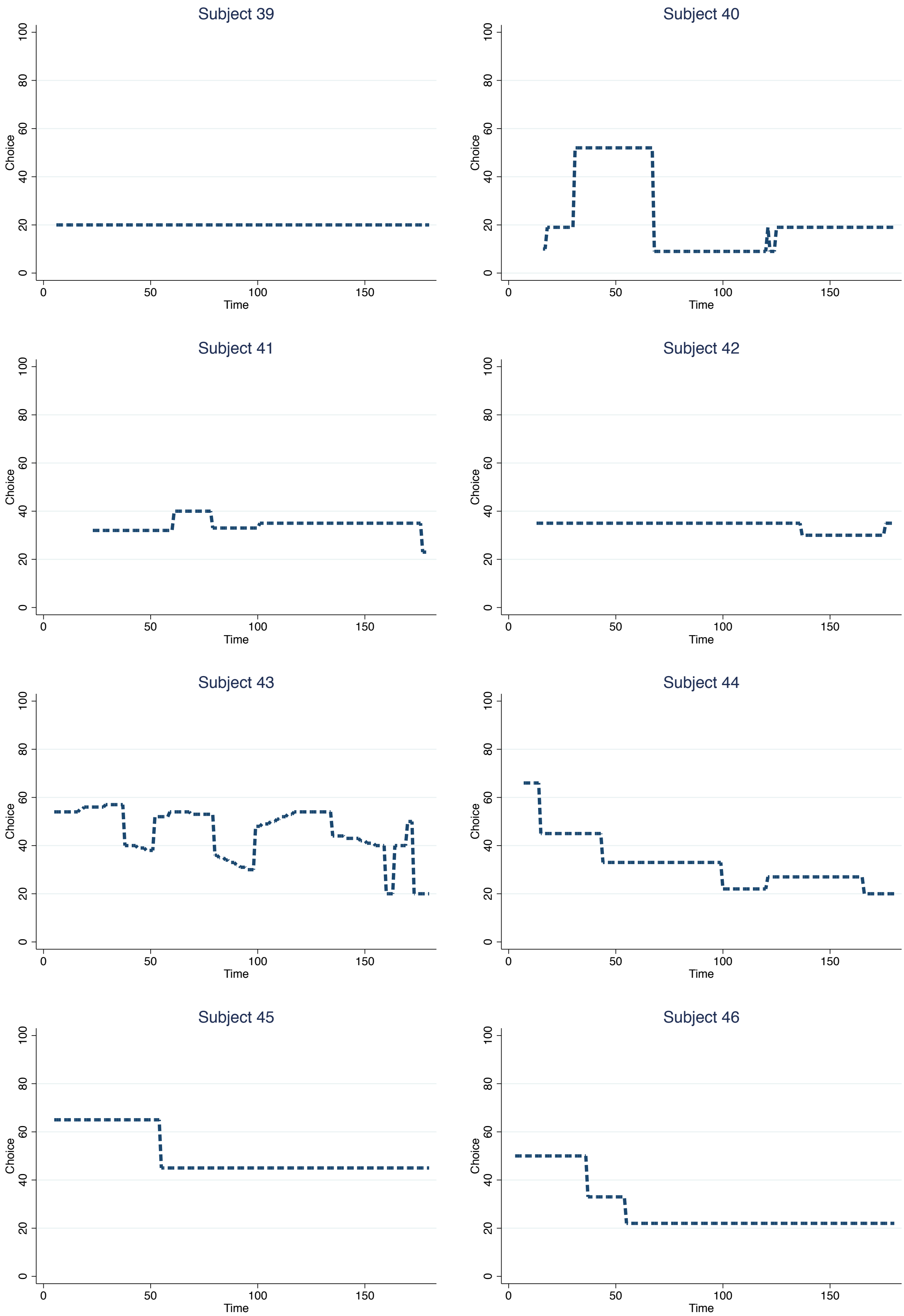
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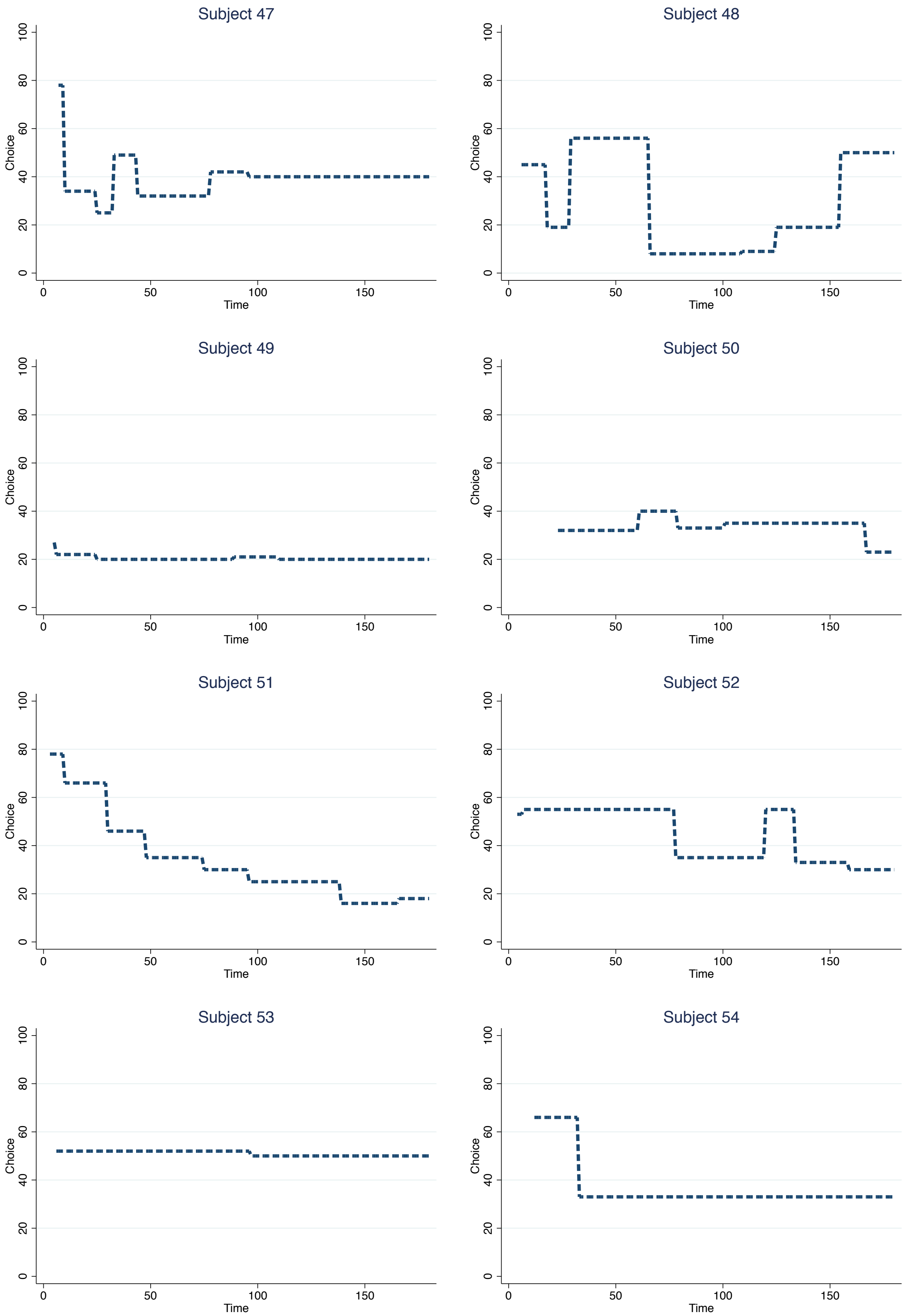
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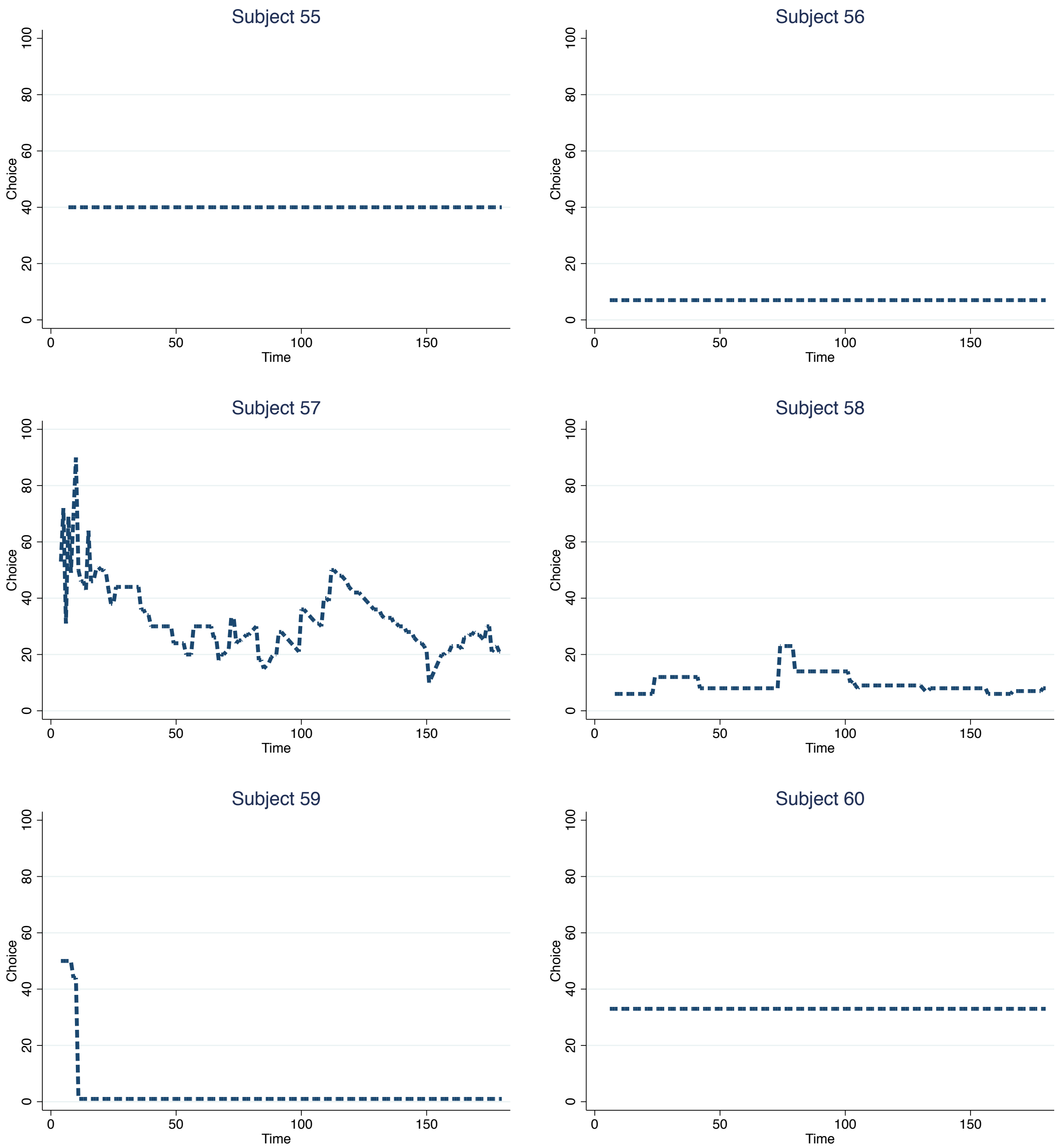

Figure 3: Individual time paths: choices over time.

References

[1] Arad, Ayala. 2012. “The Tennis Coach Problem: A Game-Theoretic and Experimental Study.” *The B.E. Journal of Theoretical Economics (Contributions)*, 12 (1).

[2] Bosch-Domenech, Antoni, Montalvo, Jose, Nagel, Rosemarie, and Albert Satorra. 2002. “One, Two, (Three), Infinity, . . . : Newspaper and Lab Beauty-Contest Experiments.” *The American Economic Review*, 92 (5): 1687-1701.

[3] Burchardi, Konrad, and Stefan Penczynski. 2014. “Out of Your Mind: Eliciting Individual Reasoning in One Shot Games.” *Games and Economic Behavior*, Vol. 84, p. 39-57.

[4] Caplin, Andrew, and Mark Dean. 2011. “Search, Choice, and Revealed Preference.” *Theoretical Economics*, 6:19-48.

[5] Caplin, Andrew, Dean, Mark, and Daniel Martin. 2011. “Search and Satisficing.” *American Economic Review*, 101 (7): 2899-2922.

[6] Chen, Chun-Ting, Huang, Chen-Ying, and Joseph Wang. 2013. “A Window of Cognition: Eyetracking the Reasoning Process in Spatial Beauty Contest Games.” *Working Paper.*

[7] Coricelli, Giorgio, and Rosemarie Nagel. 2009. “Neural correlates of depth of strategic reasoning in medial prefrontal cortex.” *Proceedings of the National Academy of Sciences (PNAS): Economic Sciences*, 106(23): 9163-9168.

[8] Costa-Gomes, Miguel A., Crawford, Vincent, and Bruno Broseta. 2001. “Cognition and Behavior in Normal-Form Games: An Experimental Study.” *Econometrica*, 69(5): 1193-1235.

[9] Costa-Gomes, Miguel, and Vincent Crawford. 2006. “Cognition and Behavior in Two-Person Guessing Games: An Experimental Study.” *The American Economic Review*, 96(5): 1737-1768.

[10] Crawford, Vincent. 2008. “Look-ups as the Windows of the Strategic Soul: Studying Cognition via Information Search in Game Experiments.” In *The Foundations of Positive and Normative Economics*, ed. Andrew Caplin and Andrew Schotter. New York: Oxford University Press.

[11] Dawes, Robin. 1990. “The potential non-falsity of the false consensus effect.” In *Insights in decision making: A tribute to Hillel T. Einhorn, ed.* Hillel and Robin Hogarth. Chicago: University of Chicago Press.

[12] Dickinson, David, and Todd McElroy. 2010. “Rationality around the clock - sleep and time-of-day effects on guessing game responses.” *Economic Letters,* 09-03, Vol. 108, p. 245-248.

[13] Goeree, Jacob, and Charles Holt. 2004. “A Model of Noisy Introspection.” *Games and Economic Behavior*, 46(2): 365-382.

[14] Grosskopf, Brit and Rosemarie Nagel. 2008. “The Two-Person Beauty Contest,” *Games and Economic Behavior*, 62 (2008) 93-99.

[15] Ho, Teck-Hua, Camerer, Colin, and Keith Weigelt. 1998. "Iterated Dominance and Iterated Best-response in p-Beauty Contests." *The American Economic Review*, 88: 947-969.

[16] Kocher, Martin, and Matthias Sutter. 2006. "Time is money - Time pressure, incentives, and the quality of decision-making." *Journal of Economic Behavior and Organization*, 61(3): 375-392.

[17] Rubinstein, Ariel. 2007. "Instinctive and Cognitive Reasoning: A Study of Response Times." *Economic Journal*, 117: 1243-1259.

[18] Sbriglia, Patrizia. 2008. "Revealing the depth of reasoning in p-beauty contest games." *Experimental Economics,* Vol. 11, p. 107-121.

[19] Weber, Roberto. 2003. "Learning with no feedback in a competitive guessing game." *Games and Economic Behavior*, 44(1): 134-144.