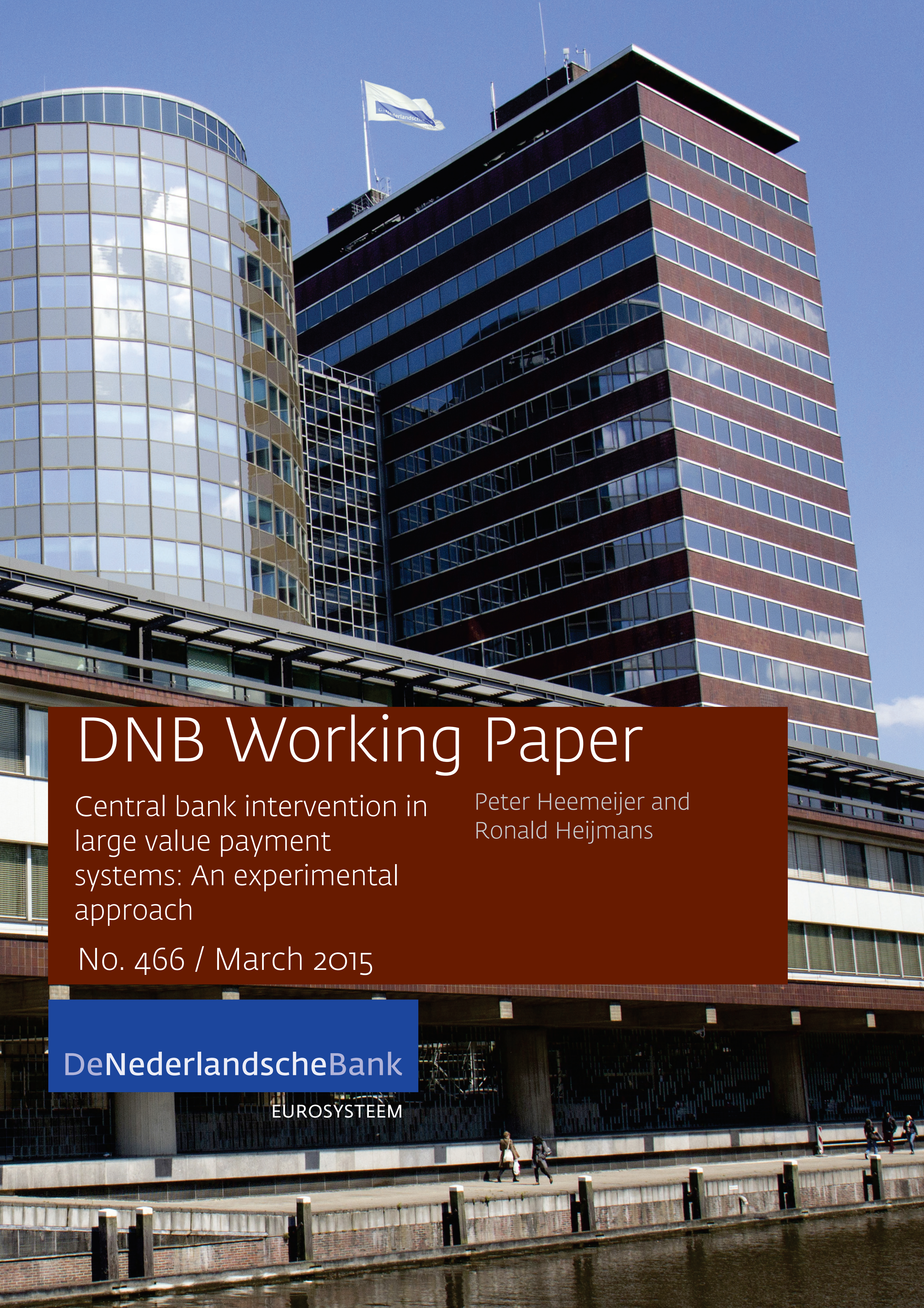

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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Central bank intervention in large value payment systems: An experimental approach *

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Abstract

This experimental study investigates the behavior of banks in a large value payment system. More specifically, we look at 1) the reactions of banks to disruptions in the payment system and 2) the way banks behavior changes to incentives of the central bank. The game used in this experiment is a stylized version of a model of Bech and Garratt (2006) in which each bank can choose between paying in the morning (efficient) or in the afternoon (inefficient) and builds on the game by Abbink et al. (2010). The results show that a positive (bail out) or negative (punishment) incentive steers payments to the inefficient or efficient equilibrium, respectively. In contrast to our expectation, providing detailed information on disruptions steers payments towards the inefficient equilibrium.

Keywords: payment systems, financial stability, experiment, decision making, central bank intervention.
JEL classifications: C92, D70, D78, E58.

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1 Introduction

Payment systems play a crucial role in the economy, as they facilitate in the settlement of financial obligations of two or more economic actors. Most payment obligations and in particular the very large payments are settled in these systems. Therefore, these systems have to live up to high standards (CPSS, 2012). During the crisis, payment systems have functioned well in a technical sense , meaning that there have not been serious disruptions. The most well known example of a wide scale disruption happened after the terrorist attacks on the World Trade Center in 2001. The damage to property and communication systems made it difficult or even impossible for some banks to execute their payments. The impact of the disruption was not limited to the banks that were directly affected. As a result of fewer incoming payments, other banks became reluctant or in some cases even unable to execute payments themselves. The Federal reserve responded by providing liquidity through the discount window and open market operations.

The fact that banks can pay in time does not necessarily mean they do. Banks can use payment systems differently. In case banks start to delay payments, this can seriously hamper payment flows, and in extreme cases cause a grid lock in which every participant in the payment system waits for other participants to make the first payment. As behavior of banks in a payment system can have serious effects on the liquidity provision between banks, it is important that they behave 'appropriately' in these systems. A central bank needs to know how to incentivize this appropriate behavior. Having the right incentives built into payment systems may help to let banks behave in a way that is best suitable for an efficient functioning payment system. Besides technical problems at these systems there are two reasons why banks do not pay in time: 1) An individual bank may have technical problems in its internal system, which makes it unable to execute payments. 2) A bank delays its payments intentionally. A relevant aspect to intentional delay is that it is usually not known for sure whether a bank delays intentionally. Just the fact that it pays later on the day does not mean it delays, as we do not know when the payment obligation was due.[1] Massarenti et al. (2012) study the timing of TARGET2 payments. They find that in the last hour of the day the system is open, most value is transferred. This means that a disruption in this last hour can have serious effects for two reasons: 1) As the value is large, a disruption can seriously harm liquidity flows. 2) As it is the last hour of the

[1] Diehl (2013) looks at measures to identify free riding behavior (or in other words delay) of banks in the German part of the European large value payment system.

day there is little time to solve the disruption and fulfil payment obligations.[2] Heijmans and Heuver (2011) look at early warning indicators in a Large Value Payment System(LVPS). They also find that the timing of payments is a crucial indicator for stress.

Timely execution of payments by participants results in reusability of liquidity. The liquidity received from a counterparty can be used to make one's own payments. In particular, in LVPSs like TARGET2, which settles each payment immediately (in real time) and individually (gross), are liquidity demanding.[3] For central banks it is therefore important that such systems have the right incentives (following from the set up of the payment system) and transparency, or at least no disincentives to pay timely (early). Bech et al. (2012) show that the monetary policy by the Federal Reserve, during the crisis, had the unintended side effect that banks start paying earlier as there was more (cheap) liquidity available by banks in the American LVPS, Fedwire.[4]

Our study is closely related to the experimental literature on coordination games, see also Abbink et al. (2010). Pure coordination games involve multiple equilibria with the same payoff consequences, provided all players choose the same action. The players' task is to take cues from the environment to identify focal points (Schelling, 1960; Mehta et al., 1994). More akin to our problem are studies on games with Pareto-ranked equilibria. In these games one equilibrium yields higher payoffs to all players than others, such that rational players should select it (Harsanyi and Selten, 1989). However, experimental subjects often coordinate on inferior equilibria. This happens in particular when the Pareto-dominant equilibrium is risky (Van Huyck et al., 1990, 1991) as is the case in our vehicle of research, or other equilibria are more salient (Abbink and Brandts, 2008). For an overview of coordination game experiments we refer to Devetag and Ortmann (2007). Besides Abbink et al. (2010) none of the existing studies tackle the problem of random disruptions.

Our research question is how behavior in a payment system that is affected by disruptions can be influenced by an authority. A disruption in our experiment is a situation in which one or more players are unable to execute their payments timely. The reason of such a disruption could be due to technical problems or (temporary) financial problems. The influence of the authority can be a negative or

[2] There is the option to postpone the closing time of the system as long as required. However, it is not likely that the closing of the system will be postponed because of a technical problem of one or a few participants.

[3] TARGET2 stands for Trans European Real Time Gross Settlement Express Transfer. TARGET2 is the real-time gross settlement (RTGS) system owned and operated by the Eurosystem.

[4] A real-time gross settlement system (RTGS) of central bank money used in the United States by its Federal Reserve Banks to settle final payments in U.S. dollars electronically between its member institutions. Owned and operated by the 12 Federal Reserve Banks, the Fedwire is a networked system for payment processing between the member banks themselves, or other Fedwire member participants.

positive incentive in case all players choose the undesired option (i.e. delaying payments) or providing information on the disruption. The players are all equal in size, i.e. the impact of any player's choices has a constant impact on any other player. The setup of our game is similar to the homogeneous market case of Abbink et al. (2010). They also investigate the situation in which not all market participants are equal in size (which they call a heterogeneous market). Our paper builds on this paper by looking at elements that (may) steer the outcome of the game other than the disruption probability.

The outline of this chapter is as follows. Section 2 describes the experimental design (including the game-theoretical model) and the procedures used. Section 3 discusses the results, while section 4 provides an analysis to explain the observed experimental data. Section 5 provides a conclusion.

2 Experimental design and procedures

2.1 Design

Our design is based on a model by Bech and Garratt (2006), which is an n-player liquidity management game similar to the setup of Abbink et al. (2010). The game envisions an economy with n identical banks, which use a Real-Time Gross Settlement System operated by the central bank to settle payments and securities. Banks intend to minimize settlement cost. In this game the business day consists of two periods in which banks can make payments: morning and afternoon. At the beginning of the day banks have a zero balance on their accounts at the central bank. At the start of each business day each bank has a request from customers to pay a customer of each of the other (n-1) banks an amount of Q as soon as possible. To simplify the model, the bank either processes all n-1 payments in the morning or in the afternoon. In case a bank does not have sufficient funds to execute a payment it can obtain intraday credit, which is costly and reflected by a fee F. This fee can be avoided by banks by delaying their payments to the afternoon. With this delay, however, there are some social and private costs involved, indicated by D. For example, a delay may displease customers or counterparties, which includes costs in terms of potential claims and reputation risk. Also, in case of operational disruptions, payments might not be settled by the end of the business days. This disruption can either be a failure at the payment system to operate appropriately or a failure at the bank itself. The costs in this case can, for example, be claims as a result of unsettled obligations or loss of reputation. The trade-off between the cost F in case of paying in the morning and cost D of paying in the afternoon is made by each bank individually. Bech and Garratt (2006) investigate the strategic adjustment banks make in response to temporary disruptions. In particular, they focus on equilibrium selection after the disruption is over.

In line with the experiment of Abbink et al. (2010) we use a simple version of the theoretical model by Bech and Garratt (2006). Because $F \geq D$ there are two equilibria in pure strategies, assuming each bank maximizes its own earnings. Either all banks pay in the morning or all banks pay in the afternoon. The morning equilibrium is the efficient equilibrium.[5] In each of the several rounds of the experiment the banks have to make a choice between paying in the morning (labeled choice X) and the afternoon (labelled choice Y). In each round, furthermore, there is a probability of 25% that a bank is forced to pay in the afternoon. This means that the bank cannot pay in the morning, but is forced to delay payment to the afternoon. Before a bank knows it is forced to choose Y, it has to make a choice first (either X or Y). In Abbink et al. (2010) banks knew directly that they are forced. Letting the participants choose first, allows for analyzing the free choice of each participant given the outcome of the previous rounds. The other banks observe that there was a delay at this bank and depending on the treatment they do or do not know whether it was caused by a disruption (a forced Y) or a deliberate decision.

The ability of an authority, like a central bank, to steer the outcome of the experiment is the core parameter of the experiment. We have implemented the central bank in three different ways:

- It can give a positive incentive by rewarding the participants if they all choose Y. This could be seen as a bail out.
- It can give a negative incentive by punishing the participants if they all choose Y.
- It can provide information to all participants about the disruptions (forced Y) of all participants.

Table 1 provides an overview of the different treatments investigated in the experiment. Instructions are presented in Appendix A. After each round, all banks see the choices of the other banks. In treatments 1, 2 and 3 it is not known by the other banks whether a bank was forced to pay in the afternoon or chose to do so intentionally. In case all participants in treatment 2 and 3 choose Y, or were forced to, a message was shown: ”All participants choose Y. Therefore the pay off is not 2 but 3 in the bail out and 1 in the punishment treatment). The experiment consists of 52 rounds. The forced

[5] See proposition 1 of Bech and Garratt (2006).

Table 1: Overview of experimental treatments.

Treatment name	Disruption probability	Y forced known to others	Number of groups
Baseline	25	No	15
Bail out	25	No	14
Punishment	25	No	17
Information	25	Yes	15

Table 2: pay-off structure of the experimental treatments.

Number of other players choosing X	Number of other players choosing Y	Your earnings from choosing X	Your earnings from choosing Y
Baseline			
4	0	5	2
3	1	3	2
2	2	1	2
1	3	-1	2
0	4	-3	2
Bail out			
4	0	5	2
3	1	3	2
2	2	1	2
1	3	-1	2
0	4	-3	3
Punishment			
4	0	5	2
3	1	3	2
2	2	1	2
1	3	-1	2
0	4	-3	1
Information			
4	0	5	2
3	1	3	2
2	2	1	2
1	3	-1	2
0	4	-3	2

Y's are predefined and pseudo−random with a probability of 25%. Each participant faces the same amount of forced Y's.

Table 2 shows the earnings of the four different treatments of Table 1, where X stands for paying in the morning and Y for paying in the afternoon. Earnings are determined by a maximum payoff of 5, while F = 2 and D = 3/4.[6]

2.2 Procedures

The experiment was run with undergraduate students of the University of Amsterdam using the CREED laboratory. Upon arrival, participants were randomly seated in the laboratory. Subsequently, the instructions for the experiment were given. Students could only participate in the experiment once.

The computerized experiment was set up in an abstract way, avoiding suggestive terms like banks. Choices were simply labeled X and Y. Forced choices were indicated by Y_f on the computer screen of participants. Participants were randomly divided in groups whose composition did not change during the experiment. Participants were labeled A1 to A5. All payoffs were in experimental Talers, which at the end of the experiment were converted into euros at a fixed exchange rate known to the participants. Each experiment took approximately 1 hour and the average earnings were EUR 22.97 including a show-up fee of EUR 5. In total, 305 students participated in the experiment.

3 Results

This section describes the results of the four experimental treatments of Table 1. We look at choice frequencies and a measure to capture the degree of coordination, which we call 'full coordination'. Full coordination is the situation where all participants make the same choice (either X or Y). Section 3.1 and section 3.2 describe the choice frequencies and the full coordination of the treatments, respectively. Section 3.3 gives insight in the reaction patterns of participants given the outcome of the previous round.

3.1 Choice frequency

We take a first look at the data by looking at the choice frequencies of the four different treatments, as Figure 1 depicts. The choices in the figure are represented, from top to bottom, by four options: the participant can 'choose' 1) Y initially but is not forced to choose Y (Y), 2) Y initially and is also forced to choose Y (Y_{Yf}), 3) X initially but is forced to choose Y (X_{Yf}) and 4) X initially and is not

[6] Earnings in case of paying in the afternoon equal: $-(n-1) \cdot D + 5$, with n being the total number of banks. Earnings if the bank instead chooses paying in the morning equal: $-(n-1-\mid Si \mid m) \cdot F + 5$, where $\mid Si \mid m$ denotes the number of other banks paying in the morning.

forced to choose Y (X). This representation allows for analyzing both the actual or initial responses (called X_{ini} or Y_{ini}) of participants and the final outcome (including disruption) in previous rounds (called X_{fin} or Y_{fin}).[7]

Table 3 and Figure 1 show that for the Baseline treatment (graph at the top left) the participants choose X_{ini} 55% of the time. This choice stays constant over the whole experiment (no significant difference between the first and second 26 rounds). Due to the disruption probability of 25%, X_{fin} is 42%. The Bailout treatment (graph at the top right of Figure 1) shows that the participants choosing X_{ini} compared to the Baseline drops to 16%. A drop is not surprising as it becomes more profitable for banks if they all coordinate on Y. The punishment treatment (graph at the bottom left of Figure 1) on the other hand shows an increase of the X_{ini} to on average 58%. An increase was expected as it becomes less profitable for banks to all choose Y. Although the average X_{ini} of the Punishment treatment is above the baseline, there are clear differences between rounds. In contrast to the Baseline treatment, the Punishment treatment shows a significant increase between the first and second 26 rounds from 46% to 70% respectively ($p < 0.01$, binomial test. The first half is lower and the second half has a higher choice frequency than the Baseline treatment. This could be seen as a learning effect. This suggests that the participants realize that if they coordinate on Y, this is less profitable for everyone. In other words, the results suggests that it is possible to steer the equilibrium by setting a negative incentive (punishment) for collective undesired behavior (coordinating on Y).

The Information treatment (graph at the bottom right of Figure 1) shows, in contrast to our expectation, that participants choose X_{ini} less often than the Baseline (28% vs 54%). This may be explained as follows. In contrast to the other treatments participants are now aware of the deliberate or disrupted Y. If they see a deliberate Y among forced Y's they are more in favor of choosing Y as well in the next round, while in the Baseline treatment they still may expect that some of the intentional Y's are forced and therefore more in favor of choosing X in the next round. The question is, however, whether this principle is also true if disruptions only occur occasionally, as is the case for LVPSs. In LVPSs participants might be reluctant to believe it was a disruption, unlike the experiment.

[7] Final outcome is defined by: $Y_{fin} = X_{Yf} + Y_{Yf} + Y$ and $X_{fin} = X$, initial choice is defined by $Y_{ini} = Y + Y_{Yf}$ and $X_{ini} = X + X_{Yf}$.

Figure 1: Frequency plots for choosing x or y for the four treatments.

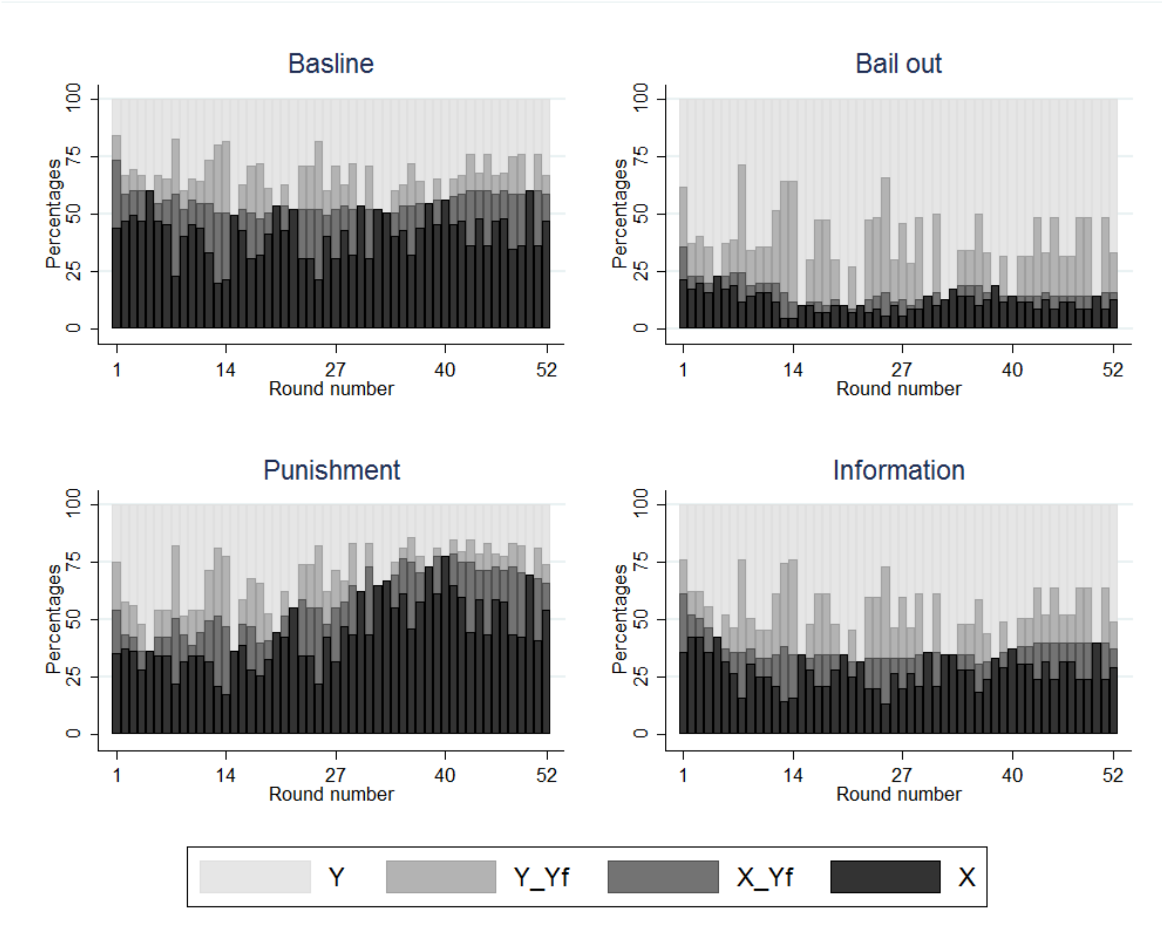


Table 3: Average choices of X per treatment.

Treatment	X_{ini} round 1-26	X_{ini} round 27 - 52	X_{ini} all rounds	X_{fin} round 1-26	X_{fin} round 27 - 52	X_{fin} all rounds
Baseline	54%	56%	55%	40%	43%	42%
Bail out	17%	15%	16%	12%	12%	12%
Punishment	46%	70%	58%	34%	55%	45%
information	38%	37%	38%	27%	28%	28%

3.2 Frequencies of full coordination

Figure 2 depicts frequencies of full coordination on either X or Y. Full coordination means that all participants in a group either choose X_{ini} or Y_{ini} (the choice of the participants before the disruption). A general observation on the coordination of the four different treatments is that each treatment moves to (almost) 100% coordination either on X or Y. An individual group moves in most cases to full coordination on either X or Y. For the Baseline treatment, Bailout and Information treatments this coordination starts in the first half of the experiment while for the Punishment treatment this only seems to begin at the latest rounds of the experiment. Besides, in this treatment it is not as persistent as for the other treatments.

The Baseline treatment (graph at the top left of Figure 2) shows that coordination on X increases from roughly 25% to 50%. The coordination on either X or Y increases in the first 20 rounds to (almost) 100% and remains close to 100% coordination.

The Bailout treatment (graph at the top right of Figure 2) on the other hand, shows only little coordination on X. The positive incentive if everyone chooses Y steers choices to the inefficient equilibrium.

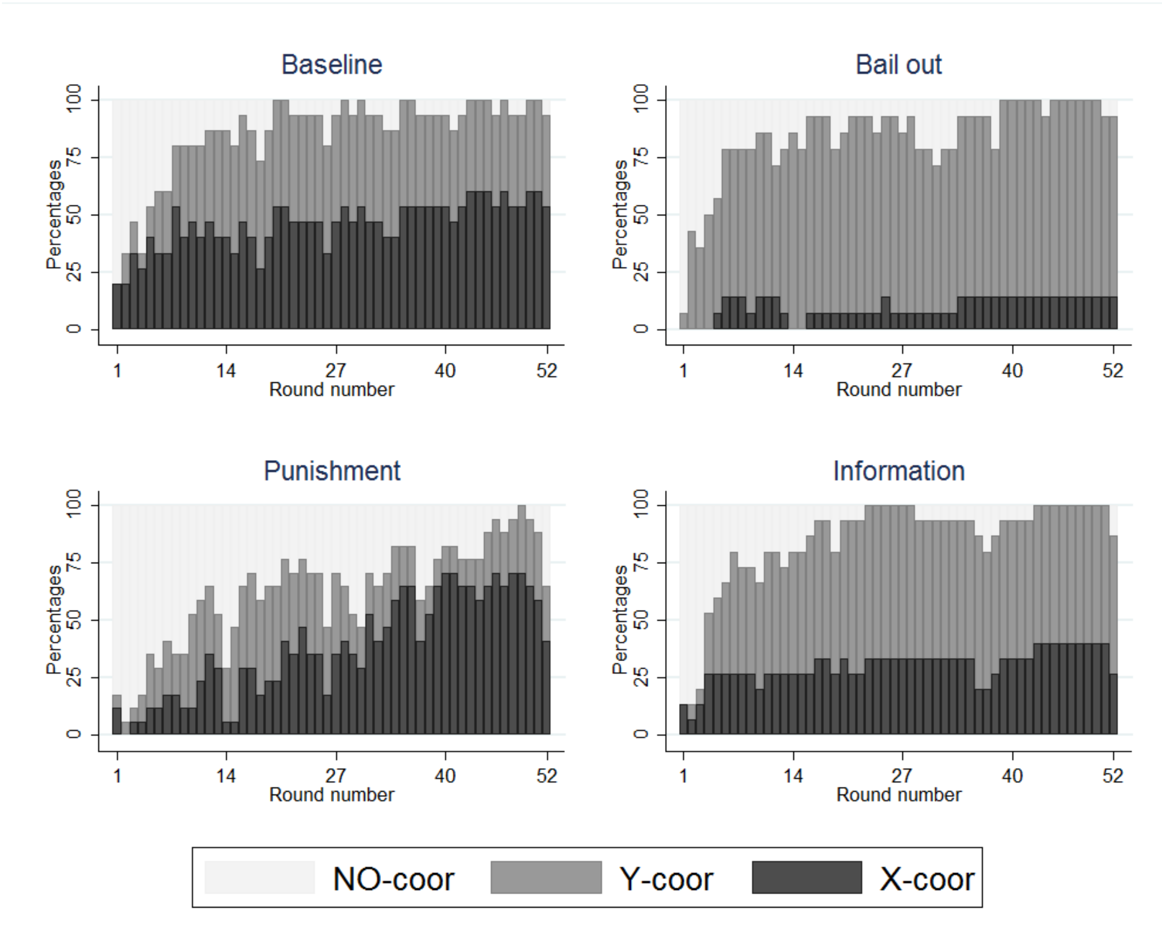
The Punishment treatment (graph at the bottom left of Figure 2) clearly shows an increasing trend of coordination on X, which is in line with the increase in choice frequency of X (see graph on the bottom left of Figure 1). This again suggests that steering the equilibrium in the payment system is possible by having a negative incentive (lower reward) for collective undesired behaviour. The trend of moving to 100% is much slower than for the other treatments, to finally reach (almost) 100% coordination.

The Information treatment (graph at the bottom right of Figure 2) shows less coordination on X but similar trends in moving to 100% coordination on either X or Y than the Baseline treatment.

3.3 Reaction patterns

The graph at the top of Figure 3 shows the average number of participants choosing X in round n given the number of participants that choose X and were able to choose X in round n − 1. The choice of a participant who was forced to choose Y is set to Y, no matter the actual choice. This graph shows that if 4 or 5 out of the 5 participant have chosen X and are not forced to choose Y in the previous round (round n-1), (almost) 5 out of 5 will choose X in the current round (round n) in each of the four treatments. In case 3 our of 5 participants have chosen X and are not forced to choose Y in the previous round, 4.5 participants on average will choose X in the current round. The differences between the four treatments are small. The largest difference between the four treatments occurs when 2 out of 5 participants choose X in the previous round. In the current round 4, 3, 3 and 3.5 participants will choose X for treatment 1, 2, 3 and 4 respectively. In the situation that all participants have chosen

Figure 2: Frequency plots of full coordination for coordination on x or y (before disruptions) for the four treatments.

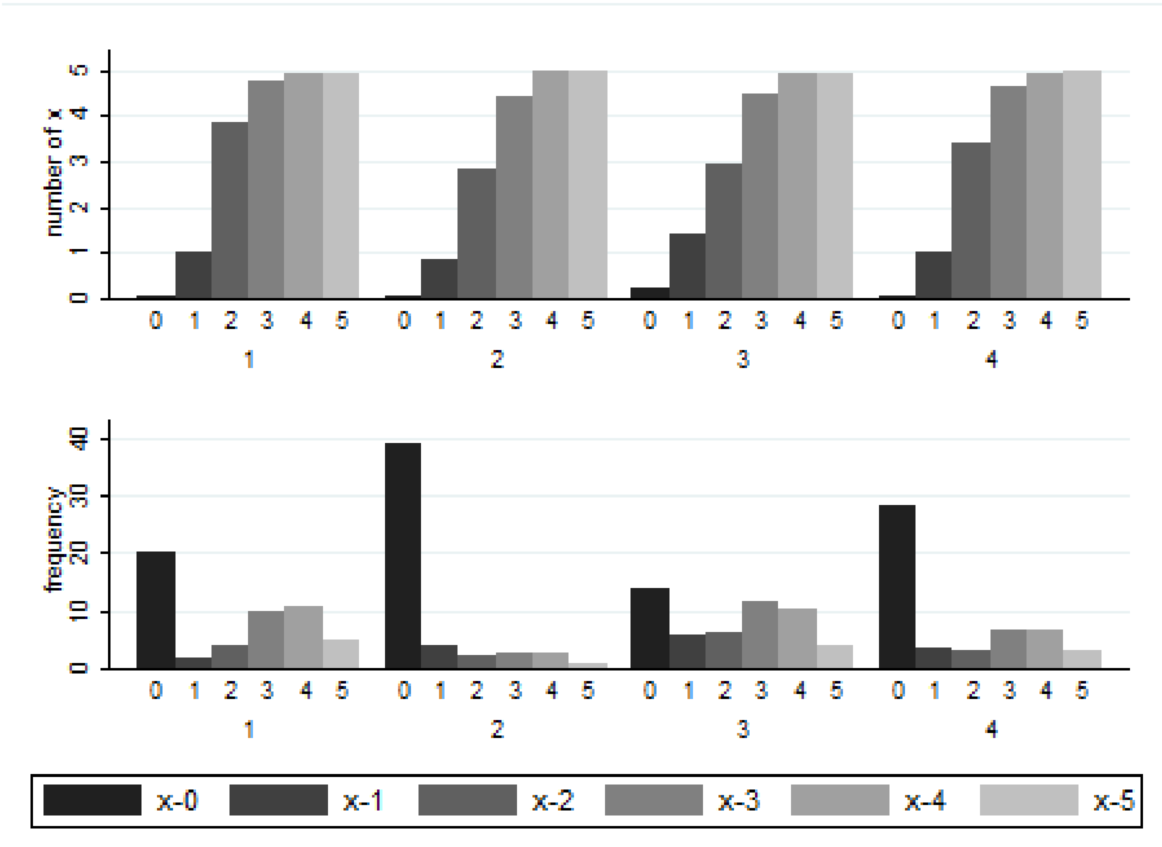


Y (or were forced to) participants will keep on choosing Y in the next round. This means that once the participants coordinate on Y it is not likely that they will move away from that equilibrium.

The graph at the bottom of Figure 3 presents the number of times a round consisted of on average 0, 1, 2, 3, 4 or 5 times X. In other words, this graphs shows the likelihood of the combination of the X and Y choices per round in the different treatments. The outcome is in line with the choice frequencies presented by Figure 1. The Baseline treatment shows that all participants in the group choose Y in 20 out of the 52 rounds. In the Bailout treatment this is almost 40 out of 52 rounds (or close to 75%), in the Punishment treatment this is 13 out of 52 and in the Information treatment this is almost 30 out of 52.

Combining the information of the two graphs of Figure 3, we can learn that a group that coordinates on the inefficient equilibrium (all Y) will not move back easily to the desired equilibrium, which is in

Figure 3: The average number of participants choosing 'x' in round 'n' if in round 'n-1' the outcome was 0, 1, 3, 4 or 5 times 'x' (top panel). The number of times the situation occurred that the number of x choice were 0, 1, 2, 3, 4 and 5 for each of the four treatments (bottom panel).



line with the findings of Abbink et al. (2010). This is equal for all treatments. But the likelihood of reaching the inefficient equilibrium varies strongly between the different treatments. In other words, we might not be able to move them away from the inefficient equilibrium with the incentives, but we can partly prevent the participants from reaching this equilibrium.

4 Dynamics

The results show that positive (bail out treatment) steers the equilibrium more to the undesired (Y) equilibrium. The negative incentive (punishment treatment) steers it more to the desired (X) one. The Information treatment unexpectedly leads to more coordination on the undesired equilibrium. This section studies some possible simple dynamics. First, we start with a behavioral rule which has limited rationality, section 4.1. Section 4.2 to section 4.4 show more advanced heuristics.

4.1 Stick to your choice

The first "heuristic" we look at, is a relatively simple one. Each player makes the same choice as in the last round or in other words sticks to his previous choice. With a probability β the player experiments and chooses the other option. The "stick to your choice" heuristic only contains very limited rationality, and is slightly more advanced than random choices.

In sum, the behavior of the players can be summarized as follows:

1. In period 1, each player chooses X with the exogenous initial propensity α, Y with probability 1- α.

2. In every following period t:

   A. Each player chooses the option that has been most successful in period t-1 with probability β.

   B. With probability 1-β, the player chooses the other option.

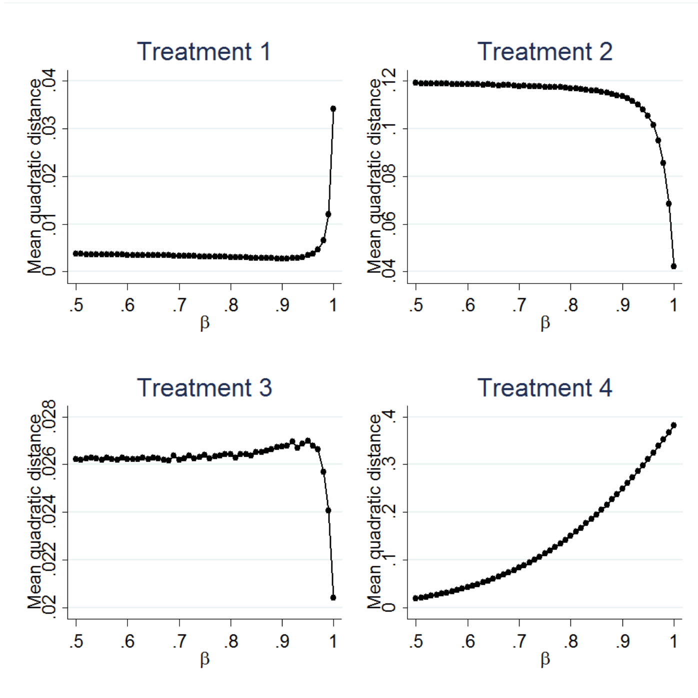
The basic principle of this behavior is valid for all heuristics mentioned in this section.

In contrast to Abbink et al. (2010) we do not show the result for just a few β's. Figure 5a shows for β value ranging from 0.5 and 1 the quadratic difference between the imitation heuristic and the actual outcome of the experiment for each of the four treatments. We intentionally start from 0.5 instead of 0, because values lower than 0.5 suggest that players experiment more often than they follow the rule, which we do not deem plausible.

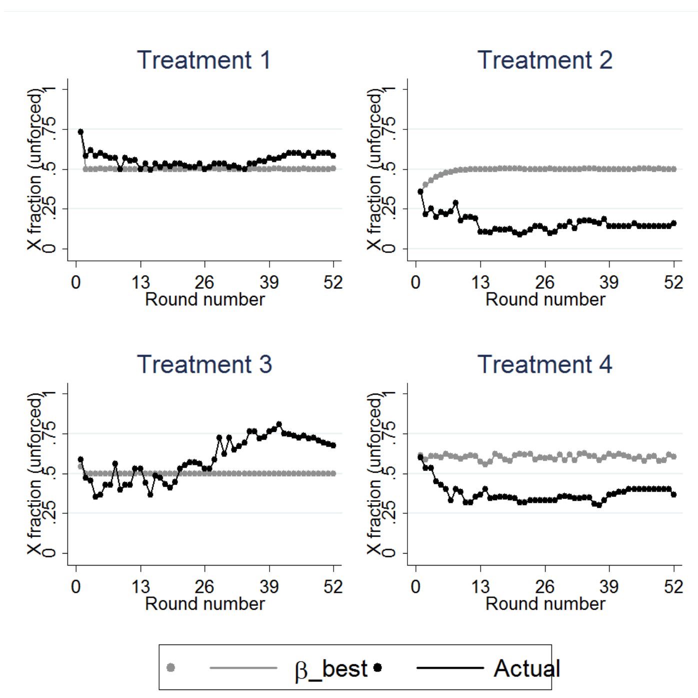
Figure 4a shows the results for the "Stick to choice" heuristic. The β values for treatment 1 and 4 are 0.89 and 0.61, respectively. The β values for treatment 2 and 3 are both 1. This means that the players in these two treatment always follow the heuristic and never experiment. Figure 4b shows for the best plausible β of Figure 4a the fraction of X according to the "Stick to your choice" heuristic and the actual experiment. The heuristic follows the actual experiment quite well for Treatment 1. For Treatment 2 and 4 heuristic overestimates the choices of X. For treatment 3 the heuristic slightly overestimates in the first half of the experiment, while it underestimates in the in the second half. We can conclude that this heuristic only gives reliable results for Treatment 1.

Figure 4: Results for "Stick to choice" heuristic.

(a) Sum of squares.



(b) Fraction.



4.2 Imitation

Imitation can be seen as simple heuristic. It ignores higher level strategic behavior. It was successful in explaining the observed behavior in Crawford (1995) and Abbink and Brandts (2008). A player following this strategy simply compares the payoffs all players gained in the previous period and copies the behavior of whoever was most successful.

We now study the predictions of a dynamic model based on the imitation heuristic. The players in such a model follow primarily the pattern of imitation. However, the model has to be complemented with some experimentation. Otherwise the game would be locked after the second round and nothing would change anymore. In other words, with some probability β the player will follow the imitation pattern and with 1- β it will choose randomly one of the other strategies. As we only have one other strategy it will choose the opposite strategy.

The best plausible β value for treatment 1 and 3 is 0.5. This means that in 50% of the cases the player chooses to follow the rule and in 50% it experiment. The β values for treatment 2 and 4 are 0.85 and 0.64, respectively.

Figure 5b shows for the best plausible β from Figure 5a the fraction of X according to the actual experiment and the imitation heuristics with this β. Optically, we can see that the heuristic follows the actual experiment quite closely for treatment 1, 2 and 4 quite closely. However, for treatment 3 it does not. This suggest that for treatment 3 there is no good plausible β for the imitation heuristic that follows the actual outcome of the experiment. The closer the mean quadratic distance is to zero, the better the heuristics fits the real experiment. The mean quadratic distance is however not constant over the whole experiment. This means that the heuristic model does not fit the outcome of the experiment as well for each round. This is especially clear for treatment 3 where the deviation varies substantially.

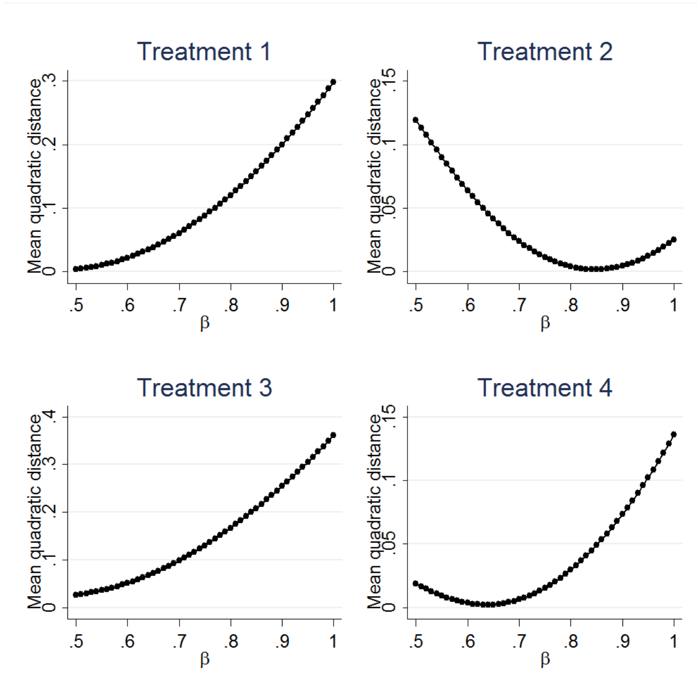
4.3 Myopic best response

The second simple heuristic we study is the myopic best response and is similar to imitation. However, myopic best response follows a very different reasoning than imitation, since it compares hypothetical instead of observed choices. A player looks at all other players' choices in the preceding round and chooses the option that would have been optimal in the light of this combination of choices. Again, an experimentation parameter ensures that behavior does not get locked in a pattern after the first round.

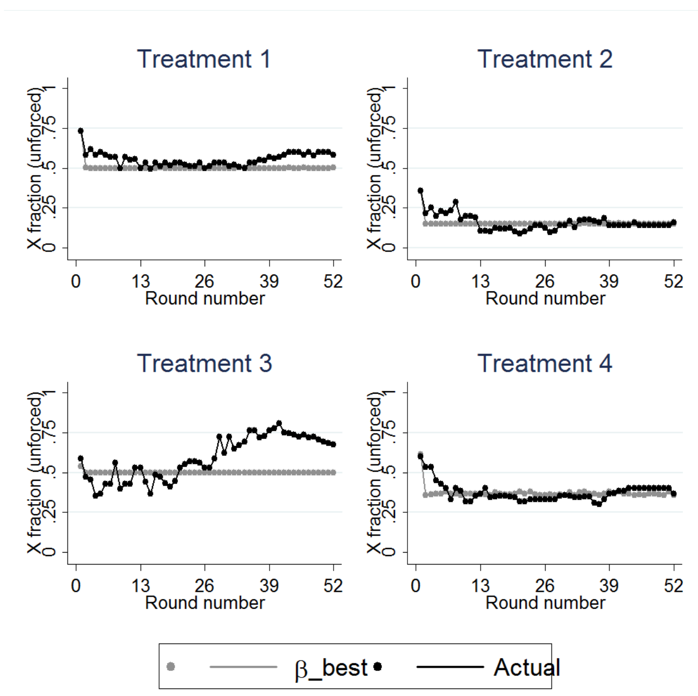
Figure 6a shows for β value ranging from 0.5 and 1 the quadratic difference between the myopic best

Figure 5: Results for Imitation heuristic.

(a) Sum of squares.



(b) Fraction.



response heuristic and the actual outcome of the experiment for each of the four treatments. The best plausible β values for treatment 1, 2, 3 and 4 are 0.66, 0.99, 0.76 and 0.50 respectively. The closer the mean quadratic distance is to zero, the better the heuristics fits the real experiment.

Figure 6b shows for the best plausible β from Figure 6a the fraction of X according to the actual experiment and the imitation heuristics with this β. The best fit of this heuristic is for treatment 1 as the two lines follow each other quite closely. For treatment 2 and 3 the lines do not follow each other closely and fluctuate over the course of the experiment. This suggest that this heuristic is not such a good predictor. For the fourth treatment the best β overestimates the actual values for almost all rounds.

4.4 Choose X when profitable best response

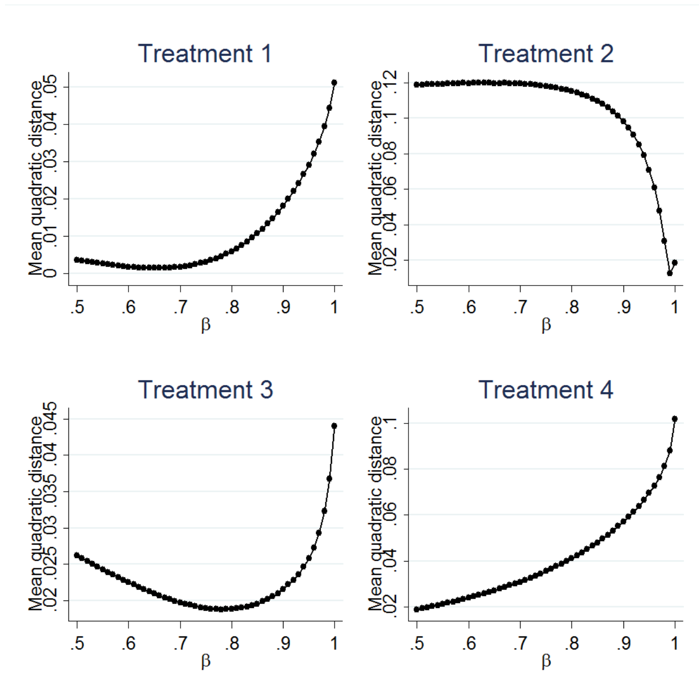
In line with Abbink et al. (2010) we also look at the heuristic choose X when profitable. The failure of the previous models to predict our data can be ascribed to their high sensitivity to Y choices observed. As soon as players observe more than one Y, they switch to the inefficient equilibrium and are unlikely to get out of it again. It is noteworthy that with two Y choices, those who chose X still made a positive profit of 1, though it is no longer the best response to choose X.

Figure 7a shows for β value ranging from 0.5 and 1 the quadratic difference between the choose X when profitable heuristic and the actual outcome of the experiment for each of the four treatments. The best plausible β values for treatment 1, 2, 3 and 4 are 0.57, 0.50, 0.62 and 0.50 respectively. The closer the mean quadratic distance is to zero, the better the heuristics fits the real experiment. Figure 7b

Figure 7b shows for the best plausible β from Figure 7a the fraction of X according to the actual experiment and the “choose X when profitable” heuristics with this β.

Figure 6: Results for Myopic best response heuristic.

(a) Sum of squares.



(b) Fraction.

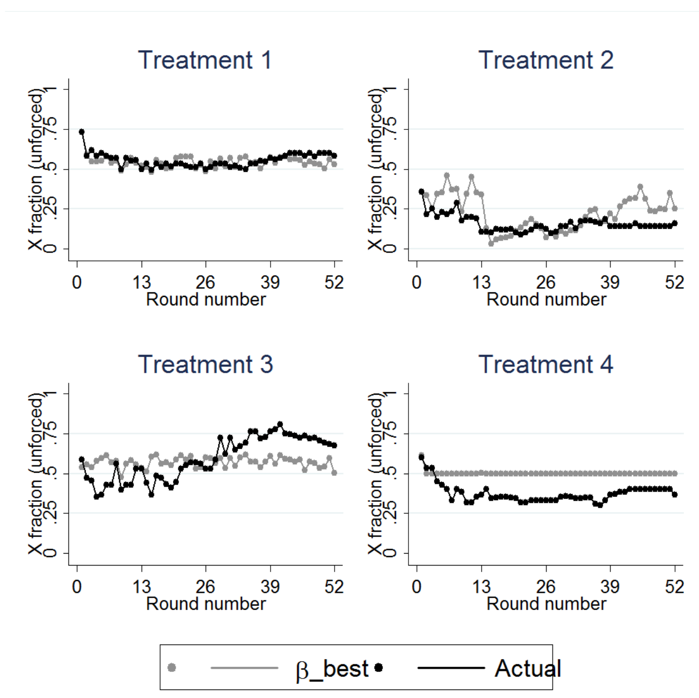
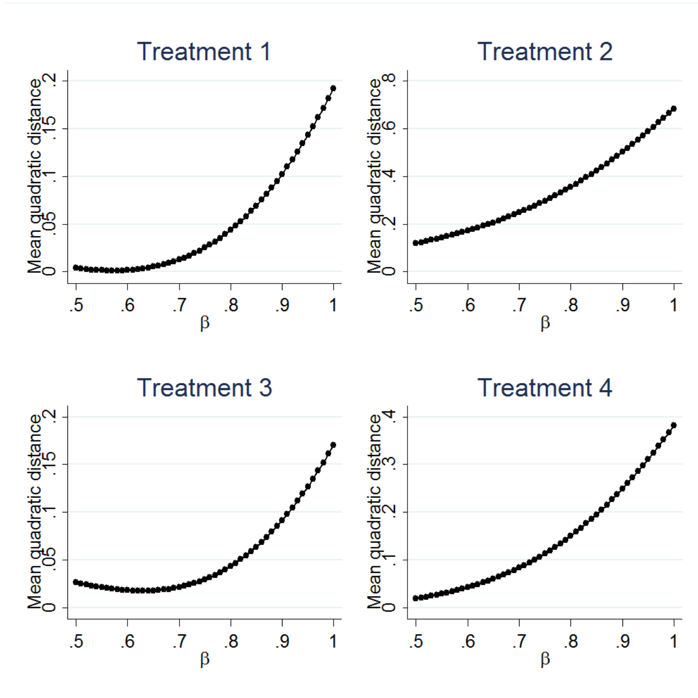
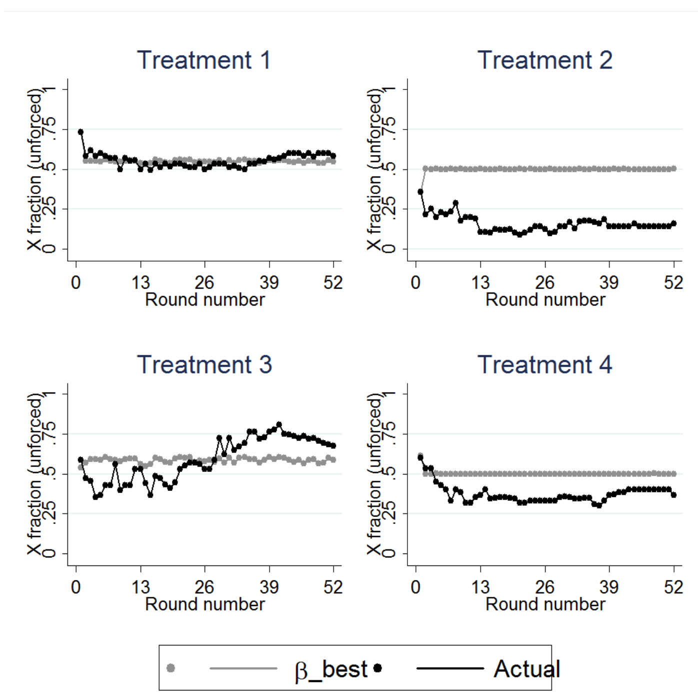


Figure 7: Results for Choose X when profitable heuristic.

(a) Sum of squares.



(b) Fraction.



5 Conclusions

In this paper we used a stylized coordination game of Bech and Garratt (2006) to experimentally study bank behavior in a large value payment system that is hindered by disruptions. The game builds on the one executed by Abbink et al. (2010). We draw the following conclusions.

First, once behavior moves in the direction of coordination on the inefficient equilibrium, it is not likely that behavior moves back to the efficient equilibrium. This is in line with the outcome of Abbink et al. (2010). The reason for this is that one player has to take the lead in going for the efficient equilibrium, but this is costly if other players do not follow.

Analysis of different types of heuristics shows that the best heuristic that fits our data best differs between the treatments. This means that there is no single heuristics that fits all treatments the best. For the Baseline treatment the “Stick to your choice” and “Choose X when profitable” heuristic fits the data best. The baseline treatment is similar to the homogeneous case of Abbink et al. (2010) (the disruption percentage is different, however). For the Bail out treatment Imitation heuristic performs best. The “choose X when profitable” heuristic performs the worst. For the Punishment treatment none of the heuristics performs well. For the Information treatment Imitation performs the best.

An intervention or action from the central bank has impact on the average choice of X. If participants know that they will be “punished” for collective undesired behavior (i.e. all participants choose Y) they will more likely choose X. A bail out on the other hand will make participants choose Y more often. The outcome of the Punishment and Bail out treatment is in line with the expectation. Surprising in the Punishment treatment is that the average X in the second half of the experiment is significantly larger than in the first half (46% vs 70%, respectively). However, as for the other treatments, as soon as all banks choose Y, the participants will keep on choosing Y. This suggest that a negative incentive for collective undesired behavior keeps participants from moving to the undesired equilibrium (i.e. all Y), but as soon as the undesired equilibrium has been reached they will stay there. In other words, an authority can build in incentives into their payment system to partly prevent participants collectively making undesired choices, but still needs an additional mechanism to move participants back to desired behavior as soon as all participants make the undesired choices simultaneously.

Providing information on the forced Y’s leads, in contrast to our expectation, to more coordination on the undesired equilibrium. This suggests that an authority has to be careful when or how providing information on (short) term disruptions as it may lead to an undesired effect.

A Instructions to the participants

A.1 Baseline treatment

1. **Introduction**

Welcome to the experiment. In the experiment you will make decisions. You can earn money by participating in the experiment. How much you earn depends on your own decisions and on the decisions of other participants in the experiment. At the end of the experiment, a show-up fee of 5 euros plus your total earnings during the experiment will be paid to you in cash. Payments are confidential: we will not inform participants of the earnings of other participants. In the experiment, all earnings will be expressed in Talers, which will be converted in euro's according to the exchange rate:

$$1 Taler = 16 eurocents.$$

In this experiment you can avoid making any loss (negative earnings). However, note that in case you end up with a loss, it will be charged against your show-up fee. At the end of the experiment, your cash reward is always either 0 or a positive amount of euro's. It is not possible that you end up with a negative cash reward.

It is not permitted to talk or communicate with others during the experiment. If you have a question, please raise your hand and we will come to your desk to answer it.

2. **Groups**

During the experiment you will participate in a group of 5 players. You will be matched with the same players throughout the experiment. In the experiment, you will be identified as "P1". The other players in your group will be labeled: "2", "P3", "P4", and "P5". You will not be informed of who the other players are, nor will they be informed of who you are.

3. **Rounds**

The experiment consists of 52 rounds. In each round you and the other 4 players in your group choose one of two options: X or Y.

4. **Earnings**

Number of other players choosing Y	Your earnings from choosing X	Your earnings from choosing Y
0	5	2
1	3	2
2	1	2
3	-1	2
4	-3	2

Your earnings in a round depend on your choice and on the choices of the other 4 players, in the following manner:

- If you choose Y, your earnings are 2 Talers regardless of the choices of the others;
- If you choose X, your earnings depend on how many of the other players choose Y.

Your exact earnings in Talers from choosing X or Y, for a given number of other players choosing Y, are listed in the previous table. This earnings table is the same for all players.
For example, if 2 other players choose Y, then your earnings from choosing X will be 1, while your earnings from choosing Y would be 2.

5. **Forced Y**

Note, however, that your preferred option may not be possible. In each round, each of you will face a chance of 25% that you are forced to choose option Y. We will call this a ”forced Y”. After you have made your preferred choice, you will see whether your option is possible or not.

Whether or not a player is forced to choose Y is randomly determined by the computer for each player separately and independently from the other players. Further, a forced Y does not depend on what happened in previous rounds.

On the computer screen where you make your decision you will be reminded of the chance of playing a forced Y, for your convenience. Furthermore, in the table at the bottom of that screen (showing past decisions and earnings) your forced Y’s are indicated in the column showing your choices with an “F”. Note that you will not be informed of other players’ forced Y choices.

6. **Exercises**

You are now kindly requested to do a few exercises on the computer to make yourself fully familiar with the earnings table. In these exercises you cannot earn any money. The exercises are not part of the 52 rounds of the experiment.

7. **Start of the experiment**

After the exercises, we will start with the experiment.

Please raise your hand if you have any question. We will then come over to your table to answer your question.

A.2 Bail out treatment

1. **Introduction**

Welcome to the experiment. In the experiment you will make decisions. You can earn money by participating in the experiment. How much you earn depends on your own decisions and on the decisions of other participants in the experiment. At the end of the experiment, a show-up fee of 5 euros plus your total earnings during the experiment will be paid to you in cash. Payments are confidential: we will not inform participants of the earnings of other participants. In the experiment, all earnings will be expressed in Talers, which will be converted in euro's according to the exchange rate:

$$1Taler = 16eurocents.$$

In this experiment you can avoid making any loss (negative earnings). However, note that in case you end up with a loss, it will be charged against your show-up fee. At the end of the experiment, your cash reward is always either 0 or a positive amount of euro's. It is not possible that you end up with a negative cash reward.

It is not permitted to talk or communicate with others during the experiment. If you have a question, please raise your hand and we will come to your desk to answer it.

2. **Groups**

During the experiment you will participate in a group of 5 players. You will be matched with the same players throughout the experiment. In the experiment, you will be identified as "P1". The other players in your group will be labeled: "2", "P3", "P4", and "P5". You will not be informed of who the other players are, nor will they be informed of who you are.

3. **Rounds**

The experiment consists of 52 rounds. In each round you and the other 4 players in your group choose one of two options: X or Y.

Number of other players choosing Y	Your earnings from choosing X	Your earnings from choosing Y
0	5	2
1	3	2
2	1	2
3	-1	2
4	-3	3

4. **Earning**

Your earnings in a round depend on your choice and on the choices of the other 4 players, in the following manner:

- If you choose Y, your earnings are 2 Talers regardless of the choices of the others;
- If you choose X, your earnings depend on how many of the other players choose Y.

Your exact earnings in Talers from choosing X or Y, for a given number of other players choosing Y, are listed in the following table. This earnings table is the same for all players.
For example, if 2 other players choose Y, then your earnings from choosing X will be 1, while your earnings from choosing Y would be 2.

5. **Forced Y**

Note, however, that your preferred option may not be possible. In each round, each of you will face a chance of 25% that you are forced to choose option Y. We will call this a ”forced Y”. After you have made your preferred choice, you will see whether your option is possible or not.

Whether or not a player is forced to choose Y is randomly determined by the computer for each player separately and independently from the other players. Further, a forced Y does not depend on what happened in previous rounds.

On the computer screen where you take your decision you will be reminded of the chance of playing a forced Y, for your convenience. Furthermore, in the table at the bottom of that screen (showing past decisions and earnings) your forced Y's are indicated in the column showing your choices with an "F". Note that you will not be informed of other players' forced Y choices.

6. **Intervention**

If, in a round of the experiment, all players choose Y or are forced to choose Y, there will be an intervention. In this round, all player's choices will be reset to X. According to the payoff table, your payoff in this round will be 3. The intervention lasts only one round, but could happen multiple times during the experiment.

7. **Exercises**

You are now kindly requested to do a few exercises on the computer to make you fully familiar with the earnings table. In these exercises you cannot earn any money. The exercises are not part of the 52 rounds of the experiment.

8. **Start of the experiment**

After the exercises, we will start with the experiment.

Please raise your hand if you have any question. We will then come over to your table to answer your question.

A.3 Punishment treatment

1. **Introduction**

Welcome to the experiment. In the experiment you will make decisions. You can earn money by participating in the experiment. How much you earn depends on your own decisions and on the decisions of other participants in the experiment. At the end of the experiment, a show-up fee of 5 euros plus your total earnings during the experiment will be paid to you in cash. Payments are confidential: we will not inform participants of the earnings of other participants. In the experiment, all earnings will be expressed in Talers, which will be converted in euro's according to the exchange rate:

$$1 Taler = 16 eurocents.$$

In this experiment you can avoid making any loss (negative earnings). However, note that in case you end up with a loss, it will be charged against your show-up fee. At the end of the experiment, your cash reward is always either 0 or a positive amount of euro's. It is not possible that you end up with a negative cash reward.

It is not permitted to talk or communicate with others during the experiment. If you have a question, please raise your hand and we will come to your desk to answer it.

2. **Groups**

Number of other players choosing Y	Your earnings from choosing X	Your earnings from choosing Y
0	5	2
1	3	2
2	1	2
3	-1	2
4	-3	1

During the experiment you will participate in a group of 5 players. You will be matched with the same players throughout the experiment. In the experiment, you will be identified as “P1”. The other players in your group will be labeled: “2”, “P3”, “P4”, and “P5”. You will not be informed of who the other players are, nor will they be informed of who you are.

3. **Rounds**

The experiment consists of 52 rounds. In each round you and the other 4 players in your group choose one of two options: X or Y.

4. **Earning**

Your earnings in a round depend on your choice and on the choices of the other 4 players, in the following manner:

- If you choose Y, your earnings are 2 Talers regardless of the choices of the others;
- If you choose X, your earnings depend on how many of the other players choose Y.

Your exact earnings in Talers from choosing X or Y, for a given number of other players choosing Y, are listed in the following table. This earnings table is the same for all players.
For example, if 2 other players choose Y, then your earnings from choosing X will be 1, while your earnings from choosing Y would be 2.

5. **Forced Y**

Note, however, that your preferred option may not be possible. In each round, each of you will face a chance of 25% that you are forced to choose option Y. We will call this a ”forced Y”. After you have made your preferred choice, you will see whether your option is possible or not.

Whether or not a player is forced to choose Y is randomly determined by the computer for each player separately and independently from the other players. Further, a forced Y does not depend on what happened in previous rounds.

On the computer screen where you take your decision you will be reminded of the chance of playing a forced Y, for your convenience. Furthermore, in the table at the bottom of that screen (showing past decisions and earnings) your forced Y's are indicated in the column showing your choices with an "F". Note that you will not be informed of other players' forced Y choices.

6. **Intervention**

If, in a round of the experiment, all players choose Y or are forced to choose Y, there will be an intervention. In this round, all player's choices will be reset to X. According to the payoff table, your payoff in this round will be 1. The intervention lasts only one round, but could happen multiple times during the experiment.

7. **Exercises**

You are now kindly requested to do a few exercises on the computer to make you fully familiar with the earnings table. In these exercises you cannot earn any money. The exercises are not part of the 52 rounds of the experiment.

8. **Start of the experiment**

After the exercises, we will start with the experiment.

Please raise your hand if you have any question. We will then come over to your table to answer your question.

A.4 Information treatment

1. **Introduction**

Welcome to the experiment. In the experiment you will make decisions. You can earn money by participating in the experiment. How much you earn depends on your own decisions and on the decisions of other participants in the experiment. At the end of the experiment, a show-up fee of 5 euros plus your total earnings during the experiment will be paid to you in cash. Payments are confidential: we will not inform participants of the earnings of other participants. In the experiment, all earnings will be expressed in Talers, which will be converted in euro's according to the exchange rate:

$$1 Taler = 16 eurocents.$$

Number of other players choosing Y	Your earnings from choosing X	Your earnings from choosing Y
0	5	2
1	3	2
2	1	2
3	-1	2
4	-3	2

In this experiment you can avoid making any loss (negative earnings). However, note that in case you end up with a loss, it will be charged against your show-up fee. At the end of the experiment, your cash reward is always either 0 or a positive amount of euro's. It is not possible that you end up with a negative cash reward.

It is not permitted to talk or communicate with others during the experiment. If you have a question, please raise your hand and we will come to your desk to answer it.

2. **Groups**

During the experiment you will participate in a group of 5 players. You will be matched with the same players throughout the experiment. In the experiment, you will be identified as "P1". The other players in your group will be labeled: "2", "P3", "P4", and "P5". You will not be informed of who the other players are, nor will they be informed of who you are.

3. **Rounds**

The experiment consists of 52 rounds. In each round you and the other 4 players in your group choose one of two options: X or Y.

4. **Earning**

Your earnings in a round depend on your choice and on the choices of the other 4 players, in the following manner:

- If you choose Y, your earnings are 2 Talers regardless of the choices of the others;
- If you choose X, your earnings depend on how many of the other players choose Y.

Your exact earnings in Talers from choosing X or Y, for a given number of other players choosing Y, are listed in the following table. This earnings table is the same for all players.

For example, if 2 other players choose Y, then your earnings from choosing X will be 1, while your earnings from choosing Y would be 2.

5. **Forced Y**

Note, however, that your preferred option may not be possible. In each round, each of you will face a chance of 25% that you are forced to choose option Y. We will call this a ”forced Y”. After you have made your preferred choice, you will see whether your option is possible or not.

Whether or not a player is forced to choose Y is randomly determined by the computer for each player separately and independently from the other players. Further, a forced Y does not depend on what happened in previous rounds.

On the computer screen where you take your decision you will be reminded of the chance of playing a forced Y, for your convenience. Furthermore, in the table at the bottom of that screen (showing past decisions and earnings) your forced Y's are indicated in the column showing your choices with an ”F”. In the same way, you will be informed of other players' forced Y choices.

6. **Exercises**

You are now kindly requested to do a few exercises on the computer to make you fully familiar with the earnings table. In these exercises you cannot earn any money. The exercises are not part of the 52 rounds of the experiment.

7. **Start of the experiment**

After the exercises, we will start with the experiment.

Please raise your hand if you have any question. We will then come over to your table to answer your question.

References

Abbink, K., Bosman, R., Heijmans, R., and van Winden, F. (2010). Disruptions in Large Value Payment Systems: An Experimental Approach. *De Nederlandsche Bank Working Paper*, 263.

Abbink, K. and Brandts, J. (2008). Pricing in Bertrand Competition with Increasing Marginal Costs. *Games and Economic Behaviour*, 63(1):1–31.

Bech, M. and Garratt, R. (2006). Illiquidity in the Interbank Payment System Following Wide-scale Disruptions. *Federal Reserve Bank of New York Staff Reports*, 239.

Bech, M., Martin, A., and McAndrews, H. (2012). Settlement Liquidity and Monetary Policy Implementation: Lessons from the Financial Crisis. *FRBNY Economic Policy Review*.

CPSS (2012). Principles for Financial Market Infrastructures: Disclosure Framework and Assessment Methodology. *Bank for International Settlements*.

Crawford, V. (1995). Adaptive Dynamics in Coordination Games. *Econometrica*, 63(1):103–143.

Devetag, F. and Ortmann, A. (2007). When and Why? A Critical Survey on Coordination Failure in the Laboratory. *Experimental economics*, 10:311–344.

Diehl, M. (2013). Measuring Free Riding in Large-Value Payment Systems: The Case of TARGET2. *Journal of Financial Market Infrastructures*, 1(3):31–53.

Harsanyi, J. and Selten, R. (1989). A General Theory of Equilibrium Selection in Games. *MIT Press*.

Heijmans, R. and Heuver, R. (2011). Is this Bank Ill? The Diagnosis of Doctor TARGET2. *De Nederlandsche Bank Working Paper*, 316.

Massarenti, M., Petriconi, S., and Lindner, J. (2012). Intraday Patterns and Timing of TARGET2 Interbank Payments. *Journal of Financial Market Infrastructures*, 1(2):3–24.

Mehta, J., Starmer, C., and Sugden, R. (1994). The Nature of Salience: An Experimental Investigation of Pure Coordination Games. *American Economic Review*, 84:658–673.

Schelling, T. (1960). *The Strategy of Conflict*. Harvard University Press.

Van Huyck, J., Battalio, R., and Beil, R. (1990). Tacit Coordination Games, Strategic Uncertainty and Coordination Failure. *American Economic Review*, 80:234–248.

Van Huyck, J., Battalio, R., and Beil, R. (1991). Strategic Uncertainty, Equilibrium Selection, and Coordination Failure in Average Opinion Games. *Quarterly Journal of Economics*, 106:885–910.

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