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Cooperation in Experimental Games of Strategic Complements and Substitutes

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We conduct a laboratory experiment aimed at examining whether strategic substitutability and strategic complementarity have an impact on the tendency to cooperate in finitely repeated two-player games with a Pareto-inefficient Nash equilibrium. We find that there is significantly more cooperation when actions exhibit strategic complementarities than in the case of strategic substitutes. The difference is to some extent driven by a difference in the speed with which some pairs reach stable full cooperation, but mainly by differences in choices of pairs that do not succeed in reaching full cooperation.

1. INTRODUCTION

An important theme in industrial organization is the incidence of tacit collusion. In his survey of industrial organization experiments, Holt (1995) suggests that price-setting contexts are more prone to collusion than quantity-setting contexts: “if tacit collusion causes prices to be above non-cooperative levels in price-choice experiments, why do quantities tend to be above non-cooperative Cournot levels (...)?” (p. 423). The *if* part has recently been corroborated by experimental studies,[1] but to our knowledge, no attempt has been made to shed more light on the *why* part of Holt’s remark.

In this paper, we present results from a laboratory experiment suggesting that the difference in collusion is related to the fact that choices in price-setting games are strategic complements, whereas choices in quantity-setting games are strategic substitutes. The implemented games are finitely repeated games with two players and a Pareto-inefficient Nash equilibrium.

Whether choices are strategic substitutes or strategic complements depends on the effect of a change in a player’s choice on the marginal payoff of another player. The

1. See Suetens and Potters (2007), which is based on the data contained in Altavilla, Luini and Sbriglia (2005), Davis (2002), Fouraker and Siegel (1963), and Huck, Normann and Oechssler (2000).

effect is negative in the case of strategic substitutes and positive in the case of strategic complements.[2]

A straightforward but important implication of strategic complementarity is that a change in one player's choice gives the other player an incentive to move in the *same* direction, whereas with strategic substitutability the incentive for the other player is to move in the *opposite* direction. This implies that in the case of strategic complements a best-responding player will partially follow a cooperative move made by another player. For example, in the typical case of oligopolistic price competition with substitute goods (strategic complements), if a firm that aims at colluding sets a price above the Nash equilibrium level, then the best response for the competitor is to set a price above the Nash equilibrium level as well. In this scenario, the average price will always be more collusive than the Nash equilibrium price. In the typical case of quantity competition with substitute goods (strategic substitutes), however, if a firm sets a (collusive) quantity below the Nash equilibrium level, then a best-responding firm will set a quantity above the Nash equilibrium level. The average outcome will now, all else equal, deviate to a lesser extent from the Nash prediction than in the case of strategic complements.[3] The theoretical work of Haltiwanger and Waldman (1991) that highlights how aggregate outcomes are shaped by the interaction between the nature of strategic interaction and heterogeneity of players is based on this intuition (see also Camerer and Fehr, 2006). They show that, for the same distribution of cooperators and best-responders in a population, the aggregate outcome will deviate more from the Nash equilibrium toward a cooperative outcome under strategic complementarity than under strategic substitutability. This inspired us to expect more cooperation (collusion) with strategic complements (price-setting) than with strategic substitutes (quantity-setting).

In order to ensure a *ceteris paribus* comparison of behaviour in games of strategic substitutes and games of strategic complements, in our experiment, we control for potential confounds in existing price- and quantity-setting experiments. First, we use neutral labelling instead of price or quantity labels because the latter two might trigger different behaviour. Framing effects have been shown to be potentially important in several experiments and questionnaires (see, *e.g.* Tversky and Kahneman, 1981; Hoffman *et al.*, 1994; Huck, Normann and Oechssler, 2004; Zhong, Loewenstein and Murnighan, 2007). Second, we control for the sign of the externality by disentangling it from the "sign" of the strategic interaction.[4] In price and quantity games, both signs covary: quantities are strategic substitutes and generate a negative externality,

2. A game is characterized by strategic complements (substitutes) if $\forall i, j$ and $i \neq j : \frac{\partial^2 \pi_i}{\partial x_i \partial x_j} > 0 (< 0)$, implying that the best-response functions are upward- (downward-) sloping (see Topkis, 1978; Bulow, Geanakoplos and Klemperer, 1985; Fudenberg and Tirole, 1984). Strategic complementarity or substitutability also have a bearing on the learning dynamics in games (Milgrom and Roberts, 1991).

3. Furthermore, in a price-setting game the player making a cooperative deviation from the Nash equilibrium will be better off relative to the Nash equilibrium if the other player best-responds to this deviation, whereas in a quantity-setting game the player initiating a cooperative deviation will be worse off relative to the Nash equilibrium if the other player best-responds. Based on this strategic effect of altruism, Bester and Güth (1998) and Rotemberg (1994) show that altruistic preferences may be beneficial in material payoff terms in games with strategic complements, but not so in games with strategic substitutes.

4. Games characterized by strategic substitutability or strategic complementarity have externalities by nature; this (at least locally) follows from the fact that $\dfrac{\partial^2 \pi_i}{\partial x_i \partial x_j} \neq 0$ implies that $\dfrac{\partial \pi_i}{\partial x_j} \neq 0$.

while prices are strategic complements and generate a positive externality.[5] Finally, and most importantly, we impose the same standard theoretical benchmarks (Nash, cooperation and corresponding payoffs) across strategic substitutes and complements treatments. The relative position of the Nash equilibrium and the joint payoff maximum within the strategy space differs substantially between price-choice and quantity-choice experiments, and so do the corresponding payoffs. For example, under price competition the relative payoff gain when moving from Nash equilibrium play to joint profit, maximizing cooperation is usually larger than under quantity competition.[6]

It is not only in industrial organization that the prevalence of cooperation may interact in an important way with strategic complementarity or substitutability.[7] Consider, for example, a situation of team production, where members of a team decide how much effort to put into a team task. This is an example where actions can be either strategic substitutes or complements depending on whether the team members' skills are substitutes or complements. Furthermore, strategic complementarities are also present in environments such as arms races and conspicuous consumption, while common-pool resource environments (public bads), strategic trade policy and patent races tend to be characterized by strategic substitutability. Thus, there are many environments for which a relation between the type of strategic interaction and the incidence of cooperation may be relevant.

Our experiment is also related to the experimental literature on cooperation in (finitely) repeated games with two players, such as prisoners' dilemma games or trust games. In such games, at least some players cooperate or learn to cooperate up until the final rounds, where cooperation breaks down (see Selten and Stoecker, 1986; Engle-Warnick and Slonim, 2006). Kreps *et al.* (1982) rationalize this pattern of cooperation combined with "end-effects" by introducing a small fraction of reciprocal types such that it may pay off for a rational player to cooperate as well as long as the end of the game is not too close. Camerer and Weigelt (1988) and Andreoni and Miller (1993) find experimental support in favour of this model. Yet, in this literature, no distinction is made between games of strategic complements and games of strategic substitutes.[8]

Ours is not the first experimental study to examine the relevance of strategic complementarity and substitutability for behaviour. Motivated by Haltiwanger and Waldman (1985, 1989), Fehr and Tyran (2008) examine the adjustment of prices after an economic shock. They find that this adjustment is slower if the game has strategic complementarities compared to the case of strategic substitutability. An important difference with our study is that Fehr and Tyran focus on the speed of convergence and do not address issues of cooperation. This is reflected in their choice to implement games with a *efficient* Nash equilibrium. Fehr and Tyran mention that they

5. There is literature that suggests that the sign of the externality may have an impact on cooperative play. Andreoni (1995), Sonnemans, Schram and Offerman (1998), Willinger and Ziegelmeyer (1999), Park (2000), and Zelmer (2003) find more cooperation in positive externality games than in negative externality games, while Brewer and Kramer (1986) find an effect in the opposite direction.

6. Moreover, in most studies, both the equilibrium price and the equilibrium quantity are in the lower end of the strategy space. To the extent that there is a random component to behaviour, this may induce relatively cooperative (competitive) outcomes in price-choice (quantity-choice) games.

7. See Eaton (2004) for a discussion and typology of dilemma environments based on the sign of the externality and the sign of strategic interaction.

8. Repeated games also allow for learning, *e.g.* to play the static Nash equilibrium. Such learning is typically studied in repeated game experiments with more than two players (see, *e.g.*, Rassenti *et al.*, 2000; Offerman, Potters and Sonnemans, 2002).

want to rule out the possibility "that collusion slows down adjustment to the equilibrium".[9] Whether collusion (cooperation) occurs more frequently under strategic complementarity than under strategic substitutability is precisely what we are interested in.

The experimental results confirm our expectation that there is significantly more cooperation, on average, under strategic complementarity than under strategic substitutability. The difference is to some extent driven by a difference in the speed with which some pairs reach stable full cooperation, but mainly by differences in choices of pairs that do not succeed in reaching full cooperation.

The remainder of the paper is organized as follows. In Section 2 we explain the experimental design and procedure. The experimental results are presented in Section 3, and Section 4 contains concluding remarks.

2. THE EXPERIMENT

2.1. *Design*

Since our aim is to examine whether the nature of strategic interdependence has an influence on cooperation in dilemma games, we design strategic substitutes (SUBST) and strategic complements (COMPL) treatments. In all treatments, fixed pairs of subjects play a finite repetition of the same stage game. We implement quadratic payoff functions and ensure that the stage game has a unique and Pareto-dominated Nash equilibrium and a symmetric socially efficient outcome. Games characterized by strategic substitutability or strategic complementarity have externalities by nature. In the case of a negative externality the Nash equilibrium is Pareto-dominated by lower actions and *vice versa* for games with a positive externality (see Eaton and Eswaran, 2002). In our design, we deal with this potential confound by running SUBST and COMPL treatments for both positive and negative externality cases. This gives the following four treatments:

1. strategic substitutes
   (a) negative externalities (SUBSTneg)
   (b) positive externalities (SUBSTpos)
2. strategic complements
   (a) negative externalities (COMPLneg)
   (b) positive externalities (COMPLpos).

It is straightforward to show that transforming a symmetric game with a positive externality into one with a negative externality can be done without changing incentives. Suppose that the decision variable of player i in a positive externality game is represented by x_i, with $x_i \in [0, m]$. The transformation of this game into one with a negative externality–without changing incentives–is achieved by replacing the decision variable x_i by $m - y_i$ for $i = 1, 2$, where y_i is the decision variable of player i in the corresponding negative externality game. The transformation is somewhat similar to the transformation of a public good into a public bad game, or of a give-some into a take-some game (see, *e.g.* Andreoni, 1995; van Dijk and Wilke, 2000).

For the comparison across treatments to be "clean", we require that both theoretical benchmarks–the Nash equilibrium and the joint payoff maximum (JPM)–are the same in

9. Chen and Gazzale (2004) examine the impact of the *degree* of strategic complementarity on the speed of convergence to equilibrium. In their study, the equilibrium is also efficient, and hence, cooperation is not an issue.

the COMPL and SUBST treatments. We want to exclude the possibility that the mere location of these benchmarks within the strategy space could cause any of the treatments to appear more cooperative. For instance, if behaviour were random and uniform over the strategy space, then all the treatments should look equally non-cooperative. Also, we want the *payoff levels* of the two benchmarks to be the same across the treatments. Moreover, we impose the restriction that the "optimal defection payoff"−that is, the best response to fully cooperative play by the other player−is the same across the different treatments. This implies that an analysis on the scope for cooperation in the spirit of Friedman (1971) gives the same outcome in all treatments. A final restriction is that the absolute values of the slopes of the (linear) best-response functions are the same in the treatments. This ensures that best-reply dynamics generate the same speed of convergence across SUBST and COMPL.[10]

In sum, our requirements for SUBST and COMPL consist of six common features: (1) the same Nash equilibrium choice, (2) the same Nash equilibrium payoff, (3) the same JPM choice (conditional on the sign of the externality), (4) the same JPM payoff, (5) the same optimal defection payoff, and (6) the same best-response functions' slopes (in absolute values). Figure 1 visualizes requirements 1, 3 and 6. The Nash equilibrium is in the middle of the strategy space in each of the treatments. The distance to the JPM point is the same in all treatments. The (linear) best-response functions are equally "steep" across the treatments.

We use quadratic payoff functions with six parameters for the stage games. This allows us to impose the six requirements listed above. The payoff function of player i in a two-player positive externality COMPL game is defined as follows:

$$\pi_i^{\text{COMPLpos}}(x_i, x_j) = a + bx_i + cx_j - dx_i^2 + ex_j^2 + fx_ix_j, \tag{1}$$

with $b, c, d, f > 0$, $e \geq 0$, $x_i, x_j \geq 0$, $i, j = 1, 2$ and $j \neq i$. These restrictions are sufficient to ensure that the game generates a positive externality $\left(\frac{\partial \pi_i}{\partial x_j} > 0\right)$ and is one of strategic complements $\left(\frac{\partial^2 \pi_i}{\partial x_i \partial x_j} > 0\right)$. However, they are not all necessary. For example, a linear price competition game would have $c < 0$ and $e = 0$. The Nash equilibrium is unique and symmetric:

$$x^{\text{Nash}} = \frac{b}{2d - f} \tag{2}$$

where $2d > f$ for x^{Nash} to be strictly positive. The joint payoff maximizing choice is also unique and symmetric:

$$x^{\text{JPM}} = \frac{b + c}{2(d - e - f)} \tag{3}$$

where $d > e + f$ for x^{JPM} to be strictly positive.

In a SUBSTpos game, the payoff of player i is defined as follows:

$$\pi_i^{\text{SUBSTpos}}(x_i, x_j) = \alpha + \beta x_i + \gamma x_j - \delta x_i^2 + \epsilon x_j^2 - \zeta x_ix_j, \tag{4}$$

10. While considerable behavioural evidence indicates that best-response dynamics are not often followed by subjects, other adaptive learning rules, such as fictitious play, are calculated from best responses. Since our games are dominance-solvable, these adaptive learning mechanisms converge to the (unique) Nash equilibrium (Milgrom and Roberts, 1991).

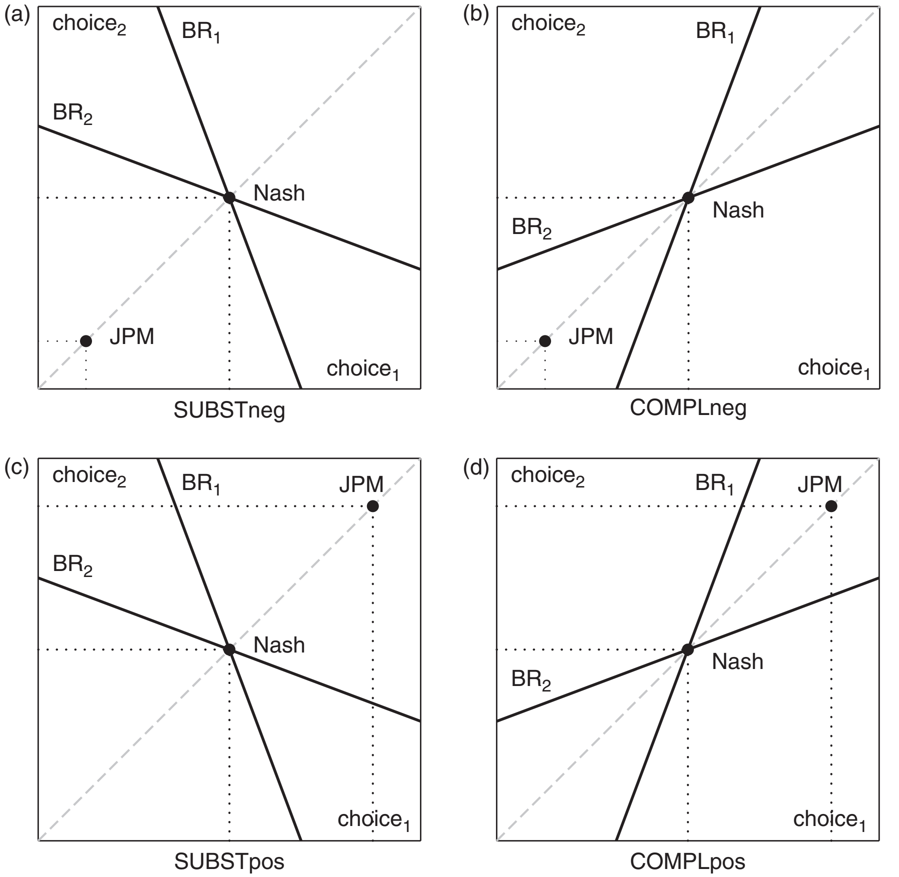

FIGURE 1

Best-response functions, Nash and JPM choices

with $\beta, \gamma, \delta, \zeta > 0$, $\epsilon \geq 0$, $x_i, x_j \geq 0$, $i, j = 1, 2$ and $j \neq i$. The game is one of strategic substitutes and for the game to generate a positive externality, the condition $\gamma + 2\epsilon x_j - \zeta x_i > 0$ must be satisfied, which is the case for the parameterization we use in the experiment. The unique and symmetric Nash equilibrium is equal to

$$x^{\text{Nash}} = \frac{\beta}{2\delta + \zeta}, \tag{5}$$

and the joint payoff maximizing choice is equal to

$$x^{\text{JPM}} = \frac{\beta + \gamma}{2(\delta - \epsilon + \zeta)} \tag{6}$$

where $\delta > \epsilon - \zeta$ for x^{JPM} to be strictly positive. For the JPM choice to be symmetric, the condition $\delta > \epsilon + \zeta$ should hold.

As noticed previously, replacing the choice variable x_i with $m - y_i$ transforms a positive externality game into a negative externality game. After the transformation, the SUBSTneg game would turn into a typical Cournot game by imposing the restrictions $\epsilon = 0$ and $\gamma = m\zeta$. For the Nash equilibria to be the same across positive and negative externality games, the Nash equilibrium must be in the middle of the choice set, such that $m = \frac{2b}{2d - f}$, and minimum and maximum actions are the same across all treatments.

The six restrictions listed above impose six linearly independent restrictions that allow unique identification of the six parameters in the payoff functions. The six restrictions are satisfied, if the parameters $\alpha, \beta, \gamma, \delta, \epsilon$ and ζ are defined in terms of a, b, c, d, e and f in the following way:[11]

$$\begin{cases} \alpha &= a \\ \beta &= \dfrac{b(2d-f)}{2d+f} \\ \gamma &= c + \dfrac{2bf}{2d+f} \\ \delta &= \dfrac{d(2d-f)^2}{(2d+f)^2} \\ \epsilon &= e + \dfrac{2f^3}{(2d+f)^2} \\ \zeta &= \dfrac{f(2d-f)^2}{(2d+f)^2} \end{cases} . \tag{7}$$

The parameters we used for the experiment are $a = -28, b = 5{\cdot}474, c = 0{\cdot}01, d = 0{\cdot}278, e = 0{\cdot}0055$ and $f = 0{\cdot}165$ (which gives $m = 28$). Table 1 provides an overview of the main theoretical benchmarks in the four treatments for the parameter constellation used in the experiment.[12] The optimal defection choice corresponding to π^{defect} is 17·4 (10·6) in the case of COMPL and a positive (negative) externality and 10·6 (17·4) in the case of SUBST and a positive (negative) externality.

11. It can be shown that the so-called sucker payoff, *i.e.* the payoff of cooperating while the other player defects, is smaller in COMPL than in SUBST if these requirements are met. In other words, it is worse to be cheated on in COMPL than in SUBST in terms of payoff loss. From this perspective, one might hypothesize there to be *less* cooperation in COMPL than in SUBST (cf. the cooperation index and index of conflict suggested by Rapoport and Chammah, 1965; Axelrod, 1967, respectively).

12. In setting the absolute value of the reaction curve's slope we are constrained by the requirement that $y^{\text{JPM}} \geq 0$. Assume that c is very small such that it becomes negligible; $c \approx 0$. In that case, the expression for $y^{\text{JPM}} \geq 0$ reduces to

$$y^{\text{JPM}} = \frac{b(2d - 4e - 3f)}{2(d - e - f)(2d - f)} \tag{8}$$

and the condition $y^{\text{JPM}} \geq 0$ reduces to $2d \geq 4e + 3f$ since $d > e + f$ and $2d > f$. If we also assume that $e \approx 0$ the condition $y^{\text{JPM}} \geq 0$ reduces to $2d \geq 3f$, or $\frac{f}{2d} \leq \frac{1}{3}$. In other words, the slope of the best-response function cannot exceed 1/3. If $c > 0$ or $e > 0$ the condition becomes $\frac{f}{2d} < \frac{1}{3}$ and the absolute value of the slope will always be strictly smaller than 1/3.

TABLE 1

Theoretical benchmarks in the experiment

	SUBST		COMPL	
	SUBSTneg	SUBSTpos	COMPLneg	COMPLpos
Choice_{min}	0·0	0·0	0·0	0·0
Choice_{max}	28·0	28·0	28·0	28·0
$\text{Choice}^{\text{Nash}}$	14·0	14·0	14·0	14·0
$\text{Choice}^{\text{JPM}}$	2·5	25·5	2·5	25·5
π^{Nash}	27·71	27·71	27·71	27·71
π^{JPM}	41·94	41·94	41·94	41·94
π^{defect}	60·14	60·14	60·14	60·14
Slope	−0·30	−0·30	0·30	0·30

2.2. *Procedure*

Six computerized sessions were conducted in CentERlab at Tilburg University in November 2004 covering the four treatments.[13] In each of the first four sessions one of the four treatments was run, and in the final two sessions mixes of all treatments were run in order to balance the number of observations across the four treatments. A total number of 110 students participated in the experiment. They were recruited through e-mail lists of students interested in participating in experiments. Each treatment had 28 participants corresponding to 14 independent observations (pairs), except treatment SUBSTneg which had 26 participants or 13 independent observations.

All participants received the same instructions (see Appendix A). The treatments differed only with respect to the payoff function. It was explained to the subjects that their earnings depended on their own choices and on the choices of one other participant in the session, which remained the same during the entire experiment. They were asked to choose a number between 0·0 and 28·0 in each round.[14] Subjects could calculate their earnings in points by means of a payoff table for combinations of hypothetical choices that are multiples of two, and by means of an earnings calculator on the computer screen for any combination of hypothetical choices.[15] They were explicitly told that choices were not restricted to be multiples of two.

The same static game was repeated 31 times with the same pairs of players, including a trial round which did not count to calculate earnings. After each round, subjects were informed about the choice of the paired participant and their own and the matched player's payoff. Earnings were denoted in points and transferred to cash at a rate of 100 points = 1 EUR. Subjects were informed about the number of rounds. The sessions lasted between 50 and 55 minutes, and average earnings were 9·30 EUR.

13. We used the experimental software toolkit *z-Tree* to program the experiment (see Fischbacher, 1999).

14. The number of possible decimal points was limited to one.

15. Earnings in points were rounded at two decimals. Payoff tables are in Appendix A. In order to show the difference in the best-response functions between strategic SUBST and COMPL, best responses for multiples of two are marked in grey (which was not the case in the experiment).

3. EXPERIMENTAL RESULTS

3.1. *Aggregate results*

We present the data in terms of the degree of cooperation which is defined as follows for pair k in round t:

$$\rho_{kt} = \frac{\text{average choice}_{kt} - \text{choice}^{\text{Nash}}}{\text{choice}^{\text{JPM}} - \text{choice}^{\text{Nash}}}.$$

When the average choice of pair k in round t is the non-cooperative Nash equilibrium, $\rho_{kt} = 0$ while $\rho_{kt} = 1$ at the JPM benchmark. When the average choice of the pair is between the Nash and the JPM benchmark, $0 < \rho_{kt} < 1$. Average choices more competitive than the Nash equilibrium imply that $\rho_{kt} < 0$. This transformation of choices is made in order to simplify comparison across treatments and has no impact on any of our conclusions.[16]

A first result is that the sign of the externality does not have an effect on the degree of cooperation under either SUBST or COMPL. Averaged over the pairs and over the rounds, the degree of cooperation is 0·24 in SUBSTneg as compared to 0·17 in SUBSTpos, and it is 0·49 in COMPLneg as compared to 0·42 in COMPLpos. These differences are not statistically significant.[17] Therefore, in what follows we pool SUBSTneg and SUBSTpos into SUBST and COMPLneg and COMPLpos into COMPL.

Our main experimental result is expressed in Figure 2, which depicts the evolution of the average degree of cooperation in the SUBST and COMPL treatments. Clearly, the aggregate data support the hypothesis that strategic complementarity facilitates cooperation compared to strategic substitutability. Table 2 provides statistical details for all rounds combined (1–30), and separately for the first half (1–15), the second half (16–30) and the first and final rounds of the experiment. The second and third columns give averages (and standard deviations) of the degree of cooperation for SUBST and COMPL, respectively. The p-values in the 4th column correspond to Mann-Whitney U test statistics of the null hypothesis that the degree of cooperation is the same in SUBST and COMPL. H_0 is overall rejected in favour of the alternative hypothesis that the degree of cooperation is larger in COMPL than in SUBST, except in the first round.

Figure 2 also shows that end-game effects occurred in all treatments, which is common in finitely repeated social dilemma games (see, *e.g.* Ledyard, 1995; Selten and Stoecker, 1986). However, Table 2 shows that the end-game effect is significantly stronger in SUBST than in COMPL, which is most likely due to the difference in optimal defection choice between SUBST and COMPL.

Furthermore, the error bars in Figure 2 display that between-pair variability does not seem to decline in time, for SUBST or COMPL. No general convergence to the Nash equilibrium of the stage game or any other outcome takes place.

It is interesting also to look at within-pair variability. Table 3 contains data on the absolute difference between the choices of the two players within each pair, averaged over different sets of rounds. The table shows that players' choices are more coordinated in periods 16–30 than in periods 1–15 ($p < 0{\cdot}002$ in a Wilcoxon signed-ranks test). Later, we will show that this is mainly due to pairs who manage to reach full, stable cooperation. However, what stands out most clearly in the table, is that within-pair differences are significantly higher in SUBST than

16. Alternatively, the degree of cooperation could have been calculated in terms of the average realized payoffs: (average payoffs−Nash payoffs)/(JPM payoffs−Nash payoffs). Doing so does not alter any of our conclusions.

17. Non-parametric test statistics for $H_0 : \overline{\rho}^{\text{neg}} = \overline{\rho}^{\text{pos}}$ are in Appendix B.

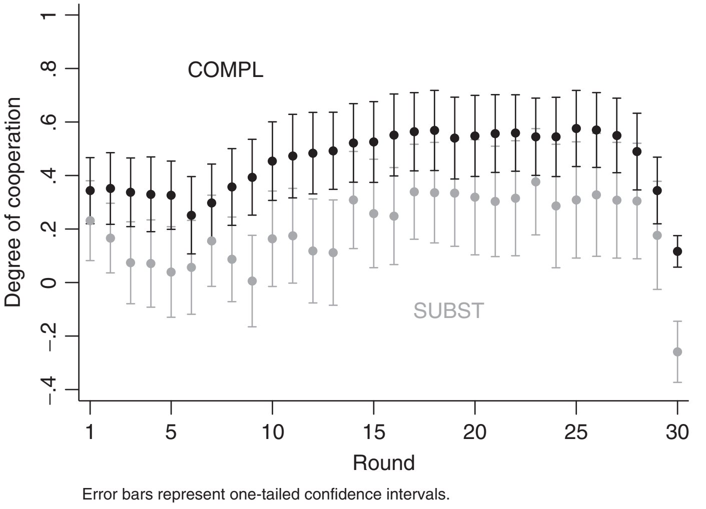

FIGURE 2

Average degree of cooperation

TABLE 2

Treatment effect: SUBST versus COMPL

	$\overline{\rho}$ (s.d.[a])		
	SUBST	COMPL	p-value[b]
Rounds 1–30	0·20 (0·41)	0·45 (0·38)	0·012
Rounds 1–15	0·13 (0·38)	0·40 (0·39)	0·006
Rounds 16–30	0·27 (0·54)	0·51 (0·40)	0·050
Round 1[c]	0·23 (0·57)	0·34 (0·46)	0·164
Round 30	−0·26 (0·35)	0·12 (0·18)	0·000
N	27	28	

[a] Standard deviation measures between-pair variability.
[b] $H_1 : \overline{\rho}_{\text{SUBST}} < \overline{\rho}_{\text{COMPL}}$ (one-tailed Mann-Whitney U test).
[c] Based on $54 + 56$ independent observations.

in COMPL throughout. Overall, choices within pairs differ on average by 4·4 under SUBST and by 1·6 under COMPL. This is in line with the fact that a combination of cooperative play and best response gives a larger difference in choices under SUBST than under COMPL. We come back to the idea of heterogeneous play below.

3.2. *Endogenous strategic complementarity*

As outlined in the Introduction, strategic complementarity gives a player an incentive to follow behavioural changes (*e.g.* cooperative moves) of the other player, while strategic substitutability gives a player an incentive to move in the opposite direction. Yet, these behavioural patterns can only partly be recovered from the data. In fact, we find that a behavioural change by one player is, on average, followed by a move in the same direction by the other player in *both* COMPL and SUBST. This implies that if a player moves towards

TABLE 3

Within-pair variability: SUBST versus COMPL

	abs(choice$_1$-choice$_2$) (s.d.[a])		
	SUBST	COMPL	p-value[b]
Rounds 1–30	4·4 (2·64)	1·6 (0·99)	0·000
Rounds 1–15	5·3 (3·03)	2·1 (1·31)	0·000
Rounds 16–30	3·5 (2·91)	1·1 (1·03)	0·000
Round 1[c]	5·3 (5·96)	3·9 (4·31)	0·391
Round 30	6·7 (4·55)	1·4 (1·85)	0·000
N	27	28	

[a] Standard deviation measures between-pair variability.
[b] H_1 : SUBST > COMPL (one-tailed Mann-Whitney U test).
[c] Based on $54 + 56$ independent observations.

TABLE 4

Regression results on changes in choices

	β_1		β_2	
	Estimate	p-value	Estimate	p-value
All	0·14	0·006	0·17	0·003
JPM pairs	0·35	0·000	0·03	0·795
Non-JPM pairs	0·06	0·120	0·22	0·000

$\Delta\text{choice}_{it} = \beta_0 + \beta_1 \Delta\text{choice}_{jt-1} + \beta_2 \text{COMPL}\Delta\text{choice}_{jt-1} + u_{it}$.
Regressions include individual random effects.
Standard errors are robust to within-pair dependency.
Two-tailed p-values are reported.

(away from) the JPM choice, the other player also moves on average towards (away from) the JPM choice, in SUBST as well as in COMPL. However, the extent to which such a move is followed is significantly greater in COMPL than in SUBST. For example, estimating the model $\Delta\text{choice}_{it} = \beta_0 + \beta_1 \Delta\text{choice}_{jt-1} + \beta_2 \text{COMPL}\Delta\text{choice}_{jt-1} + u_{it}$ yields $\hat{\beta}_1 = 0{\cdot}14$ with $p = 0{\cdot}006$ and $\hat{\beta}_2 = 0{\cdot}17$ with $p = 0{\cdot}003$ (see Table 4).[18]

This pattern can be explained well by the presence of reciprocal players, that is, players who respond cooperatively to cooperative acts and non-cooperatively to non-cooperative acts.[19] Since such players follow cooperative (and other) choices by others, their presence generates a form of strategic complementarity. This endogenous strategic complementarity is strengthened by the strategic complementarity embedded in the payoff structure of COMPL, while it is–at least partially–compensated by the strategic substitutability inherent in SUBST.

18. COMPL is a treatment dummy variable.

19. There exists ample evidence for the presence of reciprocal players (see, for instance, Axelrod and Hamilton, 1981; Keser, 2000; Fischbacher, Gächter and Fehr, 2001).

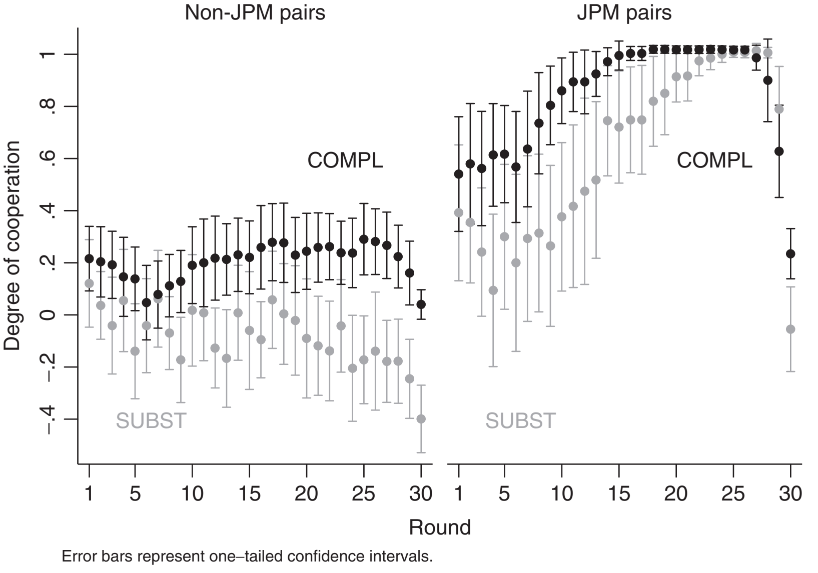

FIGURE 3

Average degree of cooperation for non-JPM and JPM pairs

3.3. *JPM versus non-JPM pairs*

A closer look at the evolution of individual choices within pairs suggests that a different choice pattern emerges between pairs that succeed and pairs that do not succeed in jointly maximizing payoff (see Appendix C). An important behavioural similarity across all treatments is that when choices of *both* subjects in a pair are at the JPM level in the same round, the choices remain at this level until (almost) the end of the experiment. Out of the 55 pairs there are 24 of which both subjects simultaneously make a choice at the JPM level in at least one round.[20] Out of these 24 pairs, 92% (22 pairs) keep making choices at the JPM level until the last but one, two, three or four rounds of the experiment.[21] The latter type of pair is much related to how Selten and Stoecker (1986) define cooperative end-effect play. We refer to this type of pair as a JPM pair. The rest of the pairs are classified as non-JPM pairs. There are 11 JPM pairs in SUBST and 11 in COMPL covering 40% of all pairs.[22]

That behaviour of JPM and non-JPM pairs evolves differently is clearly illustrated in Figure 3 and Tables 5 and 6. In the first half of the experiment, JPM pairs cooperate significantly more in COMPL than in SUBST. This suggests that pairs succeed sooner in coordinating on the JPM choice in COMPL than in SUBST, or that, in other words, strategic complementarities tend to speed up the process of getting to full cooperation. Indeed, under SUBST it takes, on average, 14 rounds to attain stable full cooperation, while under COMPL it takes 7 rounds ($p = 0{\cdot}039$ in a one-tailed Mann-Whitney U test). The difference in degree of cooperation between SUBST and COMPL obviously disappears in the second half: once pairs

20. We say that the choice of a pair is at the JPM level if the choice of both subjects is in the interval [25, 26] in positive externality games and in the interval [2, 3] in negative externality games. The exact JPM choices are 25·5 and 2·5, respectively, but using the afore-mentioned intervals is behaviourally better justified: subjects often round their choice at an integer number.

21. End-effects covering three or four rounds are each observed for one pair.

22. Pairs 1, 3, 4, 5, 9, 11, 18, 19, 21, 22, 25, 28, 29, 30, 31, 32, 35, 37, 43, 46, 51 and 54 are classified as JPM pairs. The graphs in Appendix C are a tool that helps to visualize the definition of JPM pairs.

TABLE 5

Treatment effect for JPM pairs: SUBST versus COMPL

	$\overline{\rho}$ (s.d.[a])		
	SUBST	COMPL	p-value[b]
Rounds 1–30	0·61 (0·27)	0·84 (0·13)	0·051
Rounds 1–15	0·38 (0·46)	0·75 (0·26)	0·045
Rounds 16–30	0·85 (0·15)	0·93 (0·06)	0·234
Round 1[c]	0·39 (0·65)	0·54 (0·49)	0·383
round 30	−0·05 (0·32)	0·23 (0·19)	0·007
N	11	11	

[a] Standard deviation measures between-pair variability.
[b] $H_1 : \overline{\rho}_{\text{SUBST}} < \overline{\rho}_{\text{COMPL}}$ (one-tailed Mann-Whitney U test).
[c] Based on 22 + 22 independent observations.

TABLE 6

Treatment effect for non-JPM pairs: SUBST versus COMPL

	$\overline{\rho}$ (s.d.[a])		
	SUBST	COMPL	p-value[b]
Rounds 1–30	−0·08 (0·17)	0·20 (0·26)	0·001
Rounds 1–15	−0·03 (0·19)	0·17 (0·28)	0·024
Rounds 16–30	−0·13 (0·26)	0·24 (0·27)	0·000
Round 1[c]	0·12 (0·48)	0·22 (0·39)	0·182
Round 30	−0·40 (0·30)	0·04 (0·14)	0·000
N	16	17	

[a] Standard deviation measures between-pair variability.
[b] $H_1 : \overline{\rho}_{\text{SUBST}} < \overline{\rho}_{\text{COMPL}}$ (one-tailed Mann-Whitney U test).
[c] Based on 32 + 34 independent observations.

succeed in coordinating on the JPM choice, behaviour also stabilizes in SUBST until the last but few rounds.[23] This also implies that, for JPM pairs, cooperative moves are, on average, followed to the same extent under SUBST and COMPL (see Table 4).

For non-JPM pairs, we observe that the difference in degree of cooperation between COMPL and SUBST is significant, and increases throughout the experiment: in the first half it is 0·20 ($p = 0{\cdot}024$) and in the second half it is 0·37 ($p = 0{\cdot}000$). The average choice in COMPL slightly increases, while in SUBST it decreases. Furthermore, a cooperative move is, in this case, on average, only followed with COMPL. This implies that the endogenous strategic complementarity discussed in Section 3.2 was largely the consequence of behaviour of JPM pairs (see Table 4): $\hat{\beta}_1 = 0{\cdot}06$ with $p = 0{\cdot}120$ and $\hat{\beta}_2 = 0{\cdot}22$ with $p = 0{\cdot}000$.

These observations are in line with the idea that heterogeneity of players causes differences in aggregate outcomes between COMPL and SUBST. Our main result that the degree of cooperation is significantly higher under COMPL than under SUBST is driven by behaviour of non-JPM pairs, and of JPM pairs before reaching stable cooperation (*i.e.* heterogeneous

23. The strong end-effect observed for JPM pairs suggests that cooperation of JPM pairs is, to a large extent, strategic.

behaviour). Once a pair reaches stable cooperation and both subjects simultaneously make JPM choices (*i.e.* homogeneous behaviour), the degree of cooperation is equally high (close to 1) in SUBST as in COMPL.

The heterogeneity explanation is supported by results of simulations assuming two different types of players: cooperative and non-cooperative players. A cooperative player is assumed to always reciprocate full mutual cooperation and also tries to induce cooperation by playing fully cooperatively with a certain probability. This probability is positively related to the cooperativeness of the partner's response to his own earlier full cooperation. Otherwise, he punishes by playing a Cournot best-reply or by playing spitefully, each with a certain probability. A non-cooperative player only plays Cournot best-reply or plays spitefully, again, each with a certain probability.[24] A JPM pair consists of two cooperative players and a non-JPM pair can be either a combination of two non-cooperative players or of a cooperative and a non-cooperative player. The simulations replicate the key features of the experimental data (see Appendix D for more details). JPM pairs reach full cooperation more quickly under COMPL than under SUBST and, before they reach it, play is more cooperative in the former than in the latter case. For non-JPM pairs, play is more cooperative under COMPL than under SUBST throughout. In both cases, the main mechanism behind the difference is that a best-response to full cooperation is or looks more cooperative under COMPL than under SUBST.

4. CONCLUDING REMARKS

In his survey on industrial organization experiments Holt suggests that experimentalists should not only test theoretical predictions and document any deviations; they should also examine possible causes: "There are many instances in which non-cooperative equilibria in the market period games provide biased predictions, but I think that we should begin with these predictions and, as experimentalists, try to explain the direction of the bias" (Holt, 1995, p. 423). This is what our experiment aims to do. Starting from the observation that price-choice experiments tend to be more collusive than quantity-choice experiments, we zoom in on one of the possible reasons for this difference: whether choices are strategic complements or substitutes. To isolate the effect of this factor, we control for potentially confounding factors: framing effects, the sign of the externality, and the location and payoffs of various benchmark outcomes.

Our experiment shows that behaviour is more cooperative in games characterized by strategic complements than in games characterized by strategic substitutes. The aggregate effect is large and significant. The average degree of cooperation–measured in terms of the relative distance to the Nash equilibrium–is more than twice as large under complementarity than under substitutability. The effect is not uniform across pairs, however (just as in, for instance, Offerman, Potters and Sonnemans, 2002). About 40% of the pairs manage to reach full, stable cooperation, and to do so takes longer under strategic substitutes than under complements. The aggregate effect is mainly driven by the behaviour of the 60% non-cooperative pairs who overall play more aggressively and whose choices are less coordinated under substitutes than under complements.

These observations are in line with the ideas put forward by Haltiwanger and Waldman (1991, 1993) that heterogeneity of players causes differences in aggregate outcomes between complements and substitutes. Whereas Fehr and Tyran (2005, 2008) and Camerer and Fehr (2006) argue that heterogeneous degrees of sophistication interact significantly with the

24. A spiteful player maximizes the difference in payoffs. Including spiteful behaviour is not necessary in order to generate differences in cooperation between COMPL and SUBST. However, it is one way to generate negative degrees of cooperation, as observed for non-JPM pairs under SUBST (see Figure 3).

type of strategic environment–the presence of less sophisticated players moves aggregate outcomes further away from the equilibrium under complements than under substitutes–our results suggest that this interaction also applies to heterogeneous degrees of cooperativeness. Indeed, if two cooperative players are matched in a finitely repeated game, at some point full cooperation is reached and, once reached, no difference in cooperation is left between cases of substitutes and complements. However, if a cooperative player is matched with a best-responding player, then the best-responding player will move in the same direction if choices are strategic complements, and in the opposite direction if choices are substitutes. As a consequence, aggregate outcomes tend to deviate more from the static Nash equilibrium when choices are complements. This mechanism corresponds well with the observation that the aggregate effect in our experiment is mainly driven by pairs who do not succeed in reaching full cooperation–among those are the heterogeneous pairs–and to some extent by the cooperative pairs *before* they attain full cooperation.

Understanding the incidence of cooperation is a topic of interest in several other domains than price and quantity competition. Inter-firm cooperation is, for example, a key question in the literature on R&D and technological spillovers (see d'Aspremont and Jacquemin, 1988; Kamien, Muller and Zang, 1992). R&D competition is characterized by strategic complementarity when spillovers are high, and by strategic substitutability when spillovers are low. Our results suggest that (all else equal) the former case will be more conducive to cooperation than the latter. Another example is the voluntary provision of a public good. Contributions to a public good are strategic complements if production of the public good is characterized by increasing returns to scale, and strategic substitutes if production of the public good is characterized by decreasing returns to scale. Our results suggest that contributions to the public good will be higher when the production function has increasing returns to scale. Due recognition of the underlying type of strategic interaction will contribute to a better understanding of the prevalence of cooperation in any environment where the Nash equilibrium is Pareto-dominated.

APPENDIX A. INSTRUCTIONS[25]

You are participating in an experiment on economic decision making and will be asked to make a number of decisions. If you follow the instructions carefully, you can earn a considerable amount of money. At the end of the experiment, you will be paid your earnings in private and in cash.

During the experiment you are not allowed to talk to other participants. If something is not clear, please raise your hand and one of us will help you.

Your earnings depend on your own decisions and on the decisions of one other participant. The identity of the other participant will not be revealed. The other participant remains the same during the entire experiment and will be referred to as "the other" in what follows.

The experiment consists of 30 periods. In each period you have to choose a number between 0·0 and 28·0. The other also chooses a number between 0·0 and 28·0. Your earnings in points depend on your choice and the other's choice. The table attached to these instructions gives information about your earnings for some combinations of your choice and the other's choice. The other gets the same table.

You can calculate your and the other's earnings in more detail (for choices that are not multiples of 2 for instance) by using the EARNINGS CALCULATOR on your screen. By filling in a hypothetical value for your own choice and a hypothetical value for the other's choice you can calculate your and the other's earnings for this combination of choices.

You enter your decision under DECISION ENTRY by clicking on Enter.

In each period you have about 1 minute to enter your decision.

25. Note that in the payoff tables in the experiment the best-response curves were not marked in grey.

Your choice ↓	The other's choice → 0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0
0.0	41.27	36.50	31.91	27.50	23.27	19.22	15.36	11.68	8.18	4.87	1.73	–1.22	–3.99	–6.57	–8.98
2.0	46.88	41.91	37.13	32.52	28.10	23.86	19.81	15.93	12.24	8.73	5.40	2.26	–0.71	–3.49	–6.09
4.0	51.84	46.68	41.70	36.90	32.28	27.85	23.60	19.53	15.64	11.94	8.42	5.08	1.92	–1.05	–3.85
6.0	56.14	50.78	45.61	40.62	35.81	31.18	26.74	22.47	18.39	14.49	10.78	7.25	3.89	0.72	–2.26
8.0	59.79	54.24	48.87	43.68	38.68	33.86	29.22	24.76	20.49	16.40	12.49	8.76	5.21	1.85	–1.33
10.0	62.78	57.04	51.48	46.10	40.90	35.88	31.05	26.40	21.93	17.64	13.54	9.62	5.88	2.32	–1.06
12.0	65.12	59.18	53.43	47.85	42.46	37.25	32.22	27.38	22.72	18.24	13.94	9.82	5.89	2.14	–1.43
14.0	66.81	60.67	54.72	48.96	43.37	37.97	32.75	27.71	22.85	18.17	13.68	9.37	5.24	1.30	–2.46
16.0	67.84	61.51	55.37	49.41	43.63	38.03	32.61	27.38	22.33	17.46	12.77	8.27	3.95	–0.19	–4.15
18.0	68.22	61.70	55.36	49.20	43.23	37.43	31.83	26.40	21.15	16.09	11.21	6.51	2.00	–2.34	–6.49
20.0	67.94	61.23	54.69	48.34	42.17	36.19	30.38	24.76	19.32	14.07	8.99	4.10	–0.61	–5.14	–9.48
22.0	67.01	60.10	53.37	46.83	40.47	34.29	28.29	22.47	16.84	11.39	6.12	1.03	–3.87	–8.59	–13.13
24.0	65.43	58.32	51.40	44.66	38.11	31.73	25.54	19.53	13.70	8.06	2.59	–2.69	–7.78	–12.70	–17.43
26.0	63.19	55.89	48.77	41.84	35.09	28.52	22.14	15.93	9.91	4.07	–1.58	–7.06	–12.35	–17.46	–22.39
28.0	60.29	52.80	45.49	38.37	31.42	24.66	18.08	11.68	5.47	–0.57	–6.42	–12.09	–17.57	–22.88	–28.00

FIGURE A1

Payoff table for SUBSTneg

Your choice ↓	The other's choice → 0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0
0.0	–28.00	–22.88	–17.57	–12.09	–6.42	–0.57	5.47	11.68	18.08	24.66	31.42	38.37	45.49	52.80	60.29
2.0	–22.39	–17.46	–12.35	–7.06	–1.58	4.07	9.91	15.93	22.14	28.52	35.09	41.84	48.77	55.89	63.19
4.0	–17.43	–12.70	–7.78	–2.69	2.59	8.06	13.70	19.53	25.54	31.73	38.11	44.66	51.40	58.32	65.43
6.0	–13.13	–8.59	–3.87	1.03	6.12	11.39	16.84	22.47	28.29	34.29	40.47	46.83	53.37	60.10	67.01
8.0	–9.48	–5.14	–0.61	4.10	8.99	14.07	19.32	24.76	30.38	36.19	42.17	48.34	54.69	61.23	67.94
10.0	–6.49	–2.34	2.00	6.51	11.21	16.09	21.15	26.40	31.83	37.43	43.23	49.20	55.36	61.70	68.22
12.0	–4.15	–0.19	3.95	8.27	12.77	17.46	22.33	27.38	32.61	38.03	43.63	49.41	55.37	61.51	67.84
14.0	–2.46	1.30	5.24	9.37	13.68	18.17	22.85	27.71	32.75	37.97	43.37	48.96	54.72	60.67	66.81
16.0	–1.43	2.14	5.89	9.82	13.94	18.24	22.72	27.38	32.22	37.25	42.46	47.85	53.43	59.18	65.12
18.0	–1.06	2.32	5.88	9.62	13.54	17.64	21.93	26.40	31.05	35.88	40.90	46.10	51.48	57.04	62.78
20.0	–1.33	1.85	5.21	8.76	12.49	16.40	20.49	24.76	29.22	33.86	38.68	43.68	48.87	54.24	59.79
22.0	–2.26	0.72	3.89	7.25	10.78	14.49	18.39	22.47	26.74	31.18	35.81	40.62	45.61	50.78	56.14
24.0	–3.85	–1.05	1.92	5.08	8.42	11.94	15.64	19.53	23.60	27.85	32.28	36.90	41.70	46.68	51.84
26.0	–6.09	–3.49	–0.71	2.26	5.40	8.73	12.24	15.93	19.81	23.86	28.10	32.52	37.13	41.91	46.88
28.0	–8.98	–6.57	–3.99	–1.22	1.73	4.87	8.18	11.68	15.36	19.22	23.27	27.50	31.91	36.50	41.27

FIGURE A2

Payoff table for SUBSTpos

Your choice ↓ \ The other's choice →	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0
0.0	41.27	31.42	21.61	11.84	2.12	–7.56	–17.19	–26.78	–36.33	–45.83	–55.29	–64.70	–74.07	–83.40	–92.68
2.0	51.11	41.91	32.76	23.66	14.60	5.58	–3.40	–12.33	–21.21	–30.05	–38.85	–47.61	–56.32	–64.98	–73.60
4.0	58.72	50.19	41.70	33.25	24.85	16.49	8.18	–0.09	–8.32	–16.50	–24.64	–32.73	–40.78	–48.79	–56.75
6.0	64.11	56.23	48.40	40.62	32.88	25.18	17.52	9.91	2.35	–5.17	–12.65	–20.09	–27.48	–34.82	–42.12
8.0	67.27	60.06	52.89	45.76	38.68	31.64	24.65	17.70	10.79	3.93	–2.89	–9.66	–16.39	–23.08	–29.72
10.0	68.21	61.66	55.15	48.68	42.26	35.88	29.55	23.26	17.01	10.81	4.65	–1.46	–7.53	–13.56	–19.54
12.0	66.93	61.03	55.18	49.38	43.62	37.90	32.22	26.59	21.01	15.47	9.97	4.51	–0.90	–6.26	–11.58
14.0	63.42	58.19	53.00	47.85	42.75	37.69	32.68	27.71	22.78	17.90	13.06	8.27	3.52	–1.19	–5.85
16.0	57.69	53.11	48.58	44.10	39.66	35.26	30.90	26.59	22.33	18.11	13.93	9.79	5.70	1.66	–2.34
18.0	49.73	45.82	41.95	38.12	34.34	30.60	26.91	23.26	19.65	16.09	12.57	9.10	5.67	2.28	–1.06
20.0	39.55	36.30	33.09	29.92	26.80	23.72	20.69	17.70	14.75	11.85	8.99	6.18	3.41	0.68	–2.00
22.0	27.15	24.55	22.00	19.50	17.04	14.62	12.24	9.91	7.63	5.39	3.19	1.03	–1.08	–3.14	–5.16
24.0	12.52	10.59	8.70	6.85	5.05	3.29	1.58	–0.09	–1.72	–3.30	–4.84	–6.33	–7.78	–9.19	–10.55
26.0	–4.33	–5.61	–6.84	–8.02	–9.16	–10.26	–11.32	–12.33	–13.29	–14.21	–15.09	–15.93	–16.72	–17.46	–18.16
28.0	–23.41	–24.02	–24.59	–25.12	–25.60	–26.04	–26.43	–26.78	–27.09	–27.35	–27.57	–27.74	–27.87	–27.96	–28.00

FIGURE A3

Payoff table for COMPLneg

Your choice ↓ \ The other's choice →	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0
0.0	–28.00	–27.96	–27.87	–27.74	–27.57	–27.35	–27.09	–26.78	–26.43	–26.04	–25.60	–25.12	–24.59	–24.02	–23.41
2.0	–18.16	–17.46	–16.72	–15.93	–15.09	–14.21	–13.29	–12.33	–11.32	–10.26	–9.16	–8.02	–6.84	–5.61	–4.33
4.0	–10.55	–9.19	–7.78	–6.33	–4.84	–3.30	–1.72	–0.09	1.58	3.29	5.05	6.85	8.70	10.59	12.52
6.0	–5.16	–3.14	–1.08	1.03	3.19	5.39	7.63	9.91	12.24	14.62	17.04	19.50	22.00	24.55	27.15
8.0	–2.00	0.68	3.41	6.18	8.99	11.85	14.75	17.70	20.69	23.72	26.80	29.92	33.09	36.30	39.55
10.0	–1.06	2.28	5.67	9.10	12.57	16.09	19.65	23.26	26.91	30.60	34.34	38.12	41.95	45.82	49.73
12.0	–2.34	1.66	5.70	9.79	13.93	18.11	22.33	26.59	30.90	35.26	39.66	44.10	48.58	53.11	57.69
14.0	–5.85	–1.19	3.52	8.27	13.06	17.90	22.78	27.71	32.68	37.69	42.75	47.85	53.00	58.19	63.42
16.0	–11.58	–6.26	–0.90	4.51	9.97	15.47	21.01	26.59	32.22	37.90	43.62	49.38	55.18	61.03	66.93
18.0	–19.54	–13.56	–7.53	–1.46	4.65	10.81	17.01	23.26	29.55	35.88	42.26	48.68	55.15	61.66	68.21
20.0	–29.72	–23.08	–16.39	–9.66	–2.89	3.93	10.79	17.70	24.65	31.64	38.68	45.76	52.89	60.06	67.27
22.0	–42.12	–34.82	–27.48	–20.09	–12.65	–5.17	2.35	9.91	17.52	25.18	32.88	40.62	48.40	56.23	64.11
24.0	–56.75	–48.79	–40.78	–32.73	–24.64	–16.50	–8.32	–0.09	8.18	16.49	24.85	33.25	41.70	50.19	58.72
26.0	–73.60	–64.98	–56.32	–47.61	–38.85	–30.05	–21.21	–12.33	–3.40	5.58	14.60	23.66	32.76	41.91	51.11
28.0	–92.68	–83.40	–74.07	–64.70	–55.29	–45.83	–36.33	–26.78	–17.19	–7.56	2.12	11.84	21.61	31.42	41.27

FIGURE A4

Payoff table for COMPLpos

After each period you are informed about the other's choice and your and the other's earnings in that period. A history of your and the other's past choices and earnings is available at the bottom right of your computer screen.

The first period is a trial period and does not count when calculating your earnings. Your total earnings in points are the sum of your earnings in points over the 30 periods. Your earnings in points will be converted into EUR according to the following rate: 100 points = 1 EUR.

APPENDIX B. EXTERNALITY TREATMENT EFFECTS

TABLE B1

Externality treatment effects (Mann-Whitney U tests)

	$\overline{\rho}_{\text{SUBST}}$ (s.d.)			$\overline{\rho}_{\text{COMPL}}$ (s.d.)		
	Negative	Positive	p-value	Negative	Positive	p-value
Rounds 1–30	0·24 (0·42)	0·17 (0·41)	0·519	0·49 (0·42)	0·42 (0·36)	0·795
Rounds 1–15	0·22 (0·39)	0·06 (0·37)	0·128	0·45 (0·43)	0·34 (0·35)	0·511
Rounds 16–30	0·26 (0·53)	0·28 (0·56)	0·730	0·53 (0·43)	0·49 (0·39)	0·982
N	13	14		14	14	

$H_1 : \overline{\rho}_{\text{neg}} \neq \overline{\rho}_{\text{pos}}$ (two-tailed).

APPENDIX C. EVOLUTION OF INDIVIDUAL CHOICES BY PAIR

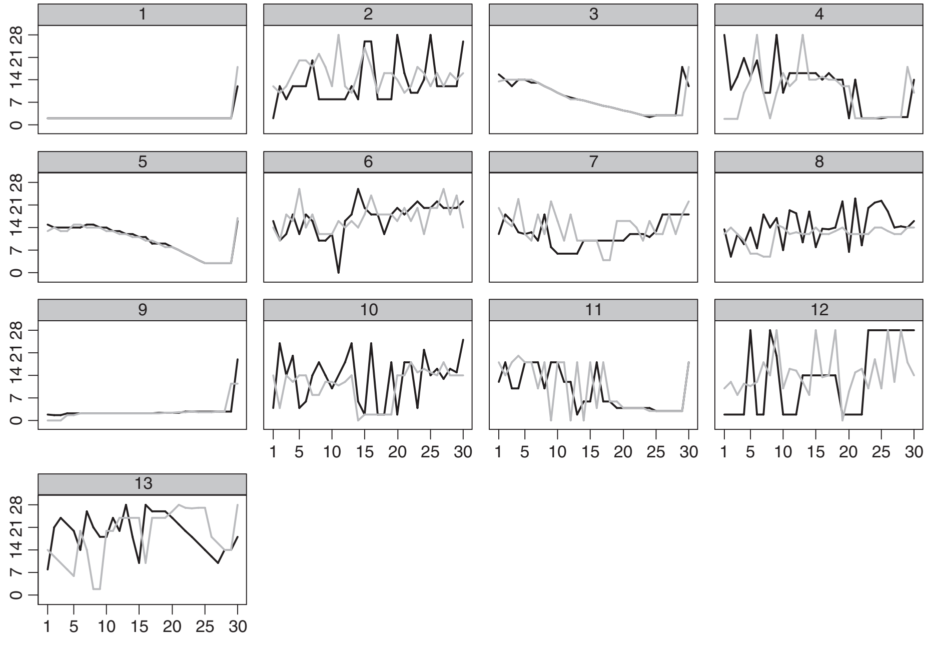

FIGURE C1

SUBSTneg

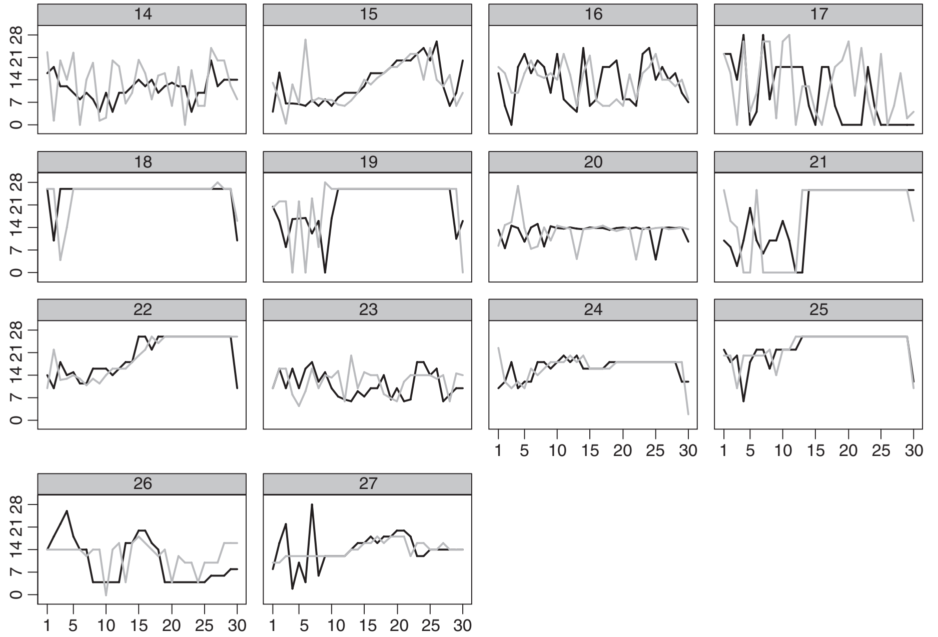

FIGURE C2
SUBSTpos

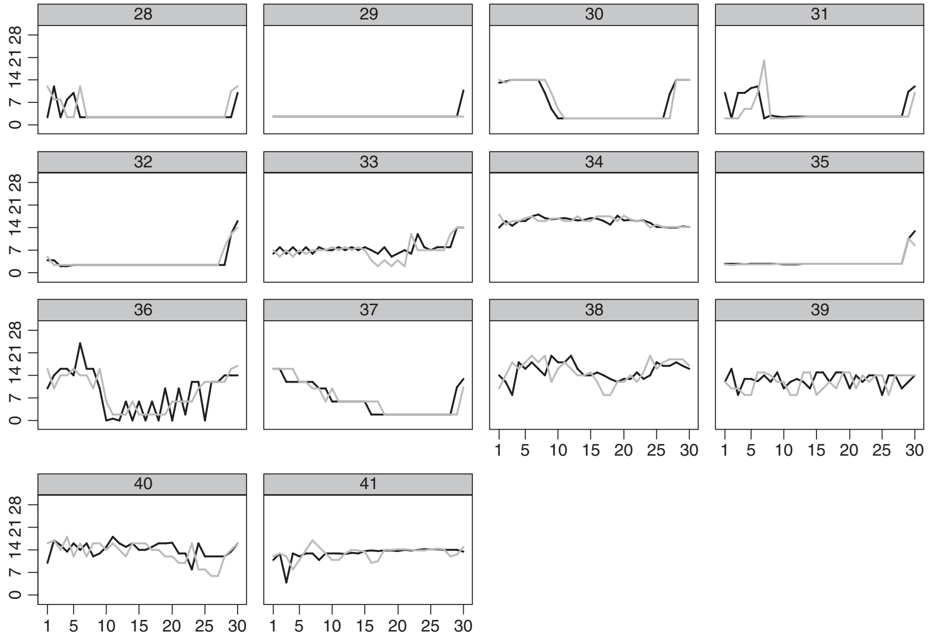

FIGURE C3
COMPLneg

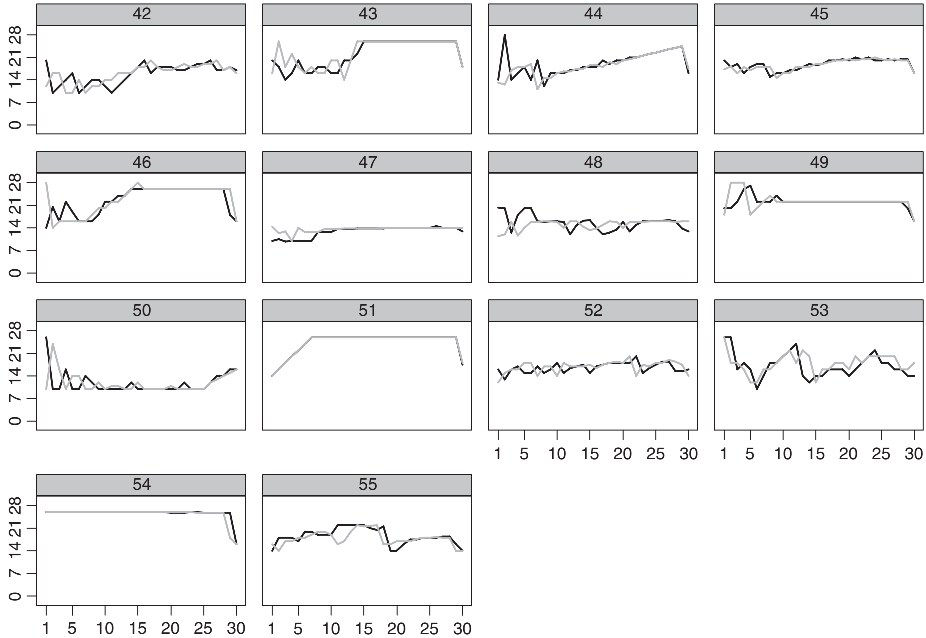

FIGURE C4

COMPLpos

APPENDIX D. SIMULATIONS

We use simulations to show that the interaction between two types of players (cooperative and non-cooperative players) can replicate the key features of the experimental data before end-game effects set in. Non-cooperative players are defined to only play non-cooperatively. In each period they condition their choice on the partner's previous choice: they play a myopic best-reply with probability β and spitefully with probability $1-\beta$ where spiteful play is defined as maximizing the difference in payoffs. Cooperative players are assumed to always reciprocate full mutual cooperation and to try to induce it with some probability. More specifically, a cooperative player is defined to play fully cooperatively for sure in period t if in period $t-1$ the pair reached full cooperation. Otherwise he plays fully cooperatively with probability α_t and non-cooperatively with probability $1-\alpha_t$. In order to add the intuition that the probability of full cooperation depends on whether the partner has responded in a cooperative way to one's own induced cooperation, α_t is history-dependent. That is, given one's own (full) cooperation in period $t-2$, we assume that α_t is the following positive function of the degree of cooperativeness of the partner in period $t-1$: $\alpha_t = 1/(1+e^{-k(y_{t-1}-14)})$. In the first two periods of play and in periods where one did not fully cooperate in period $t-2$, α_t is thus constant and, say, equal to α. The non-cooperative play of a cooperative type is assumed to consist of myopic best-reply with probability $\beta(1-\alpha_t)$ and spiteful play with probability $(1-\beta)(1-\alpha_t)$.

We assume that the share of cooperative players is equal to p and the share of non-cooperative players is equal to $1-p$. We calibrate p by equalizing p^2 to 40%, which is the percentage of JPM pairs observed in the experiment. This implies that among the non-JPM pairs there are $(1-p)^2$ matches of two non-cooperative types as well as $2p(1-p)$ matches of a non-cooperative with a cooperative type. In the first period, cooperative types play fully cooperatively with probability α and otherwise randomize over the full action set. Non-cooperative types always randomize in the first period.

Figure D1 shows average degrees of cooperation for JPM and non-JPM pairs separately, each based on 1000 simulations with $k=0.5$, $\alpha=0{\cdot}4$ and $\beta=0{\cdot}75$.[26] One can see that the simulations replicate the key features of the experimental data. The matching of two cooperative types generates convergence to full cooperation, and before

26. An $\alpha =$ of 0·4 corresponds to the percentage of JPM choices of players in a JPM pair observed in the first round of the experiment.

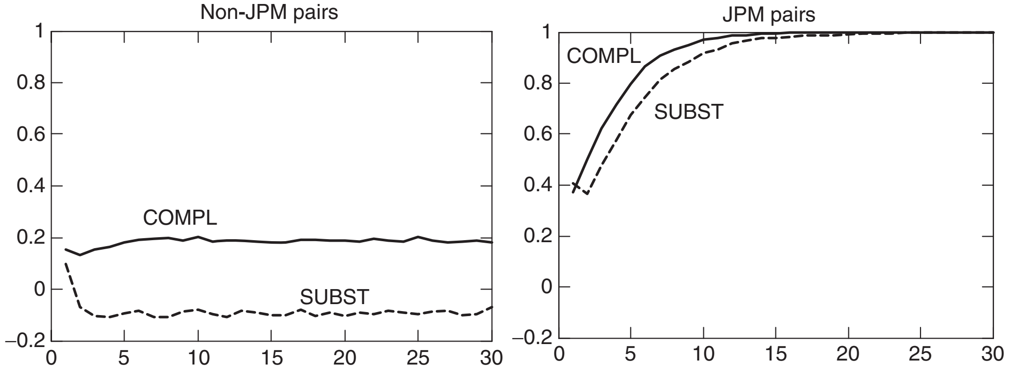

FIGURE D1

Simulated evolution of average degree of cooperation for non-JPM and JPM pairs

convergence is reached, the degree of cooperation is higher under COMPL than under SUBST. Moreover, with COMPL convergence is faster than with SUBST. The main intuition is that a best-reply to full cooperation is more cooperative in the former than in the latter case. This leads to a higher probability of another fully cooperative act (α_t), generating a higher speed of convergence. The difference between SUBST and COMPL for non-JPM pairs is driven by cooperative types meeting non-cooperative types.

We should note that, first, the presence of the spiteful component is not necessary to generate differences between SUBST and COMPL. Its presence is only necessary to replicate negative degrees of cooperation observed for non-JPM pairs in SUBST. That is, the larger β (and thus the smaller the probability of spiteful play), the lower the degree of cooperation of non-JPM pairs and the lower the speed of convergence to full cooperation for JPM pairs. Second, the differences are robust to changes in the baseline probability for a cooperative player to choose the JPM choice (α). The lower α, the lower the speed of convergence. For a large α, however, the difference between SUBST and COMPL in the speed of cooperation build-up of JPM pairs disappears. Third, the qualitative features of the simulation results are robust to changes in k in $\alpha_t = 1/(1 + e^{-k(y_{t-1}-14)})$. Yet, as k decreases, the difference in speed of cooperation build-up of JPM pairs decreases and disappears for $k = 0$. Moreover, the logistic specification is not crucial. A (piecewise) linear specification would generate qualitatively similar differences.

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