Voluntary Separation as a Disciplinary Device for Long-Term Cooperation: Reconciling Theory with Evidence

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May 2018

Abstract

In this paper, we provide an evidence-based theory to explain how partners forge a cooperative relationship when both parties have the liberty to unilaterally terminate the match. We utilize laboratory methods to gather insights on the evolution of cooperation in a voluntarily separable repeated prisoner's dilemma game (VSRPD). We observe behavioral patterns that are at odds with out-for-tat (OFT) which, based on the VSRPD literature, is a disciplinary device that helps facilitate mutual cooperation in the long run. Our Pro-Partnership Proposition is formulated to accommodate the observation that human subjects often favor a more forgiving stay-but-act-like-a-stranger move instead of OFT to punish norm violators. A new class of equilibria, called the CoDe-indifferent equilibria, is introduced to address the within-match rewards and punishments found in the data.

JEL classification: C73, C91

Keywords: voluntary separation, repeated prisoner's dilemma

We are grateful to the Center for Experimental Business Research at the Hong Kong University of Science and Technology for laboratory facilities. Yang gratefully acknowledges financial support from the National Science Council, Taiwan (NSC94-2451-H-001-026). We thank seminar participants at Academia Sinica, Peking University, Groupe dAnalyse et de Thorie Economique, University of Wisconsin-Milwaukee, and Shanghai University of Finance and Economics for their helpful comments.

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1. Introduction

How do self-interested, competitive egoists establish mutual cooperation in the long run? In theory, *Grim Trigger* is perhaps the most effective strategy to sustain cooperation due to its unforgiving nature against exploitation. But this willingness to invoke permanent retaliation has also posed a serious challenge for Grim Trigger to build constructive relationships with responsive, exploratory players. In Axelrod's (1984) renowned computer tournaments, Grim Trigger was ranked the last among the strategies that always started cooperation as their first move. The strategy that came in first was a retaliatory yet more forgiving strategy called *Tit-For-Tat* (TFT)—cooperating on the first move and thereafter copying what the opponent did on the previous move. Although TFT has advantages that help promote its early success, it also has weaknesses which make it less stable and robust from the evolutionary point of view (Selten and Hammerstein, 1984; Fudenberg and Maskin, 1990). In fact, in a series of simulations by Nowak and Sigmund (1992, 1993), TFT is shown to be dominated by *Generous Tit-For-Tat* and *Win-Stay*, *Lose-Shift* (also known as *Pavlov* or *Perfect Tit-For-Tat*).[1] It is important to note that, regardless of whether it is TFT, Generous TFT, Win-Stay, Lose-Shift, or even Grim Trigger, the underlying mechanism that facilitates mutual cooperation is the strategy's willingness to reciprocate. But how does a player reciprocate if her partner could walk away any time to escape punishment or to look for better opportunities? Episodes like this happen often in our real life. Relationships such as business partnerships, co-authorships, romantic relationships, or even marriages are mostly built on a voluntary basis and do not require mutual agreement to dissolve. Unfortunately, there aren't always signs and tags that could help us identify potential cooperative partners either. So, what choices do we have to elicit and sustain cooperation when pre-interaction partner-selection is not possible whereas an option to exit is readily available?

There are two possible options to discipline a cheating partner. The victim could resort

[1] Generous TFT cooperates with a positive probability after its partner defected, and fully otherwise. Win-Stay, Lose-Shift cooperates after mutual cooperation or mutual defection from the last round, and defects otherwise.

to a TFT-like strategy by continuing the interaction, retaliating, and then resuming cooperation. Obviously, this option would not even be an option if the cheater himself has no interest to remain matched. This is perhaps why, so far, the literature on the voluntarily separable repeated prisoner's dilemma game (VSRPD) has relied on more straightforward *Out-For-Tat* (OFT) to attain mutual cooperation in equilibrium (Eeckhout, 2006; Fujiwara-Greve and Okuno-Fujiwara, 2009; Rob and Yang, 2010).[2] In these studies, OFT is coupled with a less cooperative phase which we call the *trust-building phase* that partners have to undergo at the beginning of a match.[3] As soon as a certain condition holds in the trust-building phase, the match enters the *eternal-cooperation phase*. Otherwise, it is dissolved immediately. For example, in an equilibrium proposed by Eeckhout (2006), mutual defection has to be present in the single-period trust-building phase. Fujiwara-Greve and Okuno-Fujiwara (2009) extend this equilibrium to multiple rounds of mutual defection as a cost that partners ought to endure before they could finally enjoy the fruit of mutual cooperation.[4] The painful cost to re-establish a new, cooperative relationship makes OFT a credible threat to deter exploitation or norm violations.

Under numerous conditions, the effectiveness of OFT has received some support from studies that utilize agent-based computer simulations (Schuessler, 1989; Aktipis, 2004; Izquierdo, Izquierdo and Vega-Redondo, 2010, 2014). Yet, there is no empirical evidence which suggests that humans would forgo TFT and use predominantly OFT as a tactic to achieve cooperation. In fact, there are many instances where people are able to overcome challenges to restore their relationships. Therefore, it is a bit too early to rule out TFT as a reasonable strategy either from an empirical or a theoretical point of view. Our contribution to the literature is twofold. First, we contribute to the literature by providing empirical evidence

[2]Datta (1996), Ghosh and Ray (1996), and Kranton (1996) study how cooperation can be achieved when players have an option to terminate the current match and start anew with a different partner in settings different from the standard binary-choice prisoner's dilemma game.

[3]The trust-building phase is the same idea as the phenomenon of gradualism or "starting small" studied by Watson (1999, 2002), Blonski and Probst (2004), and Andreoni and Samuelson (2006). It is worth noting that the feature of heading for the matching pool to start anew is not being considered in these papers.

[4]We will characterize all relevant strategies from the binary-choice VSRPD literature in Section 4.2.

from a laboratory experiment that studies what retaliatory means that human subjects use to achieve mutual cooperation when partners could part ways any time.[5,6] Note that, in reality, there are many reasons why partners prefer not to opt out of a broken relationship. In the case of marriage, for example, children and financial stability are often the main concerns that spouses have during the divorce process. In a laboratory experiment, there is no such attachment between partners which, theoretically speaking, would give OFT a tremendous edge over TFT in our study. In spite of this advantage, we observe behavior that is inconsistent with OFT. And so with the empirical data in hand, our second contribution to the literature is to formulate a theory that could address the behavioral regularities observed in the experiment. To further shed lights on how cooperation comes about, we adopt finite mixture model analysis similar to Breitmoser's (2015) to assess the explanatory power of our theory.

There are two stages in each period of our experiment. Partners simultaneously and independently choose to cooperate or to defect in Stage 1 and, after observing the outcome of the prisoner's dilemma game, decide if they wish to continue the interaction for another period in Stage 2. A match is dissolved immediately if at least one partner decides to leave for the matching pool. Finally, we use a random ending rule to create an infinitely repeated environment. As reported in Section 3, we observe results that are in stark contrast to the current VSRPD literature which suggests that, once a match survives beyond the

[5] Dal Bó (2005), Aoyagi and Fréchette (2009), Duffy and Ochs (2009), Blonski, Ockenfels and Spangalo (2011), Dal Bó and Fréchette (2011), Fudenberg, Rand and Dreber (2012), and Breitmoser (2015), to name just a few, are the most recent examples in the experimental literature that investigate the evolution of cooperation between a fixed set of partners in iterated prisoner's dilemma games. Our paper differs from these studies in that, in our experiment, we allow subjects to leave for the matching pool to be paired with a randomly selected counterpart as they wish. More importantly, we move beyond the experimental arena and aim to consolidate theory with empirical evidence from the lab. See Dal Bó and Fréchette (2017) for a survey on the determinants of cooperation in infinitely repeated games.

[6] Hauk and Nagel (2001) and Hauk (2003) are the very few experimental studies that examine the impact of exit options on cooperation in finitely repeated prisoner's dilemma games. Their experiments differ from ours in many ways. For instance, their exit options focus on *pre-interaction* partner selection, whereas our assortment mechanism is *post-interaction* partner refusal. Also, in their studies, each subject could simultaneously play multiple two-person prisoner's dilemma games with up to six partners, while our subjects only had to deal with one partner in every period. Their games are finitely repeated games, whereas ours is an infinitely repeated game.

initial matching period (the trust-building phase), any deviation from mutual cooperation would prompt a retaliatory breakup. Almost three quarters of the unilateral cooperators in our experiment, when facing such a scenario, choose to continue interacting with their defecting partners. Between-match punishment is obviously not our subjects' first choice against exploitation. Instead, they favor within-match punishment in that the unilateral cooperators' estimated defection rate in the next matching period is close to 75 percent. This defection rate is not significantly different from the initial defection rate in new matches which suggests that, as punishment, most of our unilateral cooperators prefer to treat their defecting counterparts like newly met strangers. The *Pro-Partnership Proposition* proposed in Section 4.2 incorporates this observation and outlines the conditions under which an *out* can be replaced by a *stay-but-act-like-a-stranger* move on the same equilibrium path.

Not only unilateral cooperators are less likely to cooperate with their defecting partners, those who themselves defected in the last matching period are less likely to cooperate with their defecting partners too. In other words, it doesn't matter whether one cooperated in the last period or not, she is less likely to cooperate in the current period if her partner defected last time. In Section 4.3, we introduce a new class of equilibria, which we refer to as the *CoDe-indifferent equilibria*, to address these reciprocal behaviors in different states of the relationship.[7]

Within the class of the CoDe-indifferent equilibria, our focus is on a strategy which we call *Semi-Tit-For-Tat*. The idea of Semi-TFT comes from the observation that unilateral defectors, like those whom they took advantage of, also prefer to reciprocate in kind. These TFT behaviors are at odds not only with the current VSRPD literature but also with the finding by Breitmoser (2015) that direct reciprocity is rarely present in the iterated prisoner's dilemma game between fixed partners.[8] Since we are interested to see how a strategy similar

[7] We term this class of equilibria *CoDe-indifferent* based on the observation that, when facing a defecting partner or a newly paired counterpart, players tend to be indifferent between playing C and D.

[8] According to Breitmoser, following their respective cooperation and defection, a fixed pair of partners would cooperate at the same rate in the next period. Although our data in the voluntary-separation setting contradicts this finding, we do have another set of data collected through a fixed-partnership environment in which direct reciprocity is not being observed as found by Breitmoser.

to Breitmoser's pans out in our voluntary separation setting, we construct a CoDe-indifferent equilibrium strategy, called *Semi-Grim*, that integrates Breitmore's no-direct-reciprocity result. In Section 5 where we estimate the distribution of the strategies used by our subjects, Semi-TFT and Semi-Grim are pitted against Always Defection (ALLD) and several OFT strategies in either their original forms from the literature or their modified versions where *out* is replaced by *stay-but-act-like-a-stranger* as prescribed by the Pro-Partnership Proposition. We find that, when pitted against the OFT strategies in their original forms, Semi-TFT and Semi-Grim alone account for 75 percent of the data. The modification made on the OFT strategies dramatically improve the model fit from their original forms. These modified OFT strategies, when included with Semi-TFT and Semi-Grim, explain 43 percent of the data. Semi-TFT and Semi-Grim together account for a smaller, but still sizable share of 32 percent. These estimates highlight the significance of reciprocating in kind as well as willingness to forgive in promoting long-term cooperation in the VSRPD game.

The rest of the paper is organized as follows. Sections 2 and 3 summarize the experimental design and results. Section 4 proposes the Pro-Partnership Proposition and the class of CoDe-indifferent equilibria. Section 5 reports the estimated results from finite mixture models. Section 6 concludes.

2. The Experiment

The experiment, using a between-subject design, consisted of four sessions with 16 subjects each. Sessions were conducted at Hong Kong University of Science and Technology, 64 undergraduate students were recruited via a university-wide e-Recruit system. Some of the subjects may have participated in previous economics experiments, but none had any experience in experiments similar to ours. No subject participated in more than one session of this study. Sessions lasted about one hour including initial instruction period and cash payment to subjects. Although the experiment was conducted in experimental currency ("francs"), subjects were paid in local currency and earned an average of 14.5 U.S. dollars.[9] All communication between subjects took place via a computer interface that was programmed and conducted using the Ztree software package (Fischbacher, 2007). In other words, decisions were made anonymously.

The timing of activity within a given session was as follows. Upon arriving at the experiment, subjects were randomly assigned a computer terminal in the laboratory. Once everyone was seated, the instructions were then read aloud for the subjects who followed along with their own copy of the text. Subjects were allowed to ask questions at any time. When there were no further questions, the computer randomly divided subjects into eight pairs and the first period began shortly afterward. Each session consisted of 40 periods and each period was divided into two stages. In Stage 1, subjects played a prisoner's dilemma (PD) game with the payoff table presented in Table 1. Decisions were made simultaneously and independently by subjects clicking on the button that represented their decisions on their computer screens.[10] Before the game moved on to Stage 2, the computer displayed a summary screen that included the decisions made by the partners as well as their respective period earnings. In Stage 2, subjects were asked to decide simultaneously and independently whether or not they wished to remain matched with the same counterpart for the next period. They made these decisions by simply clicking on the STAY SAME or BREAK UP button on the screen. The match was terminated if at least one of the two players selected BREAK UP.

[**Table 1: About Here**]

A random ending rule was in effect in order to induce a discount factor of $\frac{7}{8}$. Operationally, the computer was being programmed so that one of the eight matches was randomly terminated at the end of each period.[11] This decision was made independent of the pairs' breakup

[9] For comparison, employees at fast food chains in Hong Kong earned an average hourly wage rate that was less than US$3.

[10] To avoid framing effects in the experiment, we used options A and B to substitute defection and cooperation, respectively.

[11] In case no match was being terminated endogenously, the computer would randomly dissolve two pairs

decisions. Therefore, if the computer happened to dissolve a match that was intended to be continued by both partners, the match would be ended according to the computer's decision. If the computer picked a match that had already been terminated by at least one of the two partners, the partnership would be ended either way. After one's match ended, he or she would enter the matching pool to be paired with a random person from the pool for the next period. It is worth noting that at no time did subjects know about the exact number of players in the matching pool or the identity of their counterparts.

Finally, at the end of Stage 2, the computer summarized two matched counterparts' decisions made in both stages, their period earnings, the computer's breakup decision, and if the match would continue for another period or not.

3. Results from the Experiment

In this section, we will investigate how subjects react to different outcomes from the most recent PD game. More specifically, does exploitation tend to trigger an exit (on the part of the unilateral cooperator) as suggested by the OFT strategies in the literature of VSRPD games? If not, how do partners behave toward each other in the next round of interaction? Do their payoffs justify their continuation and cooperation decisions?

3.1. Continuation and Cooperation Probabilities

We follow Breitmoser's approach (2015) and estimate the average individual 1-memory strategies using random-effects linear probability models.[12] All p-values and standard errors

with a probability of $\frac{1}{2}$. This scenario never occurred in our experiment. There was an average of 7.7 subjects in the matching pool at the end of each period.

[12]As in Breitmoser (2015), we also carry out robustness checks to see if dropping subject-level random effects or having 2-memory instead of 1-memory histories alters the results. The results, included as part of the supplementary materials, are qualitatively the same as what we report here.

are bootstrapped by resampling at the subject level.[13,14] The probabilities of continuation and cooperation are regressed separately. To minimize the impact of learning and end-game effects, only the data from periods 6 to 35 are used in the bootstrap sampling procedure.

Table 2 reports the estimates of continuation and cooperation rates given 1-memory histories. After observing the outcome of mutual cooperation CC in the current period, subjects will choose to stay together 100 percent of the time and cooperate with an 81.1 percent probability in the next period of the PD game. Mutual defection DD yields a 51.9 percent probability that a defector will choose to continue. If the match does survive to the next period, the player will cooperate with a 26.8 percent probability that is not significantly different from the 16.5 percent of cooperation rate when she faces a new partner for the first time. In the case of unilateral defection or cooperation, meaning DC (a given player i defected and her partner cooperated) or CD (a given player i cooperated and her partner defected), the probability that a unilateral defector/cooperator will continue is 74.1/72.2 percent. While the two continuation rates are similar, the cooperation rates in the next period of the PD game are significantly different—66.6 percent by the unilateral defector and 26.4 percent by the unilateral cooperator.

[Table 2: About Here]

It is clear that most of the unilateral cooperators in our experiment would not resort to match termination as the first response to exploitation. But being forgiving doesn't mean that they are lenient. A 26.4 percent of cooperation rate implies that almost three quarters of the unilateral cooperators are willing to retaliate in the next round of the PD game. Note that this defection rate is not significantly different from the initial defection rate in a new match, suggesting that even when it is possible to initiate a breakup to penalize a defector, many unilateral cooperators actually prefer to impose "within-match punishment" treating

[13] 10,000 bootstrap samples are obtained using a random sample with replacement from the original subject pool.

[14] The bootstrapped p-values are adjusted with the Holm-Bonferroni method to control for cohort effects and the multiple-testing problem described in Breitmoser (2015).

the defecting counterpart like a newly met stranger.

The fact that unilateral cooperators do not usually use match termination as a response to exploitation is at odds with the OFT strategies in the literature of VSRPD games. While it may be true that some of the OFT strategies prescribe a conciliatory stay during the trust-building phase, a match should either enter the eternal-cooperation phase or dissolve immediately after at least one partner has chosen to cooperate. In other words, players would never play defection as a retaliatory punishment to elicit good behavior from their partners.

There exists other suggestive evidence that our data are in conflict with the OFT strategies. The OFT strategies differentiate the behavior between the trust-building and the mutual-cooperation phases. The last four columns of Table 2 report the marginal effects of the PD game outcomes from the first matching period (the trust-building phase).[15] Six out of the seven estimates are statistically insignificant, indicating that subjects do not behave differently in the trust-building phase compared to in the rest of the match.

Finally, we would like to point out that, following the outcomes of DC and CD, the estimated cooperation rates in the next period are 66.6 and 26.4 percents respectively. The difference is significant at the 1% level, which is in sharp contrast to Breitmoser's (2015) finding that direct reciprocity rarely prevails in a fixed-partnership setting. The existence of TFT in our voluntary separation setting is also supported by the estimated cooperation probabilities following the outcomes of CC and DD. In sum, we find that players who choose to continue interacting with cooperators will cooperate significantly more than with defectors.

3.2. Expected Payoffs

Does it pay off to continue the partnership than to leave for the matching pool? We use a similar linear regression model as in Section 3.1 to estimate the average period payoffs,

[15]Most of the OFT strategies in the literature assume that the trust-building phase would last only one period. Fujiwara-Greve and Okuno-Fujiwara (2009) is the only exception in which they also explore an equilibrium class that requires possibly more than one period of the trust-building phase. The detail of the literature will be discussed in Section 4.2.

given different 1-memory histories, that a player is likely to earn if she stays with the same partner until the match is terminated exogenously. We compare these estimates with the estimated period payoff at the start of a new match; i.e., if the player leaves for the matching pool and starts anew. The results are reported in Table 3.

[**Table 3: About Here**]

For an average cooperator, the estimated period payoff until the occurrence of an exogenous breakup is 4.428 or 4.059, depending on if her partner played C or D in the most recent PD game. Both estimates are significantly greater than 3.478, which is the estimated period payoff if she is to be paired with a new partner. For a defector, the estimated per period payoff is 3.744 or 3.550, depending on if her partner just played C or D. Neither estimate is significantly different from 3.478 at the 5% level. Therefore, we can conclude that staying in the current relationship, even with a defecting counterpart, is at least as good as leaving for the matching pool.

Next, we ask if players are better off by reciprocating after they have chosen to stay with the same partner for one more period. Table 4 provides the estimated period payoff conditional on the four 1-memory histories as well as on how players themselves behave (playing C or D) in the next round of the PD game. It is clear that players are better off by reciprocating cooperation with cooperation—the payoff by playing C is significantly greater than by playing D regardless of whether the history is CC or DC ($4.541 \gg 3.595$ after CC and $3.979 > 3.420$ after DC). Against a defecting partner, however, players are indifferent between playing C and D ($4.157 \approx 4.020$ after CD and $3.701 \approx 3.474$ after DD). This suggests that the use of retaliatory punishment does not make one worse off. Finally, we note from the last column of Table 4 that when two strangers first meet, their expected payoff by playing C is not significantly different from the payoff by playing D ($3.457 \approx 3.482$), suggesting that players in the matching pool are indifferent between the two moves as well.

[**Table 4: About Here**]

All in all, we do not find support to the OFT strategies in the literature of VSRPD games. It is in a cooperator's best interest to continue the match even with a defecting partner. Facing a cooperative partner, she will be better off by reciprocating in kind. Against a unilateral defector, she will do no worse by returning defection for defection. The benefit of playing such a TFT strategy also applies to defectors as well.

4. An Evidence-Based Theory

In Section 4.1, we will introduce the basic model environment. In Section 4.2, we will propose our *Pro-Partnership Proposition* which incorporates the stay-but-act-like-a-stranger result found in Section 3. More specifically, the Pro-Partnership Proposition will outline the conditions under which an *out* can be replaced by a *stay-but-act-like-a-stranger* move on the same equilibrium paths. With the recipe prescribed by the proposition, we will provide the modified versions of the OFT strategies in the binary-choice VSRPD literature. Finally, in Section 4.3, we will put forward a new class of equilibria, called the *CoDe-indifferent equilibria*, to address the within-match rewards and punishments observed in our data. The term "CoDe-indifferent" is used to reflect the observation that players tend to be indifferent between playing cooperation and defection when they confront a defecting counterpart or a total stranger from the matching pool.

4.1. The Model

Consider a society with a unit mass of infinitely-lived players. Time is discrete and the common discount factor is $\delta \in (0, 1)$. At the beginning of each period, players who are not in an ongoing bilateral partnership are randomly paired into new matches. Once all players are matched in pairs, they choose between cooperation (C) and defection (D) in a two-player simultaneous-move prisoner's dilemma game. Mutual cooperation CC yields a payoff of R (Reward) for each partner, whereas mutual defection DD generates P (Punishment). In the case of CD or DC, the unilateral defector receives T (Temptation) while the unilateral cooperator receives S (Sucker), where $S < P < R < T$. After observing the outcome of the prisoner's dilemma game, players decide simultaneously whether to leave for the matching pool or to stay with the current partner for another period. A match is automatically terminated if at least one of the two partners decides to leave for the matching pool.

Let $t \in \{1, 2, \cdots\}$ be the t^{th} period from the start of the current match (matching period), $m_t \in \Omega = \{\mathrm{CC}, \mathrm{CD}, \mathrm{DC}, \mathrm{DD}\}$ be the outcome of the stage game given by the respective actions chosen by a given player and her partner, and $\pi(m_t) \in \{T, R, P, S\}$ be the player's resulting period payoff. For simplicity, we follow the literature and assume that players' behaviors are match-independent. As a result, we can concentrate solely on the current match's history by denoting h_0 as the initial (empty) history when the match is first formed, $h_t \in (m_\tau)_{\tau=1}^t$ as the history after t plays of the prisoner's dilemma game, H_t as the set of all possible histories given length t, and $H = \bigcup_{t=0}^{\infty} H_t$ as the set of all possible histories.

Definition 1. *A behavior strategy* $\sigma = \left(\{x_\sigma(h)\}_{h \in H}, \{y_\sigma(h)\}_{h \in H \setminus \{h_0\}}\right) \in \Sigma$ *is a pair of mappings where* $x : H \mapsto [0, 1]$ *specifies the probability of cooperation and* $y : H \setminus \{h_0\} \mapsto [0, 1]$ *specifies the probability of continuation.*

We normalize the size of the matching pool to one and assume that, in equilibrium, the behavioral composition in the pool has a stationary distribution $\Phi \in \Delta(\Sigma)$, where Σ is the set of all behavior strategies and $\Delta(\Sigma)$ is the set of probability measures on Σ.[16] Conditional on a player's history $h_t \in H$ and her behavior strategy σ against her partner's strategy from the distribution Φ, let $p_\tau(m|h_t, \sigma, \Phi)$ denote the probability that a certain outcome m will occur in period $\tau > t$. The expected lifetime payoff of the player is therefore $\nu(h_t, \sigma, \Phi) = \sum_{\tau=t+1}^{\infty} \sum_{m \in \Omega} \delta^{\tau-t-1} p_\tau(m|h_t, \sigma, \Phi) \pi(m)$.

[16] In a polymorphic subgame perfect equilibrium, the proportions of different player types in the matching pool may be altered if some players no longer reenter it. Having all the players in the matching pool randomly select a strategy from Φ allows the distribution of the strategies in the pool to remain constant. See Mailath and Samuelson (2006) for further discussion.

Definition 2. $\Phi \in \Delta(\Sigma)$ *is a Nash equilibrium distribution if* $\nu(h_0, \sigma, \Phi) \geq \nu(h_0, \sigma', \Phi)$*, for all* $\sigma \in \operatorname{supp} \Phi$ *and all* $\sigma' \in \Sigma$*. In addition, it is a subgame perfect equilibrium distribution if* $\nu(h_t, \sigma, \Phi) \geq \nu(h_t, \sigma', \Phi)$*, for all* $\sigma \in \operatorname{supp} \Phi$*, all* $\sigma' \in \Sigma$*, and all* $h_t \in H$*.*

4.2. Pro-Partnership Proposition and Modified Out-For-Tat Strategies

Before we propose our Pro-Partnership Proposition, let us elaborate on why it is not necessary to terminate the match in order to support the same equilibrium paths found in the literature of the VSRPD games. Suppose it is common knowledge between two partners that their relationship is reaching an end point. Facing this imminent termination, the players should be indifferent between the following options: (1) moving on to be paired with someone new from the matching pool, and (2) staying with the current partner and acting like a newly met stranger, with an expectation that the partner would behave the same as well. So, for any strategy σ from the stationary subgame perfect equilibrium distribution Φ, consider a modified behavior strategy μ_σ where a player will follow the original strategy σ except when she is facing a new counterpart or when it is common knowledge between her and her partner that their match is about to be dissolved. In the former scenario, the player will randomly select a strategy from $\operatorname{supp} \Phi$. In the latter, she will follow μ_σ's prescription: stay with the current partner with a positive probability and, if the match does continue to the next period, randomly select a strategy from $\operatorname{supp} \Phi$ as if she is matched with a new counterpart. In other words, the player can avoid a breakup by simply imitating the behavior of a randomly selected player from the matching pool without changing her or her partner's expected payoff.

Proposition 1. (Pro-Partnership Proposition)[17] *For any stationary subgame perfect equilibrium distribution* Φ *where an imminent breakup is expected by both partners with certainty,*

[17]Further notations and the formal statement of the Pro-Partnership Proposition are given in the appendices A.1 and A2.

there exists a subgame perfect equilibrium distribution Φ_μ, where $\sigma \in \operatorname{supp}\Phi$ is substituted by its payoff-equivalent modification μ_σ as described above.

Proof. See appendix A. 3. ■

We can apply the Pro-Partnership Proposition to a simple example of monomorphic subgame perfect equilibrium where $\operatorname{supp}\Phi = \{\sigma\}$ and $\sigma = \big(\{x_\sigma(h)\}_{h\in H}, \{y_\sigma(h)\}_{h\in H\setminus\{h_0\}}\big)$. Suppose that, given a player's history h and her partner's mirror history $\tilde{h}$, both partners are expecting an imminent breakup; i.e. $y_\sigma(h)\cdot y_\sigma(\tilde{h}) = 0$. Let $H_\sigma^0 = \{h \in H : y_\sigma(h)\cdot y_\sigma(\tilde{h}) = 0\}$ be the set of all histories in which there is common knowledge between the partners that their match is about to be dissolved, and $H_\sigma^\infty = \{h \in H : \exists N, h = (h^1, h^2, \cdots, h^N)$ where $h^n \in H_\sigma^0$ and $n = 1, 2, \cdots, N\}$ be the set of any sequential combinations of such histories. For any history $h \in H\backslash H_\sigma^\infty$, let h_{end} be the shortest possible history such that $h = (g, h_{end})$ where $g \in H_\sigma^\infty \cup h_0$. Based on the description of the modified behavior strategy above, $\mu_\sigma = \big(\{x_{\mu_\sigma}(h)\}_{h\in H}, \{y_{\mu_\sigma}(h)\}_{h\in H\setminus\{h_0\}}\big) \in \Sigma$, where $x_{\mu_\sigma}(h) = x_\sigma(h_0)$ and $y_{\mu_\sigma}(h) > 0$ for $\forall h \in H_\sigma^\infty$, and $x_{\mu_\sigma}(h) = x_\sigma(h_{end})$ and $y_{\mu_\sigma}(h) = y_\sigma(h_{end})$ for $\forall h \in H\backslash H_\sigma^\infty$. It should come as no surprise that the two strategies σ and μ_σ are indeed payoff equivalent for any given history.

It is worth noting that, in all the OFT equilibria proposed in the literature, whether or not a match is about to end is assumed to be common knowledge between the partners. Since the condition of the Pro-Partnership Proposition is satisfied, we can modify those equilibria in a way that is described by μ_σ. But before we do so, let us first define Markov strategy that will come in handy later.

Definition 3. *A behavior strategy σ is a Markov strategy (or finite automaton) if there exists a finite partition $\Lambda = \{A_k\}_{k=0}^K$ of H into K states such that $A(h) = A(h')$ implies $\sigma(h) = \sigma(h')$, for all $h, h' \in H$.*

A Markov strategy is a strategy that depends solely on the current state $A(h)$, which implies that we can redefine the cooperation decision as $x : \Lambda \mapsto [0, 1]$ and, for simplicity, characterize the subsequent continuation decision as $y : \Lambda \times \Omega \mapsto [0, 1]$.[18] Conditional on both partners agreeing to continue, we define a state transition probability $\eta(A'|A, m)$ from state A to A' as $\eta : \Lambda \times \Omega \mapsto \Delta(\Lambda)$, where A and $A' \in \Lambda$ are the states at the start of matching period t and $t + 1$, respectively, and $m \in \Omega$ is the outcome of the prisoner's dilemma game in matching period t. If at least one partner decides to leave, both players will return to the initial state $A(h_0) = A_0 \in \Lambda$. Note that with a Markov strategy where $y(A, m) = 0$, partners should dissolve the match and enter A_0 with certainty. In case they mistakenly choose to continue, they will enter $A' \in \Lambda_{\mathit{off}}$, where $\Lambda_{\mathit{off}} \subset \Lambda$ if and only if there exist $A \in \Lambda$, $m \in \Omega$, and $h \in A$ such that $y(A, m) = 0$ and $(h, m) \in A'$.

As in the standard fixed-partnership setting, Always Defect (ALLD) is also an equilibrium strategy in the VSRPD games. Using the framework described above, we can define ALLD on the equilibrium path as $x(A_0) = 0$, $y(A_0, \text{DD}) = y_{\text{DD}} \in [0, 1]$, and $\eta(A_0|A_0, \text{DD}) = 1$. For the purpose of the model-fitting data analysis in Section 5, we assume that a player who observes an outcome $m \neq \text{DD}$ and thus is away from the equilibrium path will continue the match with some probability y_m and then play ALLD as if she is on the equilibrium path; i.e. $\Lambda_{\mathit{off}} = \{A_0\}$, $y(A_0, m) = y_m$, and $\eta(A_0|A_0, m) = 1$, for $\forall m$.[19]

As mentioned before, the OFT strategies proposed in the literature of the VSRPD game all have a trust-building phase preceding the eternal-cooperation phase. To fully characterize this common feature, let A_{EC} be the state of eternal cooperation where $x(A_{EC}) = 1$, $y(A_{EC}, m) = 1$ and $\eta(A_{EC}|A_{EC}, m) = 1$ if $m = \text{CC}$, and $y(A_{EC}, m) = 0$ and $\eta(A_0|A_{EC}, m) = 1$ if $m \neq \text{CC}$. In addition, let $x(A_0) = x_0$ be the cooperation probability when two partners meet for the first time and $M \subset \Omega$ be a subset of the outcomes from the most recent prisoner's dilemma game. The trust-building phase is such that $y(A_t, m) = 1$ and $\eta(A_{t+1}|A_t, m) = 1$ if $m \in M$, and $y(A_t, m) = 0$ and $\eta(A_0|A_t, m) = 1$ if $m \notin M$, for $t \in \{0, n-1\}$ and

[18] Alternatively, we could define $\Lambda = \Lambda_X \cup \Lambda_Y$, $x : \Lambda_X \mapsto [0, 1]$ and $y : \Lambda_Y \mapsto [0, 1]$, where Λ_Y is a partition of $\Lambda_X \times \Omega$. In doing so, we would have four more continuation states for each cooperation state we have.

[19] We require a player to always defect even outside the equilibrium path in order to limit the possibility to mischaracterize a cooperation strategy as the ALLD strategy in the data. Furthermore, to reduce the computational complexity for the data analysis in Section 5, we assume that players will choose same continuation probability given each state when they are off the equilibrium path.

$A_n = A_{EC}$. There are four classes of OFT equilibria put forward by Eeckhout (2006) and Rob and Yang (2010) in which the trust-building phase lasts only one period ($n = 1$): (1) the *forgiving-start* OFT (fOFT) where at least one cooperative play is required for the match to advance to the eternal-cooperation phase ($M = \{\text{CC}, \text{CD}, \text{DC}\}$) and $x(A_0) = x_0^f$; (2) the *asymmetric-start* OFT (aOFT) where partners are required to make opposite moves in the trust-building phase ($M = \{\text{CD}, \text{DC}\}$) and $x(A_0) = x_0^a$; (3) the *low-careful-start* OFT (lOFT) where $M = \{\text{CC}\}$ and $x(A_0) = x_0^l$; (4) the *high-careful-start* OFT (hOFT) where $M = \{\text{CC}\}$ and $x(A_0) = x_0^h > x_0^l$.[20] The initial cooperation rates x_0^f, x_0^a, x_0^l, and x_0^h are uniquely determined by their respective model parameters.[21] Finally, Eeckhout (2006) and Fujiwara-Greve and Okuno-Fujiwara (2009) explore an equilibrium class which we call *n-defections* OFT (nOFT) where a minimum number of mutual defections $n_{\min}$ is needed to enter the eternal-cooperation phase; i.e., $n \geq n_{\min}$ and $M = \{\text{DD}\}$.[22]

Again, for the model-fitting analysis in Section 5, we need to characterize the set of off-equilibrium states Λ_{off} for the OFT equilibria as well. Obviously, it would be more convenient for us to simply assume that players always defect and leave and, in case they both make a trembling hand mistake and decide to continue, they would remain in the off-equilibrium state Λ_{off}. But to avoid incorrectly identifying subjects as being trapped in Λ_{off} and also to give the OFT equilibria their best shot to fit the data, we prefer to relax this assumption and assume $\Lambda_{\mathit{off}} = A_0$ instead. In other words, if both partners choose to continue the match by mistake, they will be able to revert back to the equilibrium path as if they were in A_0. Table 5 presents all the strategies that we summarize here.

[20] We rename these equilibria from the literature for easy comparison in this paper.

[21] With the parameters used in our experiment, the initial cooperation rate in the fOFT equilibrium x_0^f equals approximately 0.2783. It is given by the following system of equations: $\nu_0^f = x_0^f(R + \delta\nu_{EC}) + (1 - x_0^f)(S + \delta\nu_{EC})$ and $\nu_0^f = x_0^f(T + \delta\nu_{EC}) + (1 - x_0^f)(P + \delta\nu_0^f)$, where ν_0^f is the lifetime utility in the initial state and $\nu_{EC} = \frac{R}{1-\delta}$ is the lifetime utility in the eternal cooperation state. The cooperation rate in the aOFT equilibrium x_0^a is approximately 0.2348, which is obtained by solving the following system of equations: $\nu_0^a = x_0^a(R + \delta\nu_0^a) + (1 - x_0^a)(S + \delta\nu_{EC})$ and $\nu_0^a = x_0^a(T + \delta\nu_{EC}) + (1 - x_0^a)(P + \delta\nu_0^a)$. x_0^l and x_0^h, which equal $\frac{1}{7}$ and $\frac{1}{3}$ respectively, are the two solutions to $\nu_0^{l,h} = x_0^{l,h}(R + \delta\nu_0^{l,h}) + (1 - x_0^{l,h})(S + \delta\nu_{EC})$ and $\nu_0^{l,h} = x_0^{l,h}(T + \delta\nu_0^{l,h}) + (1 - x_0^{l,h})(P + \delta\nu_0^{l,h})$.

[22] $n_{\min} = \ln\left(1 - \frac{\delta}{1-\delta} - \frac{T-R}{\delta(R-P)}\right)$, which is the solution to $T - R \leq \frac{\delta(1-\delta^{n_{\min}})}{1-\delta}(R - P)$.

[Table 5: About Here]

With what has been defined so far, all our Pro-Partnership proposition does is to change an OFT strategy from $y(A, m) = 0$ to $y(A, m) = y_m \in (0, 1]$ if $m \notin M$ for the trust-building phase, and from $y(A_{EC}, m) = 0$ to $y(A_{EC}, m) = y_m$ if $m \neq \text{CC}$ for the eternal-cooperation phase, so that players could choose to stay *in* rather than *out*. It also modifies the strategy in the off-equilibrium state as $x(A_{\mathit{off}}) = x(A_0)$, $y(A_{\mathit{off}}, m) = y(A_0, m)$, and $\eta(A_{\mathit{off}}, m) = \eta(A_0, m)$, for all $m \in \Omega$, so that those who choose to stay *in* would only need to behave like strangers from the matching pool in order to justify that an *out* is not necessary to elicit long-term cooperation. Table 6 summarizes these modifications with the off-equilibrium state A_{off}, which is now equivalent to A_0, not being separately laid out.

[Table 6: About Here]

4.3. CoDe-Indifferent Equilibria

While the Pro-Partnership Proposition incorporates our most important experimental finding that the majority of the unilateral cooperators prefer to use within-match punishment as a response to exploitation, it does not capture the finding that many unilateral defectors tend to reciprocate in kind as well. We will introduce a new class of equilibria called the *CoDe-indifferent equilibria* in this section to address these within-match rewards and punishments in our VSRPD game.

Definition 4. *A subgame perfect equilibrium strategy σ^* is called CoDe-indifferent if a player is indifferent between cooperation and defection anywhere on the equilibrium path.*

Let us consider a CoDe-indifferent 5-state Markov strategy σ^* as follows. Let $\Lambda = \{A_0, A_{\text{CC}}, A_{\text{CD}}, A_{\text{DC}}, A_{\text{DD}}\}$ be a set of five possible states in which a player must first make a cooperation decision $x(A_j) = x_j$, where $j \in \{0, \text{CC}, \text{CD}, \text{DC}, \text{DD}\}$, and then, given the outcome of the PD game $m \in \Omega = \{\text{CC}, \text{CD}, \text{DC}, \text{DD}\}$, a continuation decision $y(A_j, m) =$

y_m. The player will transition to a state A_m with $\eta(A_m|A_j, m) = 1$ if both she and her partner choose to stay, or to the initial state A_0 if at least one of the two partners decide to part ways (both on and off the equilibrium path).[23] Figure 1 presents a flow diagram with the five states and their respective cooperation, continuation, and transition probabilities.

[Figure 1: About Here]

To reconcile theory with evidence, we rely on our experimental data to guide us through the construction of the CoDe-indifferent equilibria. Since the results reported in Table 2 suggest that $x_{\text{DD}} < x_{\text{DC}}$, $x_{\text{CD}} < x_{\text{CC}}$, and $x_0 \approx x_{\text{DD}} \approx x_{\text{CD}}$, we decide to first consider equilibria in which these cooperation results are satisfied but, in terms of the continuation decision, we restrict ourselves to a more extreme case where $y_m = 1$, for all $m \in \Omega$. Proposition 2 below provides the condition under which such CoDe-indifferent subgame perfect equilibria always exists. Later in Proposition 3, we will allow match termination to occur; i.e., $y_m < 1$.

Proposition 2. *If $\delta \geq \max\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\}$, then there exists a CoDe-indifferent subgame perfect equilibrium in the form of $\sigma^* = \{x_0, (x_m, y_m)_{m\in\Omega}\}$, where $x_0 \leq \min\{x_{\text{DD}}, x_{\text{CD}}\}$, $x_{\text{DD}} < x_{\text{DC}}$, $x_{\text{CD}} < x_{\text{CC}}$, and $y_{\text{CC}} = y_{\text{CD}} = y_{\text{DC}} = y_{\text{DD}} = 1$.*

Proof. See appendix A. 4.[24] ■

$x_0 \leq \min\{x_{\text{DD}}, x_{\text{CD}}\}$ suggests that one should never expect a stranger from the matching pool to be more cooperative than her defecting partner. $x_{\text{DD}} < x_{\text{DC}}$ and $x_{\text{CD}} < x_{\text{CC}}$ imply that a player is less likely to cooperate with a defector than with a cooperator, regardless

[23] Our CoDe-indifferent equilibrium strategy is similar to the so-called belief-free equilibrium in a fixed-partnership setting (see Ely, Horner and Olszewski, 2005). The difference between the two equilibrium concepts is that players may not always be indifferent between staying and leaving in a voluntary separation setting according to our construction.

[24] The intuition behind the condition $\delta \geq \max\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\}$ is straightforward. On one hand, playing D rather than C will yield an extra period payoff of $T - R$ or $P - S$, depending on whether the partner cooperates. On the other hand, playing D will trigger a punishment which, in the worst-case scenario, will generate an expected payoff loss of $\frac{\delta(R-P)}{1-\delta}$ (the difference between the expected payoffs from eternal mutual cooperation and eternal mutual defection). Comparing $\frac{\delta(R-P)}{1-\delta}$ with $\max\{T - R, P - S\}$ yields the condition $\delta \geq \max\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\}$.

of whether she herself cooperated in the last period or not. It is reciprocating in kind, not out-for-tat, that constitutes a CoDe-indifferent equilibrium strategy.

The rather loose condition $\delta \geq \max\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\}$ in Proposition 2 gives a great deal of freedom to the precise relationships among the five state-dependent cooperation rates. In fact, multiple equilibria where cooperation rates are ranked differently can exist simultaneously. A complete classification of the CoDe-indifferent equilibria is summarized in Corollary 1.

Corollary 1. *Given $\delta \geq \max\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\}$, there exist several types of CoDe-indifferent equilibria with $y_{\mathrm{CC}} = y_{\mathrm{CD}} = y_{\mathrm{DC}} = y_{\mathrm{DD}} = 1$ that can be characterized according to the following conditions:*

A.	$x_0 \leq x_{\mathrm{DD}} < x_{\mathrm{DC}} \leq x_{\mathrm{CD}} < x_{\mathrm{CC}}$	*if* $\delta \geq \frac{T-R+P-S}{T-S}$*;*
B.	$x_0 \leq x_{\mathrm{DD}} \leq x_{\mathrm{CD}} < x_{\mathrm{DC}} \leq x_{\mathrm{CC}}$	*always;*
C_1.	$x_0 \leq x_{\mathrm{CD}} \leq x_{\mathrm{DD}} < x_{\mathrm{DC}} \leq x_{\mathrm{CC}}$	*if* $T + S \geq R + P$ *(sub-modularity);*
C_2.	$x_0 \leq x_{\mathrm{DD}} \leq x_{\mathrm{CD}} < x_{\mathrm{CC}} \leq x_{\mathrm{DC}}$	*if* $T + S \leq R + P$ *(super-modularity);*
D.	$x_0 \leq x_{\mathrm{CD}} \leq x_{\mathrm{DD}} < x_{\mathrm{CC}} \leq x_{\mathrm{DC}}$	*if* $\delta \geq \max\{\frac{T-R}{R-S}, \frac{P-S}{T-P}\}$*;*
E.	$x_0 \leq x_{\mathrm{CD}} < x_{\mathrm{CC}} \leq x_{\mathrm{DD}} < x_{\mathrm{DC}}$	*if* $\delta \geq \frac{T-R+P-S}{R-P}$*.*

Proof. See appendix A. 5. ■

The discount and payoff parameters used in our experiment satisfy $\delta \geq \max\left\{\frac{T-R}{T-P}, \frac{P-S}{R-S}, \frac{T-R+P-S}{T-S}, \frac{T-R+P-S}{R-P}\right\}$ and $T + S > R + P$, but not $\delta \geq \frac{T-R+P-S}{R-P}$. Therefore, in our VSRPD game, there exist equilibrium types A, B, C_1 and D, but not C_2 or E. Figure 2 illustrates the range of x_{DD} and x_{CC} for types A, B, C_1 and D given our parameters.

[Figure 2: About Here]

Next, we consider a CoDe-indifferent subgame perfect equilibrium that allows match termination to reflect the continuation decisions summarized in Table 2. Proposition 3 below shows that match termination can become part of the equilibrium strategy when $x_0 = \min\{x_{\mathrm{DD}}, x_{\mathrm{CD}}\}$. In other words, when a newly matched counterpart is equally likely to cooperate with you as your current defecting partner, leaving for the matching pool is as good as staying in the same match. This indifference between leaving and staying leads to the possibility to terminate the match.

Proposition 3. *If $\delta > \max\left\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\right\}$, then there exists a CoDe-indifferent subgame perfect equilibrium in the form of $\sigma^* = \{x_0, (x_m, y_m)_{m\in\Omega}\}$, where $x_0 = \min\{x_{\mathrm{DD}}, x_{\mathrm{CD}}\}$, $x_{\mathrm{DD}} < x_{\mathrm{DC}}$, $x_{\mathrm{CD}} < x_{\mathrm{CC}}$,*

i. $y_{\mathrm{CC}} = y_{\mathrm{CD}} = y_{\mathrm{DC}} = 1$ and $y_{\mathrm{DD}} < 1$, if $x_0 = x_{\mathrm{DD}}$;

ii. $y_{\mathrm{CC}} = y_{\mathrm{CD}} = y_{\mathrm{DD}} = 1$ and $y_{\mathrm{DC}} < 1$, if $x_0 = x_{\mathrm{CD}}$;

iii. $y_{\mathrm{CC}} = y_{\mathrm{CD}} = 1$, $y_{\mathrm{DC}} < 1$ and $y_{\mathrm{DD}} < 1$, if $x_0 = x_{\mathrm{DD}} = x_{\mathrm{CD}}$.

Proof. See appendix A. 6. ∎

Based on Proposition 3, we propose two special cases of CoDe-indifferent equilibrium: Semi-Tit-For-Tat (sTFT) and Semi-Grim (sGrim). In both cases, mutual defecting partners in the state A_{DD} would treat each other like strangers as in the initial state A_0; i.e., $x_0 = x_{\mathrm{DD}}$. In a Semi-TFT equilibrium, we assume that players, irrespective of their own choice made in the last period, are less likely to cooperate following their partners' defection. That is, $x_{\mathrm{DD}} < x_{\mathrm{DC}}$ and $x_{\mathrm{CD}} < x_{\mathrm{CC}}$. Moreover, to fully reflect the results reported in Table 2, we assume that $x_0 = x_{\mathrm{DD}} = x_{\mathrm{CD}} < x_{\mathrm{DC}} = x_{\mathrm{CC}}$. In a Semi-Grim equilibrium, we simply follow Breitmoser (2015) and assume that $x_{\mathrm{DC}} = x_{\mathrm{CD}}$. As a result, we have $x_0 = x_{\mathrm{DD}} < x_{\mathrm{DC}} = x_{\mathrm{CD}} < x_{\mathrm{CC}}$ in Semi-Grim.

Corollary 2. *If $\delta > \frac{T-R}{T-P} > \frac{P-S}{R-S}$, then there exists a CoDe-indifferent subgame perfect equilibrium, called Semi-Tit-For-Tat (sTFT), in the form of $\sigma^* = \{x_0, (x_m, y_m)_{m\in\Omega}\}$, where $x_0 = x_{\mathrm{CD}} = x_{\mathrm{DD}} \in [0, 1 - \frac{T-R}{\delta(T-P)}]$, $x_{\mathrm{CC}} = x_{\mathrm{DC}} = x_0 + \frac{T-R}{\delta(T-P)}$, $y_{\mathrm{CC}} = y_{\mathrm{CD}} = 1$, $y_{\mathrm{DC}} = \frac{P-S}{T-R}$, and $y_{\mathrm{DD}} \in [0, 1)$.*

Proof. See appendix A. 7. ∎

Corollary 3. *If $\delta \geq \frac{T-R+P-S}{T-S}$, then there exists a CoDe-indifferent subgame perfect equilibrium, called Semi-Grim (sGrim), in the form of $\sigma^* = \{x_0, (x_m, y_m)_{m\in\Omega}\}$, where $x_0 = x_{\mathrm{DD}} \in$*

$[0, 1-\frac{T-R+P-S}{\delta(T-S)}]$, $x_{\text{CD}} = x_{\text{DC}} = x_0 + \frac{P-S}{\delta(T-S)}$, $x_{\text{CC}} = x_0 + \frac{T-R+P-S}{\delta(T-S)}$, $y_{\text{CC}} = y_{\text{CD}} = y_{\text{DC}} = 1$, *and* $y_{\text{DD}} \in [0, 1)$.

Proof. See appendix A. 8. ■

The Semi-TFT and Semi-Grim equilibrium strategies, given the parameters used in our experiment, are summarized in Table 7.

[Table 7: About Here]

5. Distribution of Individual Strategies

In this section, we adopt finite mixture model analysis similar to Breitmoser's (2015) to estimate the distributions of the strategies used by our experimental subjects. In the Baseline model, we focus our attention on ALLD and the five OFT strategies—fOFT, aOFT, lOFT, hOFT, and nOFT—in their original forms. In the Pro-Partnership model, we consider ALLD and the modified OFT strategies where *out* is substituted with *stay-but-act-like-a-stranger* as prescribed by our Pro-Partnership Proposition. In the Augmented Baseline or Augmented Pro-Partnership model, we add Semi-Grim and Semi-TFT to see if our new CoDe-indifferent strategies help further explain the data.

Our finite mixture modeling procedure begins with a set of six strategies (or eight if Semi-Grim and Semi-TFT are considered). Unlike Breitmoser (2015) who conducts multiple rounds of elimination where exactly one strategy is removed from the list of survival strategies from the previous round, we consider all elimination orders and do not exclude the possibilities that a strategy discarded earlier may become significant after other strategies have been removed. We believe that this modification, exempt from elimination-order effects, is able to provide a more robust procedure to identify a model that best fits our data.[25] Other than this departure, we follow Breitmoser closely in that the frequency of

[25]It turns out that the final results, reported in Table 8, are the same as the results obtained using

each strategy being used, the continuation rates in different states as shown in Tables 5-7, and a noise parameter $\gamma \in (0, 1)$ that allows for trembling-hand errors are estimated by minimizing log-likelihood, and that the nested models are assessed using the criterion of ICL-BIC (integrated classification likelihood-Bayesian information criterion).[26,27] The model that has the smallest ICL-BIC value for the Baseline, Pro-Partnership, Augmented Baseline, and Augmented Pro-Partnership, respectively, are selected and reported in Table 8.

[**Table 8: About Here**]

It is important to note that the ICL-BIC value of the Pro-Partnership Model is smaller than that of the Baseline Model. This is true when comparing the Augmented Pro-Partnership with the Augmented Baseline as well. In other words, the substitution of stay-but-act-like-a-stranger for exit provides a better model fit for our data. Furthermore, the two augmented models' ICL-BIC values are smaller than their respective counterparts'. This highlights the empirical relevance of our two CoDe-indifferent strategies. In fact, when pitted against the OFT strategies in their original forms in the Augmented Baseline Model, Semi-TFT and Semi-Grim together account for 74.6 percent of the strategies used by our subjects. Even against the modified OFT strategies in the Augmented Pro-Partnership model, the use of the two CoDe-indifferent strategies is still prevalent, explaining about 32.1 percent of the data.

In terms of the OFT strategies, fOFT, lOFT, and hOFT are the only relevant ones in the Augmented Baseline Model. Together, they account for merely 16.8 percent of the data. After the stay-but-act-like-a-stranger modification, 43 percent of the strategies can be ex-

Breitmoser's procedure. The estimated mixtures of the strategies that survive in each round of the elimination process are included as part of the supplementary materials.

[26]The inclusion of the noise parameter γ reduces the chances to misclassify pure strategies with trembling-hand errors as mixed strategies. We assume that the noise is not only constant across subjects and histories, but also independent of decisions being made in stage 1 or 2. We also estimate models without the noise parameter ($\gamma = 0$) and find that the without-noise models have worse fits than their with-noise counterparts. Nonetheless, we continue to find that the pro-partnership modification improves ICL-BIC and that a majority of subjects choose to play Semi-TFT and Semi-Grim in the without-noise models. The results, included as part of the supplementary materials, are qualitatively the same as what we reported here.

[27]See Breitmoser's appendix for the technical details.

plained by either fOFT^{P} or hOFT^{P}. This considerable change suggests that the modification engineered on the OFT strategies not only improves the overall model fit but also enhances the explanatory power of the individual strategies.

In sum, we find that the model that consists of the OFT strategies proposed in the literature has the poorest model fit, whereas the one that considers the modified OFT strategies as well as Semi-TFT and Semi-Grim performs the best.

6. Conclusion

In this paper, we study how partners forge a cooperative relationship when either party could unilaterally dissolve the match any time as he or she wishes. There are plenty anecdotes which suggest that many people, even when they have the liberty to walk away, prefer to give their unfaithful or uncooperative partners a second chance. Such behavior is at odds with the current VSRPD literature where OFT is assumed to be the vehicle through which long-run cooperation can be obtained. In light of this disparity, our goal in this paper is to put forward a theory that is capable of explaining real human behavior. Of course, we can't build our theory based on anecdotes. Instead, the theory proposed here has a behavioral foundation that is derived from the data collected through a laboratory experiment. There are two stages in each period of the experiment. Partners first play a prisoner's dilemma game in Stage 1 and, after observing the outcome of the stage game, decide if they wish to head for the matching pool in Stage 2. The match is dissolved as long as one partner wishes to do so. We find results that are consistent with anecdotal evidence in that match termination is usually not our subjects' first choice against exploitation. Most players prefer to stay with their defecting partners and reciprocate with a cooperation rate that is not significantly different from the rate against a newly matched counterpart. Taking this result into consideration, our Pro-Partnership Proposition proposes an alternative—the stay-but-act-like-a-stranger move—to support the same equilibrium paths found in the VSRPD literature. Note that the Pro-Partnership Proposition implies that, when the intentions of a potential partner from the matching pool are not known, it may be in one's best interest to continue the current match and coax the defecting partner into cooperation. In other words, the grass may not necessarily be greener on the other side of the fence if there is no means to screen or identify the other player's type prior to any interaction. We modify various OFT strategies in the literature according to the proposition and find that such an alteration is able to dramatically improve the explanatory power of individual strategies as well as the overall model fit.

In addition to the Pro-Partnership Proposition, we also offer a new class of equilibria, called the CoDe-indifferent equilibria, to reflect the reciprocal behavior observed in the data. Within this class of the equilibria, Semi-TFT instructs a player to reciprocate defection (cooperation) with a cooperation rate that is the same as (greater than) the rate against a stranger. This implies that a unilateral cooperator from the last period must cooperate at a smaller rate than her defecting partner in the current period. Semi-Grim is similar to Semi-TFT, although in Semi-Grim a unilateral cooperator and her defecting partner would cooperate at the same rate in the current period. We include both Semi-TFT and Semi-Grim in our finite mixture model analysis. Against the original OFT strategies, the two CoDe-indifferent strategies account for 29 and 45 percents of the behavior, respectively, in our data. Against the modified OFTs that are shown to have better explanatory power, the shares are 19 and 13 percents, respectively. These estimates suggest that, to achieve long-term cooperation, the willingness to forgive (by staying with a defecting partner) and to reciprocate in kind (by using within-match rewards and punishments) is crucial even for the case when partners have the liberty to part ways any time.

We believe that our evidence-based theory has offered an important first step to unite theory with empirical evidence for the VSRPD literature. A possible extension for future research would be to utilize the method of computational simulation to explore the dynamic evolution of our model. Allowing information flow between partnerships would be another possible extension to study the robustness of the results reported here.

Appendix A. Notations and Proofs

A.1. Notations for the Formal Statement of Proposition 1

Recall that $\Phi \in \Delta(\Sigma)$ is the distribution of the behavioral composition in the matching pool. Let $\Phi(\cdot|h)$ be a player's updated belief about the distribution given the history of her current match h and thus $\Phi(\cdot|h_0) = \Phi$. As the match progresses, the player starts ruling out some of her counterpart's strategies that are inconsistent with the realized history, i.e., $\operatorname{supp}\Phi(\cdot|h) \subseteq \operatorname{supp}\Phi(\cdot|g)$ if $g \subset h$. It follows that a history h is on the equilibrium path if and only if $\operatorname{supp}\Phi(\cdot|h) \neq \emptyset$.

Let $H_\Phi \subset H$ denote all possible histories on the equilibrium path under Φ. For all $h \in H_\Phi$, $E_h y = \sum_{\sigma \in \operatorname{supp}\Phi(\cdot|h)} \Phi(\sigma|h) y_\sigma(h)$ is then the likelihood that the player will choose to continue in equilibrium given h. Let $\tilde{h}$ denote the partner's mirror history, $H_\Phi^0 = \{h \in H_\Phi : E_h y \cdot E_{\tilde{h}} y = 0\}$ be the set of all histories in which there is common knowledge between the players that their match is about to be dissolved, and $H_\Phi^\infty = \{h \in H : \exists N, h = (h^1, h^2, \cdots h^N)$ with $h^n \in H_\Phi^0, n = 1, 2, \cdots N\}$ be the set of any sequential combinations of such histories.

For any $\sigma \in \operatorname{supp}\Phi$, consider a modified behavior strategy μ_σ as follows. A player with a history h_0 always randomly selects a strategy from $\operatorname{supp}\Phi$. A player with a history $h \in H_\Phi^\infty$ would continue her match with a probability $y_{\mu_\sigma}(h) > 0$ and, if the match does survive to the next period, randomly select a strategy from $\operatorname{supp}\Phi$ as if she is paired with a new partner. It follows from the definitions of H_Φ^0 and H_Φ^∞ that her partner will behave exactly the same. In other words, whenever there is a common knowledge that the match has arrived an end point, instead of breaking up with each other as prescribed by σ, both players could follow μ_σ's instructions—continuing the interactions and acting like newly met strangers from the matching pool—without altering their respective expected payoff.

A.2. Formal Statement of Proposition 1

For any subgame perfect equilibrium distribution Φ where $H_{\Phi}^{\infty} \neq \emptyset$, there exists a subgame perfect equilibrium distribution Φ_{μ} in which $\sigma \in \operatorname{supp} \Phi$ is substituted by its payoff-equivalent modification μ_{σ} with $H_{\Phi_{\mu}}^{\infty} = \emptyset$ as described in A.1.

A.3. Proof of Proposition 1

Under the original Φ, partners with $h \in H_{\Phi}^{\infty} \neq \emptyset$ would enter the matching pool and earn an expected payoff of $v(h_0, \sigma, \Phi) = v_0$. Since all the modified strategy μ_{σ} does is to ask the partners to continue the match but treat each other like newly met strangers from the pool, i.e., to replace particular subgames played by two strangers with h_0 with identical subgames played by the same partners with h, the partners should earn the same expected payoff $v(h, \mu_{\sigma}, \Phi_{\mu}) = v_0$. It follows that $v(h, \mu_{\sigma}, \Phi_{\mu}) = v(h, \sigma, \Phi)$ for all $h \in H_{\Phi}$. ■

A.4. Proof of Proposition 2

Let x_j be a player's own cooperation rate and $\tilde{x}_j$ be her partner's cooperation rate in state A_j, where $j \in \{0, \mathrm{CC}, \mathrm{CD}, \mathrm{DC}, \mathrm{DD}\}$. The player's expected payoff in each state is

$$v_j = \tilde{x}_j \Big[x_j \big(R + \delta v_{\mathrm{CC}} \big) + \big(1 - x_j\big) \big(T + \delta v_{\mathrm{DC}} \big) \Big] + \big(1 - \tilde{x}_j\big) \Big[x_j \big(S + \delta v_{\mathrm{CD}} \big) + \big(1 - x_j\big) \big(P + \delta v_{\mathrm{DD}} \big) \Big]. \quad (1)$$

With a CoDe-indifferent Markov strategy σ^*, a player is indifferent between C and D if there exists $(\tilde{x}_{\mathrm{CC}}, \tilde{x}_{\mathrm{DC}}, \tilde{x}_{\mathrm{CD}}, \tilde{x}_{\mathrm{DD}}) \in [0, 1]^4$, such that

$$R + \delta v_{\mathrm{CC}} = T + \delta v_{\mathrm{DC}}, \quad (2)$$

and

$$S + \delta v_{\mathrm{CD}} = P + \delta v_{\mathrm{DD}}. \quad (3)$$

Substituting $v_{\mathrm{DC}} = \frac{R-T}{\delta} + v_{\mathrm{CC}}$ and $v_{\mathrm{CD}} = \frac{P-S}{\delta} + v_{\mathrm{DD}}$ from equations (2) and (3) into (1) yields

$$v_j = P + \delta v_{\mathrm{DD}} + \tilde{x}_j \Big[R - P + \delta \big(v_{\mathrm{CC}} - v_{\mathrm{DD}} \big) \Big]. \tag{4}$$

To show that $x_{\mathrm{DD}} < x_{\mathrm{DC}}$ and $x_{\mathrm{CD}} < x_{\mathrm{CC}}$, we first solve for v_{CC} and v_{DD} simultaneously using equation (4) for $j \in \{\mathrm{CC}, \mathrm{DD}\}$: $v_{\mathrm{CC}} = \frac{R}{1-\delta} + \big(\frac{1-\tilde{x}_{\mathrm{CC}}}{\varphi}\big)\big(\frac{R-P}{1-\delta}\big)$ and $v_{\mathrm{DD}} = \frac{P}{1-\delta} + \big(\frac{\tilde{x}_{\mathrm{DD}}}{\varphi}\big)\big(\frac{R-P}{1-\delta}\big)$, where $\varphi = 1 - \delta(\tilde{x}_{\mathrm{CC}} - \tilde{x}_{\mathrm{DD}}) > 0$. Next, we substitute v_{CC}, v_{DD}, v_{DC} and v_{CD} into equation (4) for $j \in \{\mathrm{CD}, \mathrm{DC}\}$ to get:

$$\tilde{x}_{\mathrm{CD}} - \tilde{x}_{\mathrm{DD}} = \Big(\frac{1}{\delta} - \tilde{x}_{\mathrm{CC}} + \tilde{x}_{\mathrm{DD}} \Big) \Big(\frac{P-S}{R-P} \Big). \tag{5}$$

and

$$\tilde{x}_{\mathrm{CC}} - \tilde{x}_{\mathrm{DC}} = \Big(\frac{1}{\delta} - \tilde{x}_{\mathrm{CC}} + \tilde{x}_{\mathrm{DD}} \Big) \Big(\frac{T-R}{R-P} \Big). \tag{6}$$

It follows from equations (5) and (6) that $\tilde{x}_{\mathrm{DD}} < \tilde{x}_{\mathrm{CD}}$ and $\tilde{x}_{\mathrm{DC}} < \tilde{x}_{\mathrm{CC}}$. Note that, since both partners must follow the same equilibrium strategy in a CoDe-indifferent equilibrium, i.e. $x_{\mathrm{CD}} = \tilde{x}_{\mathrm{DC}}$, $x_{\mathrm{DC}} = \tilde{x}_{\mathrm{CD}}$, and $x_j = \tilde{x}_j$ for $j \in \{0, \mathrm{CC}, \mathrm{DD}\}$, $\tilde{x}_{\mathrm{DD}} < \tilde{x}_{\mathrm{CD}}$ implies $x_{\mathrm{DD}} < x_{\mathrm{DC}}$ and $\tilde{x}_{\mathrm{DC}} < \tilde{x}_{\mathrm{CC}}$ implies $x_{\mathrm{CD}} < x_{\mathrm{CC}}$.

In order to have players always prefer staying than leaving ($y_{\mathrm{CC}} = y_{\mathrm{CD}} = y_{\mathrm{DC}} = y_{\mathrm{DD}} = 1$), the expected payoff in the matching pool v_0 cannot exceed the expected payoff in any of the other four states. Since equation (4) implies that $\frac{\partial v_j}{\partial \tilde{x}_j} > 0$, $v_0 \le \inf_{h \in H} v(\sigma_h^*; \sigma^*)$ is true as long as $x_0 \le \min\{\tilde{x}_{\mathrm{CC}}, \tilde{x}_{\mathrm{CD}}, \tilde{x}_{\mathrm{DC}}, \tilde{x}_{\mathrm{DD}}\} = \min\{x_{\mathrm{DD}}, x_{\mathrm{CD}}\}$.

Finally, note that equations (5) and (6) imply that the set of CoDe-indifferent subgame perfect equilibria, if exists, is a 3-parameter family with $\{x_0, x_{\mathrm{CC}}, x_{\mathrm{DD}}\} \in [0,1]^3$ being the bounded free parameters. Given that $0 \le x_0 \le x_{\mathrm{DD}} < x_{\mathrm{DC}}$ and $x_0 \le x_{\mathrm{CD}} < x_{\mathrm{CC}} \le 1$, a CoDe-indifferent equilibrium exists as long as $x_{\mathrm{DC}} \le 1$ and $x_{\mathrm{CD}} \ge 0$. It follows from equation (5) that $x_{\mathrm{DC}} = \tilde{x}_{\mathrm{CD}} \le 1$ if and only if

$$x_{\mathrm{DD}} \le \frac{R - P + \big(P - S\big)\big(x_{\mathrm{CC}} - \frac{1}{\delta}\big)}{R - S}. \tag{7}$$

Similarly, equation (6) implies that $x_{\mathrm{CD}} = \tilde{x}_{\mathrm{DC}} \geq 0$ if and only if

$$x_{\mathrm{DD}} \leq \Big(\frac{T-P}{T-R}\Big)x_{\mathrm{CC}} - \frac{1}{\delta}. \tag{8}$$

The right-hand sides of equations (7) and (8) increase in x_{CC} and thus $x_{\mathrm{DD}} \geq 0$ exists if and only if $x_{\mathrm{CC}} \geq \max\big\{\frac{T-R}{\delta(T-P)}, \frac{1}{\delta} - \frac{R-P}{P-S}\big\}$. Finally, $x_{\mathrm{CC}} \leq 1$ exists if and only if $\delta \geq \max\big\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\big\}$. This proves that $\sigma^* = \{x_0, (x_m, y_m)_{m\in\Omega}\}$ is a CoDe-indefferent subgame perfect equilibrium strategy for any $\delta \in \big[\max\big\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\big\}, 1\big]$, $x_0 \in \big[0, \min\{x_{\mathrm{DD}}, x_{\mathrm{CD}}\}\big]$, $x_{\mathrm{CC}} \in \big[\max\big\{\frac{T-R}{\delta(T-P)}, \frac{1}{\delta} - \frac{R-P}{P-S}\big\}, 1\big]$, $x_{\mathrm{DD}} \in \big[0, \min\big\{\frac{R-P+(P-S)(x_{\mathrm{CC}}-\frac{1}{\delta})}{R-S}, \big(\frac{T-P}{T-R}\big)x_{\mathrm{CC}} - \frac{1}{\delta}\big\}\big]$, $x_{\mathrm{DC}} = x_{\mathrm{DD}} + \big(\frac{1}{\delta} - x_{\mathrm{CC}} + x_{\mathrm{DD}}\big)\big(\frac{P-S}{R-P}\big)$, $x_{\mathrm{CD}} = x_{\mathrm{CC}} - \big(\frac{1}{\delta} - x_{\mathrm{CC}} + x_{\mathrm{DD}}\big)\big(\frac{T-R}{R-P}\big)$, and $y_{\mathrm{CC}} = y_{\mathrm{CD}} = y_{\mathrm{DC}} = y_{\mathrm{DD}} = 1$. ■

A.5. Proof of Corollary 1

For type A equilibria, all we need to prove is the condition for which $x_{\mathrm{DC}} \leq x_{\mathrm{CD}}$ is true. Since equations (5) and (6) imply that $x_{\mathrm{DC}} \leq x_{\mathrm{CD}}$ if $\delta \geq \frac{T-R+P-S}{(T-S)(x_{\mathrm{CC}}-x_{\mathrm{DD}})}$, the fact that the maximum value of $x_{\mathrm{CC}} - x_{\mathrm{DD}}$ is 1 immediately implies that type A equlibria exist if $\delta \geq \frac{T-R+P-S}{T-S}$.

For types B-E, we note that equations (5) and (6) also imply that $x_{\mathrm{CD}} \leq x_{\mathrm{DD}}$ and $x_{\mathrm{CC}} \leq x_{\mathrm{DC}}$ if $\delta \geq \frac{T-R}{(T-P)(x_{\mathrm{CC}}-x_{\mathrm{DD}})}$ and $\delta \geq \frac{P-S}{(R-S)(x_{\mathrm{CC}}-x_{\mathrm{DD}})}$, respectively. Combining these conditions with $x_{\mathrm{CC}} - x_{\mathrm{DD}} \leq 1$ and equations (7) and (8) yield the respective conditions for types B-E equilibria. ■

A.6. Proof of Proposition 3

To prove the condition under which the specific CoDe-indifferent equilibria exist in Proposition 3, we need to start from the equilibria where $x_0 = \min\{x_{\mathrm{DD}}, x_{\mathrm{CD}}\}$ in Proposition 2. More specifically, we will modify these equilibria such that players will face the same expected cooperation rates and enjoy the same expected payoffs with (Proposition 3) or without (Proposition 2) voluntary separation.

Let's first consider case (i). $x_0 = x_{\mathrm{DD}}$ implies that, following the outcome DD in the prisoner's dilemma game, both partners are indifferent between (1) staying with each other and entering the state A_{DD} in the next matching period, and (2) leaving for the matching pool and entering the state A_0 with their respective new counterpart. Thus, for any CoDe-indifferent subgame perfect equilibrium with *no* voluntary separation $\sigma'^* = \{x'_0, (x'_m, y'_m)_{m\in\Omega}\}$ in which $x'_{\mathrm{DD}} \leq x'_{\mathrm{CD}}$, there exists a CoDe-indifferent subgame perfect equilibrium *with* voluntary separation following the outcome DD: $\sigma^* = \{x_0,\ (x_m, y_m)_{m\in\Omega}\}$ where $x_0 = x'_{\mathrm{DD}}$, $x_m = x'_m$ for $m \in \Omega$, $y_m = y'_m = 1$ for $m \in \{\mathrm{CC}, \mathrm{CD}, \mathrm{DC}\}$ and $y_{\mathrm{DD}} \in [0, 1)$.

$x_0 = x_{\mathrm{CD}}$ in case (ii) implies that, following the outcome DC in the prisoner's dilemma game and thus facing her partner's cooperation rate $\tilde{x}_{\mathrm{DC}}(= x_{\mathrm{CD}} = x_0)$ in the following period, a player is indifferent between entering the state A_{DC} with her current partner and entering the state A_0 with a new counterpart. Her partner, on the other hand, always prefers to continue the match given $x_0 < x_{\mathrm{DC}}$. Thus, for a CoDe-indifferent equlibrium *with* voluntary separation following the outcome DC to exist, the player's cooperative partner must enjoy the same expected payoff as in the equilibrium *without* voluntary separation, and this can only be achieved by the player compensating her partner with a larger cooperation rate so that the expected cooperation rate facing her partner after factoring in the continuation rate is the same as in the case without separation. In other words, if we let $x'_{\mathrm{DC}} < 1$ be the cooperation rate in the equilibrium without breakup, and x_{DC} and y_{DC} be the cooperation and continuation rates in the equilibrium with breakup, the condition $x'_{\mathrm{DC}} = y_{\mathrm{DC}}x_{\mathrm{DC}} + (1 - y_{\mathrm{DC}})x_0$ or $x_{\mathrm{DC}} = \frac{x'_{\mathrm{DC}} - x_0(1-y_{\mathrm{DC}})}{y_{\mathrm{DC}}}$ must hold in order for a CoDe-indifferent equilibrium to exist. It follows that $x'_{\mathrm{DC}} < x_{\mathrm{DC}}$ and that $x_{\mathrm{DC}} \leq 1$ if $y_{\mathrm{DC}} \in \left[\frac{x'_{\mathrm{DC}}+x_0}{1+x_0}, 1\right)$. Based on the proof of Proposition 2, we know that $x'_{\mathrm{DC}} < 1$ if the inequality (7) holds strictly and thus $\delta > \frac{P-S}{R-S}$ must be true. So, to sum up, for any CoDe-indifferent subgame perfect equilibrium *without* voluntary separation $\sigma'^* = \{x'_0, (x'_m, y'_m)_{m\in\Omega}\}$ where $x'_{\mathrm{CD}} \leq x'_{\mathrm{DD}}$ and $\delta > \max\left\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\right\}$, there exists a CoDe-indifferent subgame perfect equilibrium *with* voluntary separation following the outcome DC: $\sigma^* = \{x_0, (x_m, x_m)_{m\in\Omega}\}$ where $x_0 = x'_{\text{CD}}$, $x_m = x'_m$ and $y_m = y'_m = 1$ for $m \in \{\text{CC}, \text{CD}, \text{DD}\}$, $x_{\text{DC}} = \frac{x'_{\text{DC}} - x_0(1-y_{\text{DC}})}{y_{\text{DC}}}$ and $y_{\text{DC}} \in [0, 1)$.

Finally, the proof for case (iii) where $x_0 = x_{\text{DD}} = x_{\text{CD}}$ is a straightforward combination of (i) and (ii). ■

A.7. Proof of Corollary 2

Consider first a CoDe-indifferent equlibrium with *no* voluntary separation. Recall that $x_{\text{CC}} = \tilde{x}_{\text{CC}}$, $x_{\text{CD}} = \tilde{x}_{\text{DC}}$, $x_{\text{DC}} = \tilde{x}_{\text{CD}}$, and $x_{\text{DD}} = \tilde{x}_{\text{DD}}$. By substituting $x_0 = x_{\text{CD}} = x_{\text{DD}}$ into equations (5) and (6), we get $x_{\text{CC}} = x_0 + \frac{T-R}{\delta(T-P)}$ and $x_{\text{DC}} = x_0 + \frac{P-S}{\delta(T-P)}$. Note that $x_{\text{CC}} \leq 1$ if and only if $x_0 \leq 1 - \frac{T-R}{\delta(T-P)}$ and $\delta \geq \frac{T-R}{T-P}$, and that $x_{\text{DC}} \leq x_{\text{CC}}$ if and only if $\frac{T-R}{T-P} \geq \frac{P-S}{R-S}$.

Now consider a similar CoDe-indifferent equlibrium *with* voluntary separations in the states A_{DD} and A_{DC} as given by case (iii) in Proposition 3. Following the condition that equates the two (expected) cooperation rates with and without separation, the cooperation rate with separation x_{DC} equals $x_{\text{CC}} = x_0 + \frac{T-R}{\delta(T-P)}$ if and only if $y_{\text{DC}} = \frac{P-S}{T-R}$. Note that $y_{\text{DC}} < 1$ if and only if $\frac{T-R}{T-P} > \frac{P-S}{R-S}$. In other words, there exists a Semi-Tit-For-Tat equilibrium $\sigma^* = \{x_0, (x_m, x_m)_{m\in\Omega}\}$, where $x_0 = x_{\text{CD}} = x_{\text{DD}} \in \left[0, 1 - \frac{T-R}{\delta(T-P)}\right]$, $x_{\text{DC}} = x_{\text{CC}} = x_0 + \frac{T-R}{\delta(T-P)}$, $y_{\text{CC}} = y_{\text{CD}} = 1$, $y_{\text{DC}} = \frac{P-S}{T-R}$ and $y_{\text{DD}} \in [0, 1)$, if $\delta > \frac{T-R}{T-P} > \frac{P-S}{R-S}$. ■

A.8. Proof of Corollary 3

Consider first a CoDe-indifferent equlibrium with *no* voluntary separation and recall that $x_{\text{CC}} = \tilde{x}_{\text{CC}}$, $x_{\text{CD}} = \tilde{x}_{\text{DC}}$, $x_{\text{DC}} = \tilde{x}_{\text{CD}}$, and $x_{\text{DD}} = \tilde{x}_{\text{DD}}$. By substituting $x_0 = x_{\text{DD}}$ and $x_{\text{CD}} = x_{\text{DC}}$ into equations (5) and (6), we get $x_{\text{CC}} = x_0 + \frac{T-R+P-S}{\delta(T-S)}$ and $x_{\text{CD}} = x_{\text{DC}} = x_0 + \frac{P-S}{\delta(T-S)} < x_{\text{CC}}$. It is clear that $x_{\text{CC}} \leq 1$ if and only if $x_0 \leq 1 - \frac{T-R+P-S}{\delta(T-S)}$ and $\delta \geq \frac{T-R+P-S}{T-S}$. Note that $\frac{T-R+P-S}{T-S} > \max\left\{\frac{T-R}{T-P}, \frac{P-S}{R-S}\right\}$ and thus the condition regarding δ in Proposition 3 satisfies here. As a result, the possibility of voluntary separation in the state A_{DD}, i.e., $y_{\text{DD}} \in [0, 1)$, will follow the same reasoning for the proof of case (i) in the proposition. In sum, there exists a Semi-Grim equilibrium $\sigma^* = \{x_0, (x_m, x_m)_{m\in\Omega}\}$, where $x_0 = x_{\text{DD}} \in \left[0, 1 - \frac{T-R+P-S}{\delta(T-S)}\right]$,

$x_{\mathrm{CD}} = x_{\mathrm{DC}} = x_0 + \frac{P-S}{\delta(T-S)}$, $x_{\mathrm{CC}} = x_0 + \frac{T-R+P-S}{\delta(T-S)}$, $y_{\mathrm{CC}} = y_{\mathrm{CD}} = y_{\mathrm{DC}} = 1$, and $y_{\mathrm{DD}} \in [0, 1)$, if $\delta \geq \frac{T-R+P-S}{T-S}$. ■

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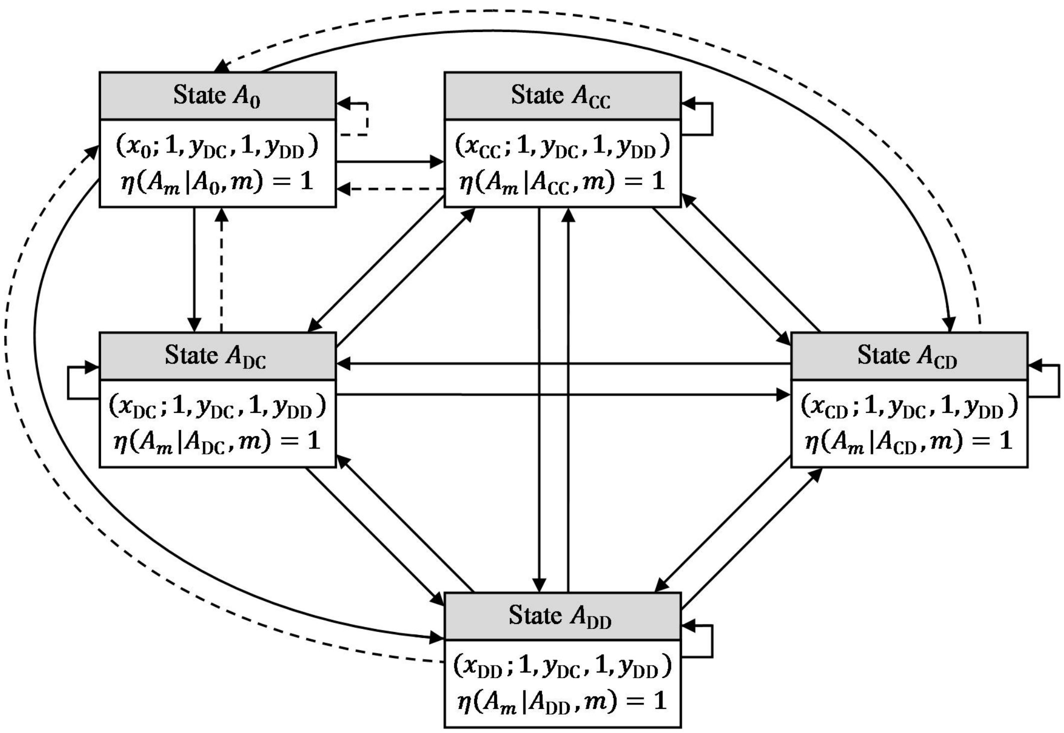
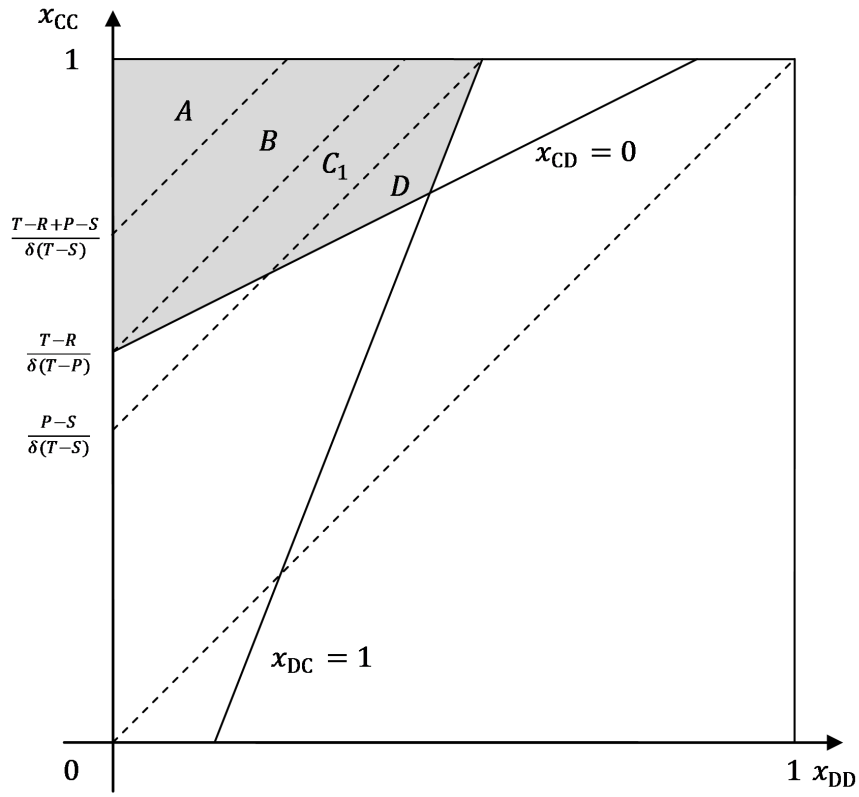
Fig. 1. CoDe-indifferent Equilibrium



Notes: The arrows with dashed lines represent the transitions back to the matching pool (the initial state A_0). The arrows with solid lines represent the transitions from one state to another after the partners have observed the outcome of the PD game and decided to continue the match for one more period.

Fig. 2. Cooperation Rates in CoDe-indifferent Equilibrium without Separation



Notes: Given the parameters of our experiment, the shaded area illustrates the range of (x_{DD}, x_{CC}) for different types of CoDe-indifferent equilibria without separation. The other three cooperation rates, x_0, x_{CD} and x_{DC}, are determined by x_{DD} and x_{CC} as shown at the end of the proof of Proposition 2 in the appendix. The four 45-degree dashed lines from left to right represent $x_{CD} = x_{DC}$, $x_{CD} = x_{DD}$, $x_{CC} = x_{DC}$, and $x_{CC} = x_{DD}$, respectively.

Table 1: Prisoner's Dilemma Payoffs

		Player 2	
		C	D
Player 1	C	5, 5	0, 8
	D	8, 0	2, 2

Table 2: Estimated Cooperation and Continuation Rates

	Outcome of the Most Recent Stage Game				New Match	Outcome of the First Stage Game			
	CC	DC	CD	DD		F×CC	F×DC	F×CD	F×DD
Continuation	1	$\gg$ 0.741**	$\approx$ 0.722**	$\gg$ 0.519**			0.057	−0.021	0.114*
		(0.053)	(0.051)	(0.045)			(0.049)	(0.061)	(0.041)
Cooperation	0.811$^{\diamond\diamond}$	$\approx$ 0.666$^{\diamond\diamond}$	$\gg$ 0.264	$\approx$ 0.268	$\approx$ 0.165	0.077	−0.087	0.106	0.024
	(0.039)	(0.065)	(0.069)	(0.043)	(0.025)	(0.058)	(0.064)	(0.121)	(0.042)

Notes: To account for the panel structure of the data, we follow Breitmoser (2015), Fudenberg, Rand, and Deber (2012) and Dal Bó and Fréchete (2011), and bootstrap the p-values. Bootstrapped standard errors are in parentheses. We obtain ten thousand samples for each model by randomly sampling the original subjects with replacement. To correct the problem caused by multiple hypothesis tests, the bootstrapped p-values are adjusted using the Holm-Bonferroni method as in Breitmoser (2015).

The continuation rates (y_{DC}, y_{CD}, y_{DD}) and cooperation rates (x_{CC}, x_{DC}, x_{CD}, x_{DD}, x_0) were estimated in two separate models. The continuation rate following mutual cooperation, $y_{\mathrm{CC}} = 1$, was not estimated as all subjects always preferred to continue. F is a dummy variable that equals one for the first matching period and zero otherwise.

The following twelve hypotheses are tested in case of continuation: $H_0 : y_{\mathrm{CC}} = y_{\mathrm{DC}}$, $H_0 : y_{\mathrm{CC}} = y_{\mathrm{CD}}$, $H_0 : y_{\mathrm{CC}} = y_{\mathrm{DD}}$, $H_0 : y_{\mathrm{DC}} = y_{\mathrm{CD}}$, $H_0 : y_{\mathrm{DC}} = y_{\mathrm{DD}}$, $H_0 : y_{\mathrm{CD}} = y_{\mathrm{DD}}$, $H_0 : y_{\mathrm{DC}} = 0$, $H_0 : y_{\mathrm{CD}} = 0$, $H_0 : y_{\mathrm{DD}} = 0$, $H_0 : F \times y_{DC} = 0$, $H_0 : F \times y_{CD} = 0$, and $H_0 : F \times y_{DD} = 0$. The relation symbols indicate the levels of statistical significance for the tests between two continuation rates: $\gg$ for $p \leq 0.01$, $>$ for $p \in (0.01, 0.05]$, and $\approx$ for $p > 0.05$. The asterisks indicate the levels of statistical significance for the tests compared to zero rate: ** for $p \leq 0.01$, and * for $p \in (0.01, 0.05]$.

The following fourteen hypotheses are tested in case of cooperation: $H_0 : x_{\mathrm{CC}} = x_{\mathrm{DC}}$, $H_0 : x_{\mathrm{CC}} = x_{\mathrm{CD}}$, $H_0 : x_{\mathrm{CC}} = x_{\mathrm{DD}}$, $H_0 : x_{\mathrm{DC}} = x_{\mathrm{CD}}$, $H_0 : x_{\mathrm{DC}} = x_{\mathrm{DD}}$, $H_0 : x_{\mathrm{CD}} = x_{\mathrm{DD}}$, $H_0 : x_{\mathrm{CC}} = x_0$, $H_0 : x_{\mathrm{DC}} = x_0$, $H_0 : x_{\mathrm{CD}} = x_0$, $H_0 : x_{\mathrm{DD}} = x_0$, $H_0 : F \times x_{\mathrm{CC}} = 0$, $H_0 : F \times x_{\mathrm{DC}} = 0$, $H_0 : F \times x_{\mathrm{CD}} = 0$, and $H_0 : F \times x_{\mathrm{DD}} = 0$. The relation symbols and asterisks have the same meanings as described above. The superscript diamonds indicate the levels of statistical significance for the tests compared to the initial cooperation rate x_0 in new matches: $^{\diamond\diamond}$ for $p \leq 0.01$, and $^{\diamond}$ for $p \in (0.01, 0.05]$.

Table 3: Estimated Average Period Payoff by Continuing the Match vs. Starting Anew

	Continue the Match								Start Anew
	Outcome of the Most Recent Stage Game								
	CC		DC		CD		DD		
Average Payoff	$4.428^{\diamond\diamond}$ (0.161)	$\gg$	3.744 (0.161)	$\approx$	$4.059^{\diamond\diamond}$ (0.139)	$\gg$	3.55 (0.162)	$\approx$	3.478 (0.116)

Notes: The average period payoffs until an exogenous breakup are estimated with subject-level random effects with bootstrapped standard errors in parentheses. Seven hypotheses are tested: $H_0 : V_{\text{CC}} = V_{\text{DC}}$, $H_0 : V_{\text{DC}} = V_{\text{CD}}$, $H_0 : V_{\text{CD}} = V_{\text{DD}}$, $H_0 : V_{\text{CC}} = V_0$, $H_0 : V_{\text{DC}} = V_0$, $H_0 : V_{\text{CD}} = V_0$, and $H_0 : V_{\text{DD}} = V_0$, where V_{CC}, V_{DC}, V_{CD}, V_{DD} are the average period payoffs for the remainder of the match conditional on different outcomes of the most recent PD stage game and V_0 is the average period payoff at the beginning of a new match. p-values are adjusted as described in Table 2. The relation symbols indicate the levels of statistical significance for the tests between two period payoffs: $\gg$ for $p \leq 0.01$, $>$ for $p \in (0.01, 0.05]$, and $\approx$ for $p > 0.05$. The superscript diamonds indicate the level of statistical significance for the tests compared to the average period payoff in a new match: $^{\diamond\diamond}$ for $p \leq 0.01$, and $^{\diamond}$ for $p \in (0.01, 0.05]$.

Table 4: Estimated Average Period Payoff by Playing C vs. D

	Continue the Match				Start Anew
	Outcome of the Most Recent Stage Game				
	CC	DC	CD	DD	
Playing C Next Period	4.541 (0.159)	3.979 (0.168)	4.157 (0.169)	3.701 (0.209)	3.457 (0.132)
	$\gg$	$>$	$\approx$	$\approx$	$\approx$
Playing D Next Period	3.595 (0.25)	3.42 (0.176)	4.02 (0.177)	3.474 (0.169)	3.482 (0.124)

Notes: The average period payoffs until an exogenous breakup are estimated with subject-level random effects with bootstrapped standard errors in parentheses. Five hypotheses are tested: $H_0 : V_{\mathrm{CC}}(\mathrm{C}) = V_{\mathrm{CC}}(\mathrm{D})$, $H_0 : V_{\mathrm{DC}}(\mathrm{C}) = V_{\mathrm{DC}}(\mathrm{D})$, $H_0 : V_{\mathrm{CD}}(\mathrm{C}) = V_{\mathrm{CD}}(\mathrm{D})$, $H_0 : V_{\mathrm{DD}}(\mathrm{C}) = V_{\mathrm{DD}}(\mathrm{D})$, and $H_0 : V_0(\mathrm{C}) = V_0(\mathrm{D})$. p-values are adjusted as described in Table 2. The relation symbols indicate the levels of statistical significance for the tests between two period payoffs: $\gg$ for $p \leq 0.01$, $>$ for $p \in (0.01, 0.05]$, and $\approx$ for $p > 0.05$.

Table 5: Equlibrium Strategies in the VSRPD Literature

Strategy	Current State	Cooperation Rate	Continuation Rate Given Outcome of the Most Recent Stage Game CC	DC	CD	DD	Resulting State Given New Match	Outcome of the Most Recent Stage Game CC	DC	CD	DD
Always Defect Strategy											
ALLD	A_0	0	y_{CC}	y_{DC}	y_{CD}	y_{DD}	A_0	A_0	A_0	A_0	A_0
Out-For-Tat Strategies: Trust-Building Phase											
fOFT	A_0	x_0^f	1	1	1	0	A_0	A_{EC}	A_{EC}	A_{EC}	A_{off}
aOFT	A_0	x_0^a	0	1	1	0	A_0	A_{off}	A_{EC}	A_{EC}	A_{off}
lOFT	A_0	x_0^l	1	0	0	0	A_0	A_{EC}	A_{off}	A_{off}	A_{off}
hOFT	A_0	x_0^h	1	0	0	0	A_0	A_{EC}	A_{off}	A_{off}	A_{off}
nOFT	$A_{t\in\{0,\dots n-1\}}$	0	0	0	0	1	A_0	A_{off}	A_{off}	A_{off}	A_{t+1}
Out-For-Tat Strategies: Eternal-Cooperation Phase($A_n \equiv A_{EC}$ *for* nOFT)											
	A_{EC}	1	1	0	0	0	A_0	A_{EC}	A_{off}	A_{off}	A_{off}
Out-For-Tat Strategies: Off-Equilibrium State											
	A_{off}	0	0	0	0	0	A_0	A_{off}	A_{off}	A_{off}	A_{off}

Notes: With parameters used in our experiment, $x_0^f \approx 0.2783$, $x_0^a \approx 0.2348$, $x_0^l = \frac{1}{7}$, $x_0^h = \frac{1}{3}$ and $n \geq 2$ in equilibrium.

Table 6: Out-For-Tat Strategies with the Pro-Partnership Modification

Strategy	Current State	Cooperation Rate	Continuation Rate Given Outcome of the Most Recent Stage Game				Resulting State Given				
							New Match	Outcome of the Most Recent Stage Game			
			CC	DC	CD	DD		CC	DC	CD	DD
Modified Out-For-Tat Strategies: Trust-Building Phase											
fOFT^{P}	A_0	x_0^f	1	1	1	y_{DD}	A_0	A_{EC}	A_{EC}	A_{EC}	A_0
aOFT^{P}	A_0	x_0^a	y_{CC}	1	1	y_{DD}	A_0	A_0	A_{EC}	A_{EC}	A_0
lOFT^{P}	A_0	x_0^l	1	y_{DC}	y_{CD}	y_{DD}	A_0	A_{EC}	A_0	A_0	A_0
hOFT^{P}	A_0	x_0^h	1	y_{DC}	y_{CD}	y_{DD}	A_0	A_{EC}	A_0	A_0	A_0
$n\text{OFT}^{\text{P}}$	$A_{t\in\{0,\ldots n-1\}}$	0	y_{CC}	y_{DC}	y_{CD}	1	A_0	A_0	A_0	A_0	A_{t+1}
Modified Out-For-Tat Strategies: Eternal-Cooperation Phase($A_n \equiv A_{EC}$ *for* nOFT^{P})											
	A_{EC}	1	1	y_{DC}	y_{CD}	y_{DD}	A_0	A_{EC}	A_0	A_0	A_0

Notes: With the parameters used in our experiment, $x_0^f \approx 0.2783$, $x_0^a \approx 0.2348$, $x_0^l = \frac{1}{7}$, $x_0^h = \frac{1}{3}$ and $n \geq 2$ in equilibrium.

Table 7: Semi-Tit-For-Tat and Semi-Grim Strategies

Strategy	Current State	Cooperation Rate	Continuation Rate Given Outcome of the Most Recent Stage Game				Resulting State Given				
							New Match	Outcome of the Most Recent Stage Game			
			CC	DC	CD	DD		CC	DC	CD	DD
sTFT	$A_0, A_{\text{DD}}, A_{\text{CD}}$	x_0^t	1	y^t	1	y_{DD}	A_0	A_{CC}	A_{DC}	A_{CD}	A_{DD}
	$A_{\text{DC}}, A_{\text{CC}}$	x_1^t									
sGrim	A_0, A_{DD}	x_0^g	1	1	1	y_{DD}	A_0	A_{CC}	A_{DC}	A_{CD}	A_{DD}
	$A_{\text{CD}}, A_{\text{DC}}$	x_1^g									
	A_{CC}	x_2^g									

Notes: With parameters used in our experiment, $x_0^t \in [0, \frac{3}{7}]$, $x_1^t = x_0^t + \frac{4}{7}$, $y^t = \frac{2}{3}$, $x_0^g \in [0, \frac{2}{7}]$, $x_1^g = x_0^g + \frac{2}{7}$, $x_2^g = x_0^g + \frac{5}{7}$, and $y_{\text{DD}} \in [0, 1]$ in equilibrium.

Table 8: Estimated Mixture Distributions

Baseline Model		Pro-Partnership Model		Augmented Baseline Model		Augmented Pro-Partnership Model	
ALLD	0.57 (0.066)	ALLD	0.288 (0.063)	ALLD	0.086 (0.038)	ALLD	0.249 (0.057)
fOFT	0.24 (0.062)	fOFT$^{\mathrm{P}}$	0.157 (0.055)	fOFT	0.071 (0.036)	fOFT$^{\mathrm{P}}$	0.135 (0.048)
aOFT		aOFT$^{\mathrm{P}}$		aOFT		aOFT$^{\mathrm{P}}$	
lOFT	0.125 (0.049)	lOFT$^{\mathrm{P}}$	0.103 (0.053)	lOFT	0.062 (0.032)	lOFT$^{\mathrm{P}}$	
hOFT		hOFT$^{\mathrm{P}}$	0.453 (–)	hOFT	0.035 (0.025)	hOFT$^{\mathrm{P}}$	0.295 (0.065)
nOFT	0.064 (–)	nOFT$^{\mathrm{P}}$		nOFT		nOFT$^{\mathrm{P}}$	
				sTFT	0.293 (0.073)	sTFT	0.189 (0.066)
				sGrim	0.453 (–)	sGrim	0.132 (–)
$\hat{y}_{\mathrm{CC}}$	1 (0.009)	$\hat{y}_{\mathrm{CC}}$	1 (0.014)	$\hat{y}_{\mathrm{CC}}$	1 (0.02)	$\hat{y}_{\mathrm{CC}}$	1 (0.008)
$\hat{y}_{\mathrm{DC}}$	0.889 (0.031)	$\hat{y}_{\mathrm{DC}}$	0.762 (0.029)	$\hat{y}_{\mathrm{DC}}$	0.209 (0.099)	$\hat{y}_{\mathrm{DC}}$	0.684 (0.044)
$\hat{y}_{\mathrm{CD}}$	0.881 (0.03)	$\hat{y}_{\mathrm{CD}}$	0.738 (0.031)	$\hat{y}_{\mathrm{CD}}$	0.127 (0.718)	$\hat{y}_{\mathrm{CD}}$	0.553 (0.059)
$\hat{y}_{\mathrm{DD}}$	0.733 (0.02)	$\hat{y}_{\mathrm{DD}}$	0.61 (0.016)	$\hat{y}_{\mathrm{DD}}$	0.691 (0.017)	$\hat{y}_{\mathrm{DD}}$	0.611 (0.016)
$\hat{\gamma}$	0.246 (0.01)	$\hat{\gamma}$	0.021 (0.004)	$\hat{\gamma}$	0.076 (0.008)	$\hat{\gamma}$	0.017 (0.004)
LL	-2034.3	LL	-1656.4	LL	-1660.7	LL	-1611.2
ICL-BIC	2055.1	ICL-BIC	1683.1	ICL-BIC	1691.7	ICL-BIC	1640.8

Notes: With the parameters used in our experiment, $x_0^f = 0.2783$, $x_0^a = 0.2348$, $x_0^l = \frac{1}{7}$, $x_0^h = \frac{1}{3}$, $n = 2$, $x_0^t = \frac{3}{14}$, and $x_0^g = \frac{1}{7}$.