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The Effects of Communication on a Middle Equilibrium in Prisoner's Dilemma

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Abstract

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1 Introduction

Over an infinite time horizon, the Prisoner's Dilemma has an infinite number of viable equilibria, each reached by a combination of strategies two players use. Of these infinite equilibria, all strategies observed in the laboratory converge to two points – the high equilibrium, where players choose to cooperate, and the low equilibrium, where players choose to defect. This paper introduces a modification to Prisoner's Dilemma which leads to the lesser-studied middle equilibrium, achieved by alternating between cooperating and defecting, giving a higher per-period payoff to each player than the high equilibrium. Preliminary theory for this modification is discussed and an experiment is conducting, testing the effect of different levels of communication on the rate and stability of the middle equilibrium over an unknown time horizon. Put specifically, this paper seeks to answer the research question: how does the level of communication affect the middle equilibrium conditions (in both rate and sustainability) in a modified form of the Prisoner's Dilemma?

The unknown time horizon is used to model infinite time in the laboratory environment, a procedure used by Normann and Wallace 2012. Participants in the experiment play "supergames," which are many periods of Prisoner's Dilemma games against the same opponent. This strategy better models real world conditions than finite time horizons, as in the real world players are not aware of when the game they are playing will end. While this paper focuses on the game itself rather than what decisions it might model in the real world, some possible extensions are discussed on Section 7.

This paper seeks to add to the significant canon on Economic decision making by presenting a decision between two somewhat desirable equilibria, one which requires more explicit coordination but gives a higher payoff. Additionally, it seeks to explore qualitatively the phenomenon of "tacit collusion," where players signal their intended strategy through game actions which may not themselves be profit-maximizing but lead to a profit-maximizing strategy. This paper also seeks to augment existing Prisoner's Dilemma literature by using known methodology in a new game and reporting conclusions such that the modified

Prisoner's Dilemma can be compared with the canonical Prisoner's Dilemma. There is a surprising lack of publications exploring a Prisoner's Dilemma with a viable middle equilibrium, and this paper seeks to augment that literature and provide a new area where study may prove fruitful.

Over the course of the paper, it is shown that the modification to Prisoner's Dilemma affects strategy choice under an infinite time horizon. The results of the experiment show that more communication leads to higher levels of middle equilibrium rates as well as a more stable equilibrium with less betrayal. Experience in the game is not shown to have a significant effect on middle equilibrium rates or stability, and anecdotally it seems that participants did not need experience in the game to realize the middle equilibrium is viable.

The paper is organized as follows. Section 2 summarizes related literature on the topic, both theoretical and experimental. Section 3 provides a theoretical backing for the modification to the Prisoner's Dilemma and its features. Section 4 explains the experimental methodology and presents two hypotheses. Section 5 summarizes the results of the experiment. Section 6 discusses some anecdotal findings and general qualitative trends from the experiment. Section 7 concludes.

	Cooperate (C)	Defect (D)
Cooperate (C)	$(1, 1)$	$(-10, 10)$
Defect (D)	$(10, -10)$	$(-1, -1)$

Table 1: Nash's Prisoner's Dilemma

2 Literature Review

In his most famous work, Nash 1951 explores the Prisoner's Dilemma for the first time. Nash identifies what he calls a "strong solution," now often referred to as a Nash Equilibrium, in the Prisoner's Dilemma game with payoffs as in Table 1. While Nash uses some negative payoffs in order to make the Prisoner's Dilemma look more similar to a zero-sum game, that conceit is not necessary for analysis and this paper uses only non-negative payoffs for simplicity. Nash's paper generalizes the earlier work of von Neumann and Morgenstern 1947 to non-cooperative games. In this case, the word "non-cooperative" means simply that communication was not allowed. von Neumann and Morgenstern's work includes only games where communication is allowed, but Nash shows that some equilibria can be sustained even in the absence of communication. The Prisoner's Dilemma is an example of a game where (under a finite time horizon when the game has a known ending point) the high equilibrium (in Nash's game, $(C, C) = (1, 1)$) cannot be sustained. In the process of proving this result, Nash updates the known minimax theorem[1] to apply to non-zero-sum games, introducing and proving the theorem that "all finite games have some mixed strategy equilibrium."

While the proof that the high equilibrium (C, C) cannot be sustained under a finite time horizon in the Prisoner's Dilemma is simple and will be shown below, theory on equilibria under an infinite time horizon lagged somewhat behind. Aumann 1959 is the first to write about infinitely repeated games using the Folk Theorem, but the work of Friedman 1971 is more relevant here. Friedman, like Nash before him, generalizes the work of Aumann to apply to non-cooperative games, showing that the set of possible equilibria payoffs in an infinitely repeated game between 2 players is a compact and convex set in $\mathbb{R}^2$, the plane of

[1] This theorem identifies best strategies for each player in zero-sum games by identifying strategies where players minimize their possible loss.

real numbers. Friedman also discussed the idea of "tacit collusion" while discussing oligopoly theory. Tacit collusion is a belief of earlier writers, who believe that if firms in oligopoly are observed to be producing at Cournot equilibrium levels (named after Cournot 1838), they must be communicating in some way, either explicitly or through certain market moves which indicated what they wanted to other firms. Friedman shows that this is not necessarily true, and that there is a Pareto optimal equilibrium at which Cournot is be possible. Tacit collusion is ignored by theoretical literature about non-cooperative games as it necessarily turns the game into a cooperative one, it will be discussed in Section 6, as it can occur in a laboratory environment.

Though the finite Prisoner's Dilemma has been used in economic and psychological experiments from the mid-twentieth century on, there were no publications with consistent methodology on the infinitely repeated Prisoner's Dilemma prior to Dal Bó 2005. Dal Bó uses a random termination rule where after each period a four-sided die is rolled to determine whether that period is the final one. The chance each period has of being the final period is Dal Bó's main treatment variable, and he also tests finite games with the same expected length as each of his random games (for games where the chance was $\frac{1}{2}$ and $\frac{1}{4}$ there were finite games of 2 and 4 periods respectively, and there was also a single-period game with the chance of being the final period equal to 1). Dal Bó finds that rates of cooperation increase significantly if there is a higher chance of the game continuing. Further, he finds that cooperation rates are higher in the first round of the random continuation games than finite games of the same expected length. These results confirm what the theory predicts, and this paper represents the first time an infinitely repeated Prisoner's Dilemma is tested with participants playing against each other in a laboratory and conclusive results. More important than the results themselves is Dal Bó's influence on experimental game theory. After Dal Bó 2005 comes a boom in papers studying the repeated Prisoner's Dilemma, many using a random termination rule to model an infinite time horizon.

Dal Bó and Fréchette 2018 performs a meta survey of infinitely repeated Prisoner's

Dilemma papers, the vast majority published in the last two decades. Those games following Dal Bó 2005 are referred to as the second wave of infinitely repeated Prisoner's Dilemma experiments, and are studied specifically because they had consistent experimental methodology, with participants playing other participants under a random termination rule. Dal Bó and Fréchette compare cooperation rates under different payoff structures, different continuation probabilities, and different rates of repetition.[2] They find that cooperation decreases as the payoff for (C, D) and (D, C) increases for the player who defects relative to the (C, C) payoff. This is expected, as there is a higher payoff to the player who defects, which decreases the relative incentive to cooperate. They also find that cooperation rates increase as the continuation probability increases, also an expected result. The rates of cooperation in the first supergame increase less than in later supergames, with only a 0.174 coefficient for the first supergame versus 0.869 for the fifteenth. This indicates that as participants learn more about the game, they are more likely to cooperate and earn a higher payoff. Comparing the results from the second wave to earlier results from Roth and Murnighan 1978, Dal Bó and Fréchette find that the new results have significantly higher cooperation percentages, indicating that playing between participants rather than against computers or experimentors increased the cooperation rates for participants.

Normann and Wallace 2012 studies the different effect termination rules had on repeated Prisoner's Dilemma games. They take four different termination rules and compare them directly with all other experimental methodology. The first rule is a finite game, where all participants are told that the game will end after 22 periods. The second is an unknown termination rule, where participants are told that the game will last *at least* 22 periods (it actually ends after 28 periods). The third and fourth are both random termination rules, where the game lasts for 22 periods and then continues with a probability of $\frac{1}{6}$ in the low random rule and $\frac{5}{6}$ in the high rule. These repeated games with long horizons are called "supergames," and each is studied as its own game, not as a collection of smaller games.

[2]How many supergames an individual participant plays.

Normann and Wallace find that there is no significant difference in rates of cooperation over the course of the entire experiment between the four treatments. However, there is a difference when looking at individual periods. In the finite termination rule, there is a notable decrease in cooperation after period 12, a phenomenon referred to as the "end-game effect." Namely, as the end of the game approaches, the punishment for defecting decreases and players are more likely to defect to get the current payoff, losing some amount of future payoff. These end-game effects exist in both random termination rules as well, though at a lower level than in the finite game. The unknown termination rule is the only one to show no end-game effects. In fact, there is an increase in cooperation as the unknown supergame goes on, though the increase is slight. Finally, Normann and Wallace find that the length of the game has a significant effect on cooperation rates, with longer horizon games having higher cooperation rates regardless of the termination rule.

Kagel 2018 studies the effects of communication on cooperation rates in a finitely repeated Prisoner's Dilemma. Kagel has two different game structures, one where individuals play one another, and one where individuals are randomly placed into teams of two, which play each other. Each supergame lasts for ten periods, and communication is allowed both before the game and between each period for individuals, with teams allowed additional communication sessions before the game and between each period for team members to talk to each other without their opponents knowing. When communication between opponents is not allowed, only the within-team communication sessions are included. Kagel finds that first-period cooperation rates are significantly higher for both individuals and teams when communication is allowed. He notes that last-period cooperation rates are significantly lower for teams than individuals, which he attributes to team members providing social support for going against societal norms of equal treatment. Kagel also finds that before the game there are three types of communication used: *fairness*, where participants point out that cooperating would lead to the same payoffs, *most money*, where participants talk about how they will make more by cooperating than defecting, and *threats*, where participants note that a defection would be paid back by defecting, so both players will lose overall. Rates of each of these types of communication are roughly the same regardless of individuals or teams, with just under 40% using fairness, just over 50% using most money, and just under 10% using threats. Overall, Kagel reports an increase in cooperation correlating with an increase in communication. However, he does not include breakdowns of individual periods other than the first and last in the paper, and he does not include overall cooperation rates.

There is a notable lack in the literature of papers examining the middle equilibrium which may exist in certain versions of the Prisoner's Dilemma. In fact, there seem to exist no papers explicitly studying it, only references to the fact that Prisoner's Dilemma games are constructed in experiments such that the middle equilibrium is not viable. One example is Dal Bó and Fréchette 2018, which states that payoffs are often set such that "alternating between cooperation and defection cannot be more profitable than joint cooperation." This paper seeks to augment the existing literature by experimenting with a modified Prisoner's Dilemma game in which the middle equilibrium is viable. There also is a gap in the literature regarding communication in the infinitely repeated Prisoner's Dilemma. Kagel 2018 explores communication but only reports results in specific periods and only studies finite games. To fill this gap, this paper explores the infinitely repeated Prisoner's Dilemma and reports results for all periods. In regards to methodology, this paper follows Dal Bó 2005 in most cases, with communication following Kagel 2018 and the termination rule following Normann and Wallace 2012. This paper seeks to augment the existing literature and present a starting point for future researchers studying alternating equilibria, in the Prisoner's Dilemma or other games.

3 Theory

	C	D
C	(α, α)	$(\beta - \eta, \alpha + \varepsilon)$
D	$(\alpha + \varepsilon, \beta - \eta)$	(β, β)

Table 2: Prisoner's Dilemma in General Form

The canonical Prisoner's Dilemma, first analyzed by Nash 1951, is a single game played between two players. They choose whether to *cooperate* (C) or *defect* (D), and receive payoffs depending on what the other player does. In Table 2, the canonical Prisoner's Dilemma is represented in general form with variable payoffs, with the first element in each 2-tuple going to the row player (referred to as player A) and the second element going to the column player (referred to as player B). These payoffs are often different between papers, but it must always hold that $\alpha + \varepsilon > \alpha > \beta > \beta - \eta$. α and β are the baseline payoffs for cooperating and defecting, while ε is the extra payoff a player gains by defecting while the other cooperates, and η is the punishment for cooperating while the other defects.

	C	D
C	$(2, 2)$	$(0, 3)$
D	$(3, 0)$	$(1, 1)$

Table 3: Canonical Prisoner's Dilemma

	C	D
C	$(2, 2)$	$(0, 5)$
D	$(5, 0)$	$(1, 1)$

Table 4: Modified Prisoner's Dilemma

In this paper, the payoffs in Table 3 ($\alpha = 2, \beta = 1, \varepsilon = \eta = 1$) are used to represent the canonical form of the Prisoner's Dilemma. In the modified form of the Prisoner's Dilemma used in this paper, everything is the same except $\varepsilon = 3$, which leads to the payoffs in Table 4. These two versions of Prisoner's Dilemma will be compared in three circumstances: the one-shot game, which is a single non-repeated game, the finitely repeated game, and the infinitely repeated game. Equilibria in repeated games are achieved by strategy profile choice for each player, but there are three important equilibria which are discussed here, each which can be achieved by a number of strategies. For annotational simplicity, these equilibria will be identified by the resulting payoffs to each player, not the strategies which lead to them. The high equilibrium is identified by a choice of (C, C) in each period, and results in a payoff of 2 to each player. The low equilibrium is identified by a choice of (D, D) in each period, and results in a payoff of 1 to each player. The middle equilibrium is identified over two periods with a choice of (C, D) in one period and (D, C) in the other, and results in a payoff of either 3 or 5 to each player, depending on whether the players are in the canonical or modified Prisoner's Dilemma.

First, as Nash 1951 showed, there is a pure-strategy equilibrium in the one-shot Prisoner's Dilemma, because the strategy to choose C is dominated by the strategy to choose D. This result holds for any form of Prisoner's Dilemma, as $\alpha+\varepsilon > \alpha$ and $\beta > \beta-\eta$. Note that what the theory predicts players *should* choose is not what they *actually* choose when presented with a one-shot Prisoner's Dilemma. Dal Bó 2005 finds that 90% of players choose D in the one-shot Prisoner's Dilemma, but those 10% choose C even though it is a dominated strategy. This result, of participants in laboratory experiments responding in a way not predicted by theory, is a common one in experimental game theory. This section explores what players *should* do when faced with these games, and the experiment itself finds what players *actually* do.

While Nash only examined the one-shot Prisoner's Dilemma, the Prisoner's Dilemma can be played any number of times between the same two players. When the game is played for more than one period, it is referred to as the repeated Prisoner's Dilemma. The repeated Prisoner's Dilemma introduces the possibility of punishment for defection. If player B defects in the first period, player A is able to "punish" them by defecting in the second period, and denying them the payoff that cooperation might bring. In a single game, there are no future consequences for defection, but in a repeated game player A can deny player B a significant amount of payoff by choosing D for the rest of the game. These punishments arise from larger strategies which encompass the entire repeated game, not just single periods.

Dal Bó and Fréchette 2019 identify six main strategy profiles that players use in the repeated Prisoner's Dilemma, which match the strategy profiles identified by Binmore 2005 with some additions. *Always Cooperate* (AC) and *Always Defect* (AD) are self-explanatory, with players using those strategy profiles playing (C) or (D) in every period. *Grim Trigger* ($Grim$) begins with the player playing (C), and if the other player plays (D) at any point, the player will similarly play (D) for the rest of the game. *Tit-for-tat* (TFT) begins with the player playing (C), and they will match what the other player played in the previous period, and *suspicious tit-for-tat* ($STFT$) is the same except the player begins with (D). Finally, *win-stay-lose-shift* ($WSLS$) begins with (C), and the player will play (C) whenever both players chose the same strategy in the previous period and (D) otherwise.

When the Prisoner's Dilemma is repeated for n periods ($n < \infty$), it is referred to as the finitely repeated Prisoner's Dilemma. The finitely repeated Prisoner's Dilemma assumes that players know which period will be the last period.[3] Consider that after the last period of the game, there are no more choices to be made. This means that players cannot be punished for defection as they would be earlier in the game, as there is no punishment mechanism if the game is over. Thus, players are incentivized to earn the highest payoff possible in the final period, so the last period of a finitely repeated Prisoner's Dilemma is similar to a one-shot Prisoner's Dilemma, and the strategy to choose D dominates the strategy to choose C. Another assumption made when discussing Prisoner's Dilemma theoretically is that each player has knowledge of the incentives facing the other player and react accordingly. Thus, they both know that the other will choose D in the final period. This means that there can be no extra punishment for choosing D in the penultimate period, as the other player will be choosing D in the final period no matter what. Thus, they both should act to maximize their payoff in the penultimate period, and should both choose as if the penultimate period is also a one-shot game, so the strategy to choose C is dominated by the strategy to choose D. This process continues with all periods in the finitely repeated game. Again, while theory predicts that players *should* choose D in all periods of the finitely repeated Prisoner's Dilemma, in practice (again in Dal Bó 2005) only about 65% of players chose the strategy *always defect*

[3]When they do not, Normann and Wallace 2012 showed that experimentally the game is more similar to a random termination rule than a finitely repeated game, a result which is used in this paper.

in the 4 period finitely repeated Prisoner's Dilemma.

Note that both of these results do not rely on specific payoffs for the Prisoner's Dilemma, only the general relationship that $\alpha + \varepsilon > \alpha > \beta > \beta - \eta$. That will now change, and the specific payoffs in Table 3 and Table 4 will be used. In some models of repeated Prisoner's Dilemma, a discount factor δ is used to represent the preference for payoff in the current period to the future. $0 \leq \delta \leq 1$, and each future period is discounted more and more such that the total utility function for a player over n periods is:

$$u(\pi) = \pi_0 + \delta\pi_1 + \delta^2\pi_2 + \cdots + \delta^n\pi_n = \pi_0 + \sum_{i=1}^{n} \delta^i \pi_i \tag{1}$$

The lower the discount factor, the more "impatient" the player is, and the more they value their present utility over the future. For an example of how a discount factor can affect strategy choice, consider a player who is calculating their total utility in the finitely repeated modified Prisoner's Dilemma with $n = 100$. If they know that their opponent is playing the *Grim* strategy, their choice of what to play in the current period is dependent on the discount factor. If they choose C, their total utility will be $u(\pi) = 2 + \sum_{i=1}^{100} 2\delta^i$. If they choose D, their total utility will be $u(\pi) = 5 + \sum_{i=1}^{100} \delta^i$. If $\delta > 0.75$, they will choose C, and if $\delta < 0.75$, they will choose D. Further, note that the canonical Prisoner's Dilemma payoffs create a different choice – the total utility of choosing D in the current period would be 2 less, as they would only get 3 in the current period instead of 5. In fact, if the player were in the canonical Prisoner's Dilemma, they would choose D only if $\delta < 0.5$. This result means that the increase of ε in the modified Prisoner's Dilemma affects the strategy choice if discount factors are involved, and the increase means that players who would have chosen C in the canonical Prisoner's Dilemma (for example, if $\delta = 0.6$) would choose D in the modified Prisoner's Dilemma.

It can seem counterintuitive to study infinitely repeated Prisoner's Dilemma. In either the canonical or the modified version, over an infinite number of periods any strategy except *always cooperate* will necessarily produce an infinite total payoff to each player. Two tools are often used to compare strategies under the infinite time horizon. The first, a discount factor, has just been discussed. In the same scenario with infinite periods instead of $n = 100$ periods, the tipping points for the discount factors are the same – in the modified Prisoner's Dilemma, a player in that situation should choose C if $\delta > 0.75$ and D otherwise, and in the canonical Prisoner's Dilemma they should choose C if $\delta > 0.5$ and D otherwise. A way of analyzing the infinitely repeated Prisoner's Dilemma which is more relevant here is Folk Theorem diagrams.

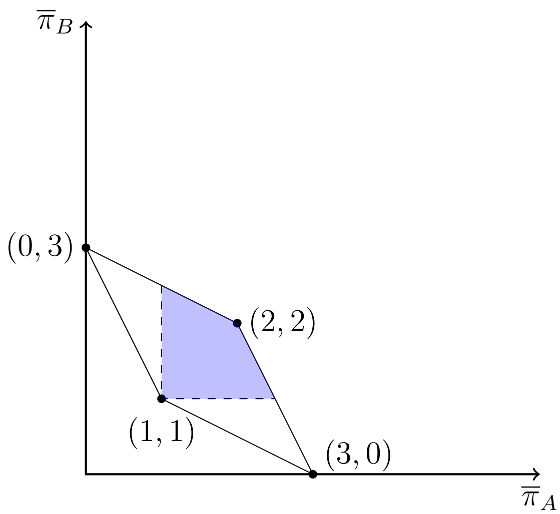

Figure 1: Canonical Prisoner's Dilemma

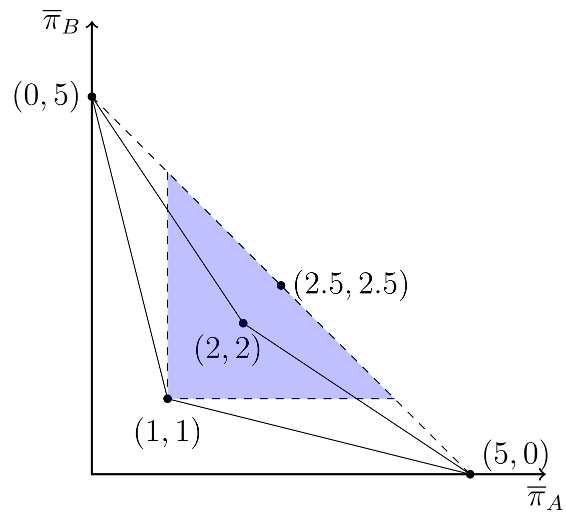

Figure 2: Modified Prisoner's Dilemma

Aumann 1959 first formalized the Folk Theorem, calling it such because it was known by game theorists in the early 1950s but never officially published. Friedman 1971 formalized the Folk Theorem to subgame perfect equilibria, and it is his methods which are used here. Consider an infinitely repeated canonical Prisoner's Dilemma, and plot the average payoffs for each player ($\overline{\pi}_A$ and $\overline{\pi}_B$) on two axes, one for player A and the other for player B. The results are Figure 1 and Figure 2.

In its most simple form, the Folk Theorem says that each point in the shaded region can be reached for some combination of strategies and choices in an infinitely repeated game. Further, the points on the upper border of the region are the set of Pareto optimal equilibria. That is, they are the equilibria for which one player cannot increase their payoff without the other losing something. Importantly, the point $(1, 1)$ is called the disagreement payoff, the equilibrium which occurs if each player chooses to defect forever. The points which lie within the bounded region (the "solution set") but outside the shaded region cannot be achieved in equilibrium. This result is not intuitive, but consider what would be required for player A to have an average payoff of 0 over the course of infinite periods. They would need to continue choosing C even as player B continues choosing D, which means they would never choose D even though it would strictly increase their payoff. This clearly violates the rationality assumption that players act in their own self-interest, so it is an impossible result.[4] The labelled points which are achievable in an infinitely repeated canonical Prisoner's Dilemma game, represented in Figure 1, are the two equilibria which can be achieved, and are referred to as the high equilibrium and the low equilibrium respectively. The high equilibrium is maintained by the players both choosing (C) for some period of time, and the low equilibrium is maintained by the players both choosing (D) for some period of time. Note that the middle equilibrium exists in the canonical Prisoner's Dilemma, but is not labelled because both players could do strictly better by choosing C in every period for the high equilibrium, so the middle equilibrium is Pareto dominated by the high equilibrium.

When the Folk Theorem graph is drawn for the modified Prisoner's Dilemma, the result is Figure 2. Note that if the payoff points are simply connected directly as in the canonical game, the resulting shape will be concave. This is impossible, as explained by Friedman 1971 who proves that the Folk Theorem shape must be a compact, convex set. Thus, there are some possible points the first graph in Figure 2 is missing, and they are added in the second graph. The added payoff points cannot be achieved in a single game, but over an infinite horizon they are possible. To see how, consider the point $(2.5, 2.5)$. This point is achieved if the players reach the point $(0, 5)$ half the time and $(5, 0)$ the other half. This process is called the "middle equilibrium" in this paper. The middle equilibrium is maintained by one player choosing (C) while the other chooses (D) in one period and then switching their choices to

[4]It is true that if player A plays $(Grim)$ and player B plays (AD), player A will receive 0 in the first period and 1 in all subsequent periods, but as the number of periods increases, $\overline{\pi}_A = \lim_{n\to\infty} \frac{n-1}{n} = 1$.

oscillate between $(0,5)$ and $(5,0)$.[5]

This discussion has focused on three specific points in the Folk Theorem diagrams, but the Folk Theorem says that every blue shaded point is a possible equilibrium. Consider the strategy where each player chooses C in the first period and D in the second and third period, and then repeats. Each player would receive an average payoff of $\frac{4}{3}$ every period, and the point $(\frac{4}{3}, \frac{4}{3})$ is shaded in blue. This represents a viable equilibrium, as it is a combination of consistent strategies, but as it is not achieved by one of the strategies mentioned above, it is not discussed further here. However, what theory predicts players will do is often different from what participants will do under laboratory conditions. Thus, an experiment is performed to test the conditions under which participants achieve the middle equilibrium.

[5]The players could switch every n periods instead, but that fact does not change the results as long as the average payoff remains $(2.5, 2.5)$, and for simplicity this paper only considers when they switch every period.

4 Data and Methodology

4.1 Experimental Methodology

There is no way to have participants play an infinite number of periods of Prisoner's Dilemma,[6] but there are two common methods used by economists. Normann and Wallace 2012 compared the two main strategies used to model infinite time horizons in the laboratory directly. The first strategy, called the *random horizon*, uses a random variable such that each period has a certain chance of being the final period, with experimental participants aware of the chance, a procedure famously used by Roth and Murnighan 1978. The second strategy, called the *unknown horizon*, has a finite number of periods participants are not aware of. Both strategies provide uncertainty as to when the final period will be, which is the preferred method for replicating infinite time horizons. Normann and Wallace found no significant difference in total cooperation rates between the two strategies when identical games were played under each horizon. They did find that end-game effects existed under the random termination rule but not under the unknown termination rule. Since this experiment is considering equilibrium rates rather than when the equilibrium will decay, the unknown horizon is used. Thus, each supergame lasts for the same number of periods. This also makes directly comparing them easier and leads to stronger results.

Almost every situation which can be represented as a game has an indefinite end point. This is illustrated by Hardin 1968, who represented nuclear proliferation between the United States and the Soviet Union as a long repeated game of canonical Prisoner's Dilemma, with an indefinite final period. That final period eventually occurred with the dissolution of the Soviet Union, 23 years after Hardin published his paper. It is true that indefinite time horizons used in the laboratory, which includes both the random and unknown horizons, are flawed models for infinite time horizons, but since all real world games are also indefinite,

[6] More precisely, there are no published examples of participants playing an infinite number of periods but as such experiments would necessarily be currently ongoing, there may be publications released an infinite time in the future from now detailing a process. As those publications will not come in the finite foreseeable future, other processes are used here.

Treatment	No Com	Some Com	High Com
Participants	16	20	14
Mean Payment	$14.56	$18.85	$14.29
Min. Payment	$13.00	$17.00	$7.00
Max. Payment	$19.00	$20.00	$25.00

Table 5: Experiment Participants Summary

they are acceptable models for the real world.

The experiment was conducted using 50 Haverford College[7] and Bryn Mawr College[8] undergraduate students. These students were recruited using posts on class Facebook pages and class GroupMe chats as well as in-person from a table outside the Dining Center. The participants were selected on a first-come-first-served basis with no discrimination on the basis of grade, major, or any racial or gender characteristics as well as any other characteristics, excepting those students already aware of the experimental hypothesis.

The experiment was conducted using small variations to the methodology outlined in Kagel 2018. Participants were divided into three treatments. In the first treatment, which is also the control treatment, they were allowed no communication with their opponent at any point. In the second, they were allowed to communicate for two minutes at the beginning of each supergame. In the third, they were allowed to communicate for two minutes at the beginning of each supergame as well as for thirty seconds after each even-numbered period. The communication was through an in-program anonymous chat feature. The participants were told the payoff structure of the modified Prisoner's Dilemma,[9] and that they would be playing at least 15 periods for each supergame. Thus, the participants did not know the true length of each supergame, though it was set at 20 periods. To facilitate this, there was no feature noting how many periods had been played in the code. The participants were randomly assigned their opponents, and played a supergame of 20

[7]Haverford College is a small liberal arts college in Haverford, Pennsylvania with approximately 1,350 students.

[8]Bryn Mawr is a small liberal arts college in Bryn Mawr, Pennsylvania which is also a historically women's college with approximately 1,700 students.

[9]The instructions given to each participant included Table 4, with (C) and (D) changed to "UP" and "DOWN" to prevent biasing the participants' choice with value statements.

periods against them. They were randomly reassigned and played a second supergame, and then reassigned again and played a third. The experiment was programmed using z-Tree, developed by Fischbacher 2007, a set of programs designed to code experiments in economics. Participants were brought in groups of 8-16 to the lab, where they played the game on individual computers, set up so that each participant could only see their own screen. Each participant was paid for 60 total periods of modified Prisoner's Dilemma where their total score was calculated in experimental currency units (ECUs) and then converted to United States Dollars (USD) at a rate of $1 = 10ECU, and each participant was also paid a $5 show-up fee.[10] After the experiment concluded, participants were asked to complete a survey with questions about their individual characteristics (such as gender and race) and their experience in each individual supergame (such as "how much did you trust your first opponent?"). Some basic summary statistics are shown in Table 5.

4.2 Data and Hypotheses

Data were collected on a per-supergame basis, so there were 75 total games studied. 74% of games contained at least one woman, and 74% of games contained at least one man,[11] with 15% containing at least one person who identifies as nonbinary. 21% of games contained an Economics major, 38% had two participants with the same gender, and the average trust level between players was 7.15, on a 10 point scale. This experiment was designed to test two hypotheses about the effect of communication on the rates of middle equilibrium. First, there is:

Hypothesis 1 *Participants will reach the middle equilibrium more often if they are allowed communication before each supergame, and will sustain the equilibrium for longer if they are allowed communication between every two periods.*

In this experiment, reaching a middle equilibrium is defined as three or more consecutive

[10] The average total payment was $17.60, with a minimum of $7 and a maximum of $25.

[11] This coincidence was entirely unexpected, and seems to be random chance.

periods where a combination of (C, D) and (D, C) are played such that if the number of consecutive periods is even, both participants receive the same total payoff over those periods and if the number of consecutive periods is odd, only one period of (C, D) or (D, C) would need to be added for both participants to receive the same total payoff over those periods. The total number of periods in the middle equilibrium is the value for how long it was sustained. This definition is unwieldy, as it must define the equilibrium in such a way that all equilibria reached by the participants are included but no non-equilibrium points are included. There are two specific situations this definition is meant to exclude, as they are not true equilibria. The first was a phenomenon observed by Kagel 2018. It happened when two players were in the high equilibrium and one chose (D). If communication was allowed, it would sometimes happen that the players would mutually agree to return to the high equilibrium if the player who had chosen (D) agreed to choose (C) and allow the other player to choose (D), after which they would both choose (C). This alludes to another feature of Kagel's results, that players care about fairness. Thus, the middle equilibrium is defined as occurring for three or more consecutive periods to ensure that this situation will not be falsely coded as an equilibrium. The second situation this definition is meant to exclude is that of a participant who is unable to communicate using the chat feature signalling that they are willing to operate in the high equilibrium by repeatedly choosing (C) while their opponent chooses (D). In this case, the participants would be using what early economists termed "tacit collusion." This situation is rarer, but can occur in the absence of true communication. To forestall it from being falsely included, the definition of middle equilibrium states that the participants must receive equal or near-equal payoffs over the course of the equilibrium.

Hypothesis 2 *Participants will reach the middle equilibrium more often and sustain it for longer if the participants have more experience playing the game.*

This hypothesis relies on an underlying basic assumption about the middle equilibrium, that it is harder to see as a viable equilibrium than either the high or low equilibria. This assumption is not based on any underlying theory, but seems at first glance to be reasonable. Thus, it will be tested with Hypothesis 2. If the middle equilibrium is truly harder to see as viable than the others, it would be expected that players who have more experience would be more likely to identify it, and there would be higher middle equilibrium rates in later games.

5 Results

The experiment was run with 50 total participants, but one of those participants clearly was not attempting to gain any payoff from the game,[12] so the supergames with that participant were excluded from the dataset. Further, in line with Normann and Wallace 2012, only the first 15 periods of each game were studied so that any endgame effects were not included in the data.

treatment	meq	meq_len	trust
1	24.000	24.000	24.000
	0.417	3.042	4.708
	0.103	0.900	0.644
2	30.000	30.000	30.000
	0.867	12.400	8.417
	0.063	0.976	0.316
3	18.000	18.000	18.000
	1.000	14.222	8.306
	0.000	0.613	0.373
Total	72.000	72.000	72.000
	0.750	9.736	7.153
	0.051	0.771	0.335

Figure 3: Key Summary Statistics

To see how the experiment went broadly, some key summary statistics are displayed in Figure 3. The first variable, labeled **meq**, is a dummy variable for whether a middle equilibrium was reached in the supergame.[13] The second variable, labeled **meq_len**, is the length of the middle equilibrium in each supergame, with a minimum of 0 (if the participants in that game did not reach a middle equilibrium) and a maximum of 15 (if the participants

[12]When looking at that player's communication after the game, they explicitly told their opponent that they would be choosing C every period and asked their opponent to choose D. When one opponent asked why, they said "im just vibing," and when presented with the strategy of alternating between (C, D) and (D, C) by the same opponent, said "ya but thats boring." It is clear that they were not attempting to get the highest payoff for themself in the experiment, so they were excluded from analysis as an outlier.

[13]A middle equilibrium, as defined above, is identified when there are three or more consecutive periods where a combination of (C, D) and (D, C) are played such that either total payoff to each player is equal or only one period of (C, D) or (D, C) would need to be added to make the total payoffs equal.

had a middle equilibrium for the entire game). The third variable, labeled `trust`, is the average of the two responses of each participant in the given game when asked the question "How much did you trust your [opponent] in game [1,2,3], on a scale of 1 for low trust to 10 for high trust?" This variable has a minimum of 1 and a maximum of 10. These variables are separated by `treatment`, which has a value of 1, 2, or 3, with 1 denoting the treatment with no communication, 2 denoting the treatment with communication only at the beginning of each supergame, and 3 denoting the treatment with communication at the beginning of each supergame and after every even round. The first value is the total number for each variable, the second is the mean, and the third is the standard error for each.[14]

An underlying assumption made for this experiment was that more communication between participants leads to more trust between them. By looking at the mean values for trust in Figure 3, it is clear that this assumption holds, but only somewhat. There is clearly much more trust in the treatments with communication allowed, but there is only a small difference between the two communication treatments, and the trust variable actually decreases from treatment 2 to treatment 3. This result is surprising, and should be kept in mind as the rest of the results are discussed here.

To test Hypothesis 1, a regression is run of the following form:

$$y_j = \beta_0 + \beta_1 s_1 + \beta_2 s_2 + \beta_3 \cdot \mathbf{X} + \varepsilon_j \tag{2}$$

Where y_{jk} is either the existence of an equilibrium in the given supergame or the length of that equilibrium, depending on which portion of Hypothesis 1 is being tested. s_1 is a dummy variable indicating whether the supergame was played in the treatment where communication was allowed only before each supergame, and s_2 is a dummy variable indicating whether the supergame was played in the treatment where communication was allowed both before the game and in between certain periods. $\mathbf{X}$ is a vector of individual characteristics. β_1 and β_2

[14] To read the values for `meq` in the treatment with no communication, see that there were 24 total supergames in that treatment, the mean of the variable is 0.417, and the standard error for that mean is 0.103

are the coefficients of interest, and Hypothesis 1 predicts that both are positive.

VARIABLES	(1) OLS	(2) w/ Controls	(3) Probit	(4) w/ Controls
someCom	0.450***	0.472***	1.321***	1.549***
	(0.121)	(0.119)	(0.390)	(0.408)
highCom	0.583***	0.611***		
	(0.103)	(0.106)		
female		-0.0343		-0.0589
		(0.138)		(0.589)
nb		0.0751		0.495
		(0.162)		(0.685)
sameGen		-0.0354		-0.158
		(0.103)		(0.509)
isEcon		0.109		0.638
		(0.101)		(0.522)
o.highCom			-	-
Constant	0.417***	0.405**	-0.210	-0.419
	(0.103)	(0.183)	(0.260)	(0.738)
Observations	72	72	54	54
R-squared	0.311	0.330		

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 4: Regression 1 with Middle Equilibrium as Dependent

First, the regression is run with `meq`, the dummy variable indicating the presence of a middle equilibrium, as the dependent variable. Results of Equation 2 are presented in Figure 4. Four regressions are run. The first is a simple OLS regression of the middle equilibrium variable on two dummies for treatments. The second is that same regression with controls added. The third is a Probit regression of the middle equilibrium variable on the treatment dummies, and the fourth is that same regression with controls. The two OLS regressions show the anticipated results from Hypothesis 1. Both the coefficients on the treatment dummies are positive and significant at the 1% level. Further, considering that the dependent variable is expressed from 0 to 1, these coefficients represent percentages. When controls are included, the probability of a middle equilibrium increases by 47.2 percentage points if participants are allowed some communication rather than no communication, and increases by 61.1 percentage points if participants are allowed communication between rounds as well rather than no communication. The difference between these two coefficients is significant at the 5% level, but not at the 1%. Note that the constant in the first regression, which represents the chance of a middle equilibrium with no communication allowed, is also significant at the 1% level and high. As the dependent variable is a dummy variable, probit regressions were also run to confirm the results. The coefficient on the dummy for high communication was omitted in the regression since every participant under high communication achieved a middle equilibrium. The coefficient on the some communication dummy is large and significant, lending additional credence to the results. Finally, none of the additional control variables[15] were significant. This trend will continue throughout the results, with none of the controls ever attaining significance.

VARIABLES	(1) OLS	(2) w/ Controls
someCom	7.008***	7.366***
	(1.276)	(1.182)
highCom	6.922***	7.241***
	(1.348)	(1.290)
female		-0.558
		(1.312)
nb		1.194
		(1.402)
sameGen		-1.373
		(1.193)
isEcon		-1.189
		(1.093)
Constant	7.300***	8.045***
	(1.200)	(1.770)
Observations	54	54
R-squared	0.517	0.595

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 5: Regression 1 with Middle Equilibrium Length as Dependent

To finish testing Hypothesis 1, Equation 2 was run with the length of the middle equilibrium (if the length was greater than zero) as the dependent variable. Results are reported

[15] `female` is a dummy for if either participant used she/her pronouns and `nb` is a dummy for if either participant used they/them pronouns. `sameGen` is a dummy for if the two participants were the same gender and `isEcon` is a dummy for if one of the participants was an Economics major.

in Figure 5. Again, the coefficients on the treatment dummies are large, positive, and significant. This regression indicates that the middle equilibrium is expected to last around seven periods longer if participants are in one of the communication treatments rather than the no communication treatment. However, unlike the first regressions, the null hypothesis that the coefficients on some communication and high communication are the same cannot be rejected. Again, note that none of the control coefficients are significant, and that the constant is again high and significant.

When evaluating Hypothesis 1, this experiment finds that the null hypothesis can *mostly* be rejected. The only case where it cannot is that there is no significant difference between the increase in middle equilibrium length under the some communication treatment and the high communication treatment. Thus, here is presented

Result 1 *Participants reach the middle equilibrium more often and sustain it for longer if they are allowed communication before each supergame, and they reach the middle equilibrium at higher levels if they are allowed communication between every two periods.*

To test Hypothesis 2, a regression is run of the following form:

$$y_j = \beta_0 + \beta_1 \tau_1 + \beta_2 \cdot \mathbf{X} + \varepsilon_j \tag{3}$$

Where are variables are the same as in Equation 2, except that τ_1 is a categorical variable denoting which game the participants are in, expressed in $\{1, 2, 3\}$. This regression is again run with two different dependent variables, one a dummy for whether a middle equilibrium occurred and another expressing the length of the middle equilibrium if it occurred.

The regression with the middle equilibrium dummy as dependent was again run under four different specifications, and results are expressed in Figure 6. Overall these results are less clear-cut than those for Regression 2. Under the OLS specifications, the coefficient on `game` is only significant with controls and only at the 10% level, less than the typical baseline for significance. However, under the Probit specification with controls, the coefficient is

VARIABLES	(1) OLS	(2) w/ Controls	(3) Probit	(4) w/ Controls
game	0.104	0.103*	0.333	0.536**
	(0.0633)	(0.0537)	(0.207)	(0.252)
someCom		0.471***		1.675***
		(0.116)		(0.435)
highCom		0.610***		
		(0.106)		
female		-0.0352		-0.119
		(0.129)		(0.582)
nb		0.0590		0.499
		(0.162)		(0.742)
sameGen		-0.0457		-0.100
		(0.0995)		(0.508)
isEcon		0.108		0.626
		(0.0987)		(0.544)
o.highCom				-
Constant	0.542***	0.206	0.0324	-1.478
	(0.146)	(0.213)	(0.423)	(1.019)
Observations	72	72	72	54
R-squared	0.039	0.368		

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 6: Regression 2 with Middle Equilibrium as Dependent

positive and significant at the 5% level. These results indicate that there may be a small game effect to the existence of a middle equilibrium, but the significance of that effect is not high and the effect is small. Thus, the null hypothesis that the game experience has no effect on the existence of a middle equilibrium cannot be rejected. As above, none of the other control variables except for the treatment variables are significant.

Results for the regression with the length of the middle equilibrium (if it occurred) as the dependent variable are expressed in Figure 7. The coefficient on the game experience variable is not significant under either specification, indicating that experience had no significant effect on the length of the middle equilibrium. Further, while the coefficient is positive, it is small relative to the size of the dependent variable, indicating a small economic significance. Again, the null hypothesis that game experience had no effect on middle equilibrium length cannot be rejected. Further, the R-squared value for the first OLS specification is extremely

VARIABLES	(1) OLS	(2) w/ Controls
game	0.408	0.781
	(0.700)	(0.559)
someCom		7.448***
		(1.209)
highCom		7.398***
		(1.300)
female		-0.475
		(1.221)
nb		1.113
		(1.466)
sameGen		-1.634
		(1.192)
isEcon		-1.102
		(1.010)
Constant	12.13***	6.353***
	(1.585)	(1.599)
Observations	54	54
R-squared	0.007	0.621

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 7: Regression 2 with Middle Equilibrium Length as Dependent

small, indicating that virtually none of the variation in middle equilibrium length was explained by game experience. This is in contrast to Figure 5, which had larger R-squared values. Both of these sets of results for Regression 3 lead to the following result:

Result 2 *The game experience of the participants has no effect on middle equilibrium length, and the effect it has on middle equilibrium rates is small and debatably significant.*

6 Discussion

It is impossible to directly compare this experiment with others in the canonical Prisoner's Dilemma due to methodological differences. However, there are some specific elements of the modified Prisoner's Dilemma which seem to be different from the canonical Prisoner's Dilemma in experiments. The first deals with tacit signalling, the concept discussed above where participants without communication signal their intent through game actions. Tacit signalling seems to be especially prevalent in the modified Prisoner's Dilemma. Multiple participants mentioned that their strategy at the beginning of the game was to switch between C and D for a few periods to signal to their opponent that they were willing to enter the middle equilibrium. This strategy worked, especially in games 2 and 3, and 42% of the games in the no communication treatment had a middle equilibrium of some form. An important difference between the treatments was the *length* of the middle equilibrium. For those who achieved a middle equilibrium, the average length was only about 7 periods, versus an average of more than 14 for both of the communication treatments. This is referenced in Result 1, but merits more discussion here.

Kagel 2018 notes that communication between periods is useful for re-establishing trust after a betrayal. It seems that even though the treatment with only communication before the game has no more way to re-establish trust after a betrayal than the no communication treatment, communication before the game leads to less betrayals in general. When looking at the actual communication logs from the treatment, this result seems to be because participants developed a plan for the entire game and stuck to it. Participants tended to focus on getting the most money first, and then fairness. An example of most money is a participant who said "so obviously the best way to do this is to take turns ... so we both get the most in the end." An example of fairness is the participant who, believing that the game would last an odd number of rounds, advised their opponents that they should both choose C in the first period and then alternate for the rest, so that they would earn the same with an odd number of rounds. While Kagel noted some level of threats among his participants, no participants explicitly threatened their opponents with punishment if they betrayed. Instead, participants seemed to use guilt to incentivize their opponents to keep to the plan. One said "I got backstabbed last round," to which their opponent responded "there are bad people here." Other participants made reference to the Haverford Honor Code, saying "I really hope that the honor code is still alive."

It is not known whether the use of guilt is a feature of the modified Prisoner's Dilemma or a feature of the participant population, undergraduates from liberal arts colleges with strong honor codes. To answer this question, an experiment would either need to be run with the same methodology and a different participant population, or an experiment would need to be run directly comparing the canonical and modified Prisoner's Dilemma with participants drawn from the same population. As this result, the use of guilt instead of threats, is one which breaks the most from established papers, such an experiment would be welcome.

Finally, mentioned in Section 4.2 was the assumption that the middle equilibrium was "harder to see" than the high or low equilibrium. While this seems to be true for some participants (one said "the best we can do is if we both choose up"), the majority of participants identified the middle equilibrium and sought a way to achieve the payoff of 5 every two periods. In fact, both of the participants who seemed not to notice the middle equilibrium in the some communication treatment referenced the fact that the game was the Prisoner's Dilemma. This result only encompasses two of the 50 participants, but it similarly motivates a further question. If the game were introduced to the participants as Prisoner's Dilemma at the beginning of the experiment (it was not) would high equilibrium rates be more prevalent than middle equilibrium rates? It seems that a majority of participants, and all of those with no game theory experience, viewed the modified Prisoner's Dilemma as an entirely new game in which to maximize their payoff, but at least two participants relied on their background knowledge of Prisoner's Dilemma rather than analyzing the game in full, to their detriment. Neither participant was an Economics major, so this result may be due to the notoriety of Prisoner's Dilemma – if this experiment instead involved Stag Hunt, a lesser known game outside of Economics, would this result still occur? It seems like it would not, but again there is no true evidence to that result. Overall, participants seemed to broadly trust one another more than in Kagel 2018 or Dal Bó 2005, and when allowed communication, participants mostly worked to earn the greatest payoff for both players.

7 Conclusion

This paper introduces a modification to Prisoner's Dilemma in which the middle equilibrium is viable and Pareto dominates the traditional high (cooperative) equilibrium. It shows that the modified game is different from the canonical game under an infinite time horizon, though it is the same under all finite time horizons except those using discount factors. Over the course of the experiment, it is shown that communication leads to higher middle equilibrium rates and a more stable middle equilibrium, but that experience in the game has no significant effect on middle equilibrium rates or stability. Finally, based on qualitative responses from the experiment it seems that players identified the middle equilibrium at high rates and sought to achieve it, and some used tacit collusion if no communication was allowed.

These results are preliminary, though they provide some support that there are questions to be explored in the modified Prisoner's Dilemma. The first area of exploration is the experimental route. A single experiment in isolation does not provide much of a canon on a game, especially one with participants drawn from a small, specific population. The two areas which are most in need of exploration from an experimental perspective are the question of the difference between the modified Prisoner's Dilemma and the traditional Prisoner's Dilemma, and the question of the use of guilt rather than threats in the communication stage. These questions can be explored through experiments, and the author hopes that future work will contribute to answering them.

The second area of exploration has little to do with this paper, but was the motivating example behind its creation. There is a tradition of using Prisoner's Dilemma to model oligopoly behavior, and Lambertini 1997 showed that the choices firms make in oligopoly can always be reduced to a Prisoner's Dilemma of the form $\alpha + \varepsilon > \alpha > \beta > \beta - \eta$. In the 1950s, companies in an oligopoly who were competing for government contracts in the electrical industry split the market temporally rather than conspiring to raise prices as a whole, a conspiracy summarized by Herling 1962. In this way, each of the 20 companies essentially had $\frac{1}{20}$ of monopoly profit rather than Cournot profit in oligopoly. This story seems familiar to the modified Prisoner's Dilemma, where in the middle equilibrium players receive the entire payoff in one out of every two periods rather than a more stable but smaller on average payoff every period. Further exploration of the way players act in equilibrium may prove fruitful in modeling such oligopoly markets where firms decide to split the market (whether temporally or by other means) rather than conspiring to raise prices across the market. It is hoped that future works will explore this topic in depth.

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