*Theo*rie en praktijk van leren en de leraar

Liber Amicorum Theo Wubbels

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Onder redactie van
Jan van Tartwijk, Mieke Brekelmans, Perry den Brok en Tim Mainhard

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Werner Raub

A theory of co-teaching[6]

Introduction

Interaction is a core element of teaching and learning. Teachers interact with students. Students interact with each other, for example, when working on a group assignment. Co-teaching is an example of interaction between teachers. The literature on interpersonal relationships in education (e.g., Wubbels, Den Brok, Levy, & Van Tartwijk, 2012) focuses on such interactions. Through interaction, actors become interdependent. It depends on both the behaviour of teachers and students how much and what students learn and how satisfactory such learning is for teachers and students. The quality of the final product of students' work on a group assignment depends on each student's contribution. Similarly, the results of co-teaching depend on each teacher's 'input' of time, effort, and expertise.

Incentive problems are a specific feature of interaction and interdependence between teachers when co-teaching a course for students in higher education. Teacher Ego's contributions of resources such as time, effort, and expertise have an effect on the overall quality of the course in terms of,

6 Jan van Tartwijk has been helpful in providing references on research into free-riding among students. Support by NWO for the PIONIER-program "The Management of Matches" (grants S 96-168 and PGS 50-370) is gratefully acknowledged.

for example, student achievements and satisfaction, results of the course evaluation by the students, and teacher satisfaction. However, the effects of teacher Ego's contributions also depend on the contributions of teacher Alter. Conversely, the effects of Alter's contributions also depend on Ego's behaviour. The likelihood of positive results of co-teaching increases when both Ego and Alter contribute a fair amount of resources. Students but also both Ego and Alter will prefer positive results to a badly taught course. On the other hand, both Ego and Alter not only co-teach the course in question, they are likewise involved in teaching other courses and also pursue research. Therefore, since resources like time and energy are limited, both Ego and Alter face incentives to reduce own contributions and to free ride on the contributions of the colleague. However, when Ego and Alter follow such incentives, positive results become less likely and both the students in the course and the teachers themselves will be worse off than had both Ego and Alter contributed more[7].

The sketch suggests that co-teaching involves features of a *social dilemma* ('collective action problem' and 'public goods problems' are other labels used in the social science literature; see Buskens & Raub, 2013 for an overview): *individual* rationality in terms of incentive-guided and goal-directed behaviour conflicts with *collective* rationality in the sense of mutually beneficial outcomes - a paradigmatic example of unintended consequences of incentive-guided and goal-directed behaviour.

Interaction and interdependence between students when working on a group assignment is associated with structurally similar incentive problems. Each student benefits, if only in terms of the grade for the assignment, when each student contributes his or her own fair share of work, while each student has an individual incentive to reduce own contributions. There is some research on such incentive problems among students (e.g., Maiden & Perry, 2011; Swaray, 2012), but incentive problems for teachers when co-teaching seem to be neglected. This paper offers a simple game-theoretic model of co-teaching. Testable predictions as well as policy implications are derived.

7 Value judgments should be applied with care in this context. The point is not, at least not necessarily, that the teachers are idling when following the incentives described. Rather, they may work hard on other courses than the one co-taught or on research projects.

A simple model of co-teaching

Co-teaching is modelled as a *co-teaching game*, a two-actor version of the *Public Goods Game* (see, e.g., Gächter & Thöni, 2011 on the Public Goods Game)[8]. The game involves two actors, teachers Ego and Alter. Each teacher has a budget $E > 0$. The budget depends, for example, on the time-budget each teacher receives for teaching the course and also includes the teacher's effort that would be available, in principle, for teaching the course. Simultaneously and independently, the teachers choose their individual contribution e_i (i = Ego, Alter) to the course, with $0 \leq e_i \leq E$. Note that $e_i = 0$ should not be interpreted as 'contributing nothing'. Rather, $e_i = 0$ represents what teacher i has to contribute at least because it would otherwise become transparent that i neglects obligations. Thus, for example, a teacher has to be present in class, has to say something while teaching in class, has to grade assignments and exams in due time, et cetera. However, how carefully the teacher prepares classes, the teacher's effort while being in class, the quality of feedback provided for students and so forth are at least to quite some degree to the teacher's discretion rather than being directly observable for and thus enforceable by an external third party such as a Board of Studies. Following common notation and terminology, we denote the minimal contribution level $e_i = 0$ as D_i, with 'D' for 'defection', while the maximum contribution level $e_i = E$ is denoted as C_i, with 'C' for 'cooperation'.

In the co-teaching game, the joint contribution $e = e_{Ego} + e_{Alter}$ is multiplied by m ($1 < m < 2$). The parameter m represents how well the teachers 'fit' in terms of complementary expertise and other complementary skills. For example, one of them may have a comparative advantage in providing the lectures, while the other's comparative advantage may be teaching work groups. Thus, m represents the benefits from co-teaching the course compared to how well the course would be taught by one teacher alone. The overall quality of the course as reflected in student achievements and satisfaction, results of the course evaluation by the students, and teacher

8 Rasmusen (2007) is a textbook on game theory covering the technical material used parsimoniously and intuitively in the paper. Note that quite some of the results likewise apply when using related but alternative game-theoretic models (see, e.g., Buskens & Raub, 2013 for details).

satisfaction, is determined by *me*. Each teacher's utility U_i derived from the course is assumed to depend on the budget E, individual contributions e, and m so that $U_i(e) = E - e_i + me/2$. Hence, the benefits from co-teaching are assumed to be distributed equally among the teachers.

Assume the standard game-theoretic elaboration of incentive-guided behaviour, namely, equilibrium behaviour: each teacher chooses a contribution level that maximizes the teacher's utility, given the contribution level of the other teacher. Since $m < 2$, it follows that contributing $e_i = 0$ maximizes each teacher's utility, irrespective of the contribution level of the other teacher. Hence, the co-teaching game has a unique equilibrium $D = (D_i, D_j)$ such that $e_i = 0$ for each teacher, with utility $P_i := U_i(D) = E$ for both teachers (j = Ego, Alter; $j \neq i$). On the other hand, both teachers are better off than in equilibrium when they both cooperate by contributing their complete endowment, since mutual cooperation $C = (C_i, C_j)$ yields $R_i := U_i(C) = mE > P_i = E$ for each teacher. However, mutual cooperation is not an equilibrium: each teacher has an incentive for defection in the co-teaching game since utility maximization, given C_j, implies to contribute nothing so that $T_i := U_i(D_i, C_j) = E + mE/2 = E(1 + m/2) > U_i(C) = R_i = mE$[9].

Often, Ego and Alter will co-teach one and the same course not only once, as we have implicitly assumed until now, but they will co-teach the course repeatedly. Alternatively, or additionally, they might co-teach also other courses or might be involved in joined research, for example, as co-authors of papers. Ego and Alter are then involved in repeated interactions with incentive problems associated with each of those interactions[10]. A simple model accounting for repeated interactions is the iterated co-teaching game[11]. The game is now played indefinitely often in rounds $1, 2, \ldots, t, \ldots$ so that after each round t, the next round $t + 1$ is played with probability w ($0 < w < 1$), while the interactions end after each round with probability $1 - w$. Each round can be seen as representing a course co-taught by Ego and Alter. After each round, Ego and Alter are informed about each other's be-

9 Notation follows meanwhile common notation for social dilemmas, with R_i "***r***eward for mutual cooperation", P_i "***p***unishment for mutual defection", and T_i "***t***emptation for unilateral defection".

10 One easily sees that co-authorship entails incentive problems that are structurally similar to those of co-teaching.

11 The following sketch is an adapted and abridged version of Buskens and Raub (2013, pp. 124-125).

haviour in that round. For example, Ego and Alter have directly observed each other's behaviour while teaching some sessions of the course together, they have exchanged their course materials, and they have studied how students have evaluated the course and each teacher's contribution.

In the iterated game, a strategy is a rule that prescribes each teacher's behaviour in each round t as a function of the behaviour of both teachers in the previous rounds. Each teacher's utility for the iterated co-teaching game is the discounted sum of the teacher's utility per round, with the continuation probability w as discount parameter. For example, when both teachers cooperate throughout, each earns $R_i + wR_i + \ldots + w^{t-1}R_i + \ldots = R_i/(1 - w)$. The continuation probability w thus represents the 'shadow of the future (Axelrod, 1984): the larger w, the more each teacher's utility from the iterated game depends on what the teacher receives in future rounds.

In the iterated co-teaching game, each teacher can use a conditional strategy that rewards the other teacher's cooperation in a focal round by own cooperation in future rounds. Conversely, a conditional strategy can punish the other teacher's defection in the focal round through own defection in at least some future rounds. If teacher j uses such a conditional strategy, i can gain T_i rather than R_i in the current round by unilaterally exploiting j's cooperation through own defection. However, defection will then be associated with obtaining at most P_i in (some) future rounds when j defects, while i's cooperation in the current round will result in earning more than P_i in those future encounters if teacher j continues cooperating.

Moreover, the larger the shadow of the future, the more important are the long-term effects of present behaviour. Thus, anticipating that the other teacher may use a conditional strategy, each teacher has to balance short-term ($T_i - R_i$) and long-term ($R_i - P_i$) incentives. It can be shown (e.g., Taylor (1976/1987) that using conditional strategies can be a basis for cooperation in the iterated co-teaching game in the sense that the iterated co-teaching game has a cooperation equilibrium, that is, an equilibrium such that both teachers cooperate in each round. Cooperation in the iterated co-teaching game is then voluntary, driven exclusively by long-term, 'enlightened' self-interest of the teachers and by reciprocity.

Consider the strategy of a teacher that is associated with the largest reward for cooperation of the other teacher and with the most severe punishment for defection. This is the strategy that prescribes to cooperate in the first

round and also in future rounds, as long as the other teacher has cooperated in all previous rounds. However, after the first defection, the teacher defects in all future rounds. Such a strategy is often labelled a '*trigger strategy*' because deviation from the 'prescribed' pattern of behaviour triggers a change in the teacher's behaviour. Obviously, when both teachers use a trigger strategy, they cooperate in each round of the iterated co-teaching game.

The following simple theorem specifies the necessary and sufficient condition for an equilibrium in the iterated co-teaching game such that both teachers cooperate in each round.

Theorem on cooperation in co-teaching. The iterated co-teaching game has a cooperation equilibrium if and only if the teachers can use conditional strategies such as the trigger strategy and

(1) $w \geq (2/m) - 1$.

Proof: see Appendix.

Condition (1) requires that the shadow of the future w is large enough compared to $(2/m) - 1$. Note that $0 < (2/m) - 1 < 1$. Note, too, that if a cooperation equilibrium based on trigger strategies exists, there may likewise exist cooperation equilibria based on other conditional strategies, including conditional strategies that employ less harsh punishment threats. Thus, it is not necessary to presuppose that cooperation in the iterated co-teaching game based on equilibrium behaviour is a result of an equilibrium in trigger strategies.

If condition (1) applies, the iterated co-teaching game has an equilibrium such that both teachers cooperate in each round of the iterated game. The teachers can then overcome the incentive problem involved in co-teaching. The equilibrium, however, is not unique. For example, defection in each round is likewise an outcome of equilibrium behaviour: if teacher Alter defects unconditionally throughout the iterated game, it is obviously utility maximizing behaviour for Ego to defect likewise and vice versa.

The "folk theorem" (e.g., Rasmusen, 2007, chapter 5.2) for repeated games implies that the iterated co-teaching game has many other equilibria, too, for large enough w. Thus, an equilibrium selection problem emerges: assuming that an equilibrium will be played, *which* equilibrium will be played? A typical, though sometimes implicit argument in the literature on equilibrium selection in this context is 'payoff dominance': in the iterat-

ed co-teaching game, an equilibrium that implies cooperation throughout the game payoff-dominates the defection equilibrium in the sense that both teachers are better off.

Conditions for cooperation, testable predictions, and policy implications concerning co-teaching

Assume now that the iterated co-teaching game is played as a non-cooperative game in the technical sense that the teachers are unable to incur binding agreements on their behaviour that are enforced by a third party such as a Board of Studies and that the behaviour of teachers is incentive-guided in the sense of equilibrium behaviour[12]. One can then derive, first, conditions for cooperation and testable predictions on co-teaching from the model. Second, the model also yields policy implications.

Conditions for cooperation and *testable predictions* can be derived under the assumption that cooperation becomes more likely when the conditions for the existence of a cooperation equilibrium of the iterated co-teaching game become less restrictive and when it becomes more likely that a cooperation equilibrium will in fact be played by incentive-guided teachers. Basically, the model yields four kinds of condition for cooperation and testable predictions[13].

First, the teachers must be able to use conditional strategies, since cooperation in the iterated co-teaching game can only be based on such strategies. After all, the only combination of unconditional strategies implying cooperation throughout the iterated game would be that each teacher cooperates in each round, irrespective of what has happened in earlier rounds. This cannot be equilibrium behaviour, since utility maximizing behaviour against unconditional cooperation of the partner requires own defec-

12 The assumption of a non-cooperative game makes sense, given that a third party like a Board of Studies cannot enforce more contributions than the minimal contribution level $e_i = 0$. Note that the assumption of a non-cooperative game does not imply that the teachers will *behave* non-cooperatively in the sense of defection. On the contrary, the aim of the analysis is precisely to specify conditions such that incentive-guided behaviour implies voluntary cooperation in the co-teaching game without external enforcement, based exclusively on enlightened self-interest and reciprocity.

13 See Raub and Voss (1986) for a more detailed analysis of such conditions and predictions for social dilemmas in general. Buskens and Raub (2013) provide an overview of the empirical evidence. Note that testable predictions as well as policy implications are of course subject to a *ceteris paribus* condition.

tion in each round. Conditional strategies, however, can be used by the teachers only if they receive *reliable information* on the behaviour of the partner in each round of the iterated game, be it through direct observation or through other means. Thus, a testable prediction is, roughly, that information on the other teacher's behaviour throughout the course should have a positive effect on the likelihood of cooperation.

Second, condition (1) in the Theorem on cooperation in co-teaching becomes less restrictive when the *continuation probability w* increases. Thus, when *w* increases, cooperation should become more likely. The probability *w* increases when the teachers can expect to co-teach the same course repeatedly over a sequence of academic years or to be engaged in other joint projects like co-authorships in research for a longer period of time. Also, *w* increases when the teachers have more opportunities for reciprocity due to multiple courses they co-teach in parallel or when they pursue other joint projects in parallel. This yields testable predictions on how the likelihood of cooperation is related to repeatedly co-teaching the same as well as other courses or to being engaged in other joint projects.

Third, condition (1) becomes less restrictive when $(2/m) - 1$ decreases, i.e., when the *benefits m from co-teaching* increase. Thus, when *m* increases, cooperation should become more likely. Testable predictions follow on how the likelihood of cooperation is related to conditions that favour an increase in *m* such as complementary expertise of the teachers as well as other complementarities.

Finally, given the equilibrium selection problem, there must be a common understanding and reciprocal expectations between the teachers that a cooperation equilibrium, if it exists, will actually be played. Such a common understanding is often referred to as *co-orientation* (e.g., Schelling, 1960). More technically, the teachers need co-orientation in the sense of a common understanding that payoff dominance will be used for equilibrium selection. Again roughly speaking, such co-orientation should increase the likelihood of cooperation. In turn, conditions that can be expected to facilitate co-orientation include (opportunities for) communication between the teachers. Note that the theoretical model implies that communication should not affect cooperation in the co-teaching game when the game is played only once, since defection is then a dominant strategy, while communication is expected to have effects for how the it-

erated game is played. Other conditions facilitating co-orientation are a common history of the teachers as well as a consistent and simple common culture that is firmly established in the respective department (e.g., Kreps, 1990).

Note that the model also yields an *additional set of predictions*, namely, on *outcome variables such as student achievements and satisfaction, course evaluations by students, and teacher satisfaction*. Assuming that cooperation of the teachers has a positive effect on such variables, one can derive predictions on how the independent variables that affect cooperation likewise have an effect on these outcome variables.

What about *policy implications*? In other words, in what respects does the analysis provide rationales for departments and Boards of Studies that run their teaching programs and, more precisely, manage co-teaching arrangements in sound ways or, respectively, what recommendations follow with respect to co-teaching arrangements? Theoretically speaking, what are formal and informal institutions ('rules of the game') that can be expected, assuming that the model has sufficient empirical support, to favourably affect the likelihood of cooperation between teachers who co-teach a course? Policy implications can be generated by reconsidering the four kinds of condition for cooperation and testable predictions.

First, it has been derived that information on the other teacher's behaviour throughout the course should have a positive effect on the likelihood of cooperation. Hence, it should be facilitated that teachers can indeed directly observe each other's behaviour by requiring, for example, that they teach some sessions of the course together and engage in various forms of intervision, that they exchange their course materials, and by designing course evaluations by students so that these evaluations also include separate evaluations of each teacher's individual performance.

Second, it makes sense from the perspective of the model to implement measures that affect the continuation probability w positively. A basic measure would be to favour longer term employment also for non-tenured staff. Also, having the same teachers co-teach the same course several times should be preferred to constant reshuffling of teacher teams. Moreover, it is preferable that teachers co-teach who are likewise engaged in other joint projects, including, for example, joint research projects.

Third, the model implies that teacher cooperation becomes more likely

when the benefits *m* from co-teaching are larger. Thus, it is preferable that teachers co-teach whose expertise and other (potential) contributions are complementary. For example, in a course on the integration of theory and empirical research, one would prefer co-teaching of a teacher who is a theoretician with a teacher who engages in empirical research, assuming that at least one of the two likewise has expertise on statistical modelling. Or, it makes sense to select co-teachers so that one has a comparative advantage as lecturer, for example, due to more experience and a better overview of the field, while the other has a comparative advantage in leading work groups.

Finally, given the model, one expects co-orientation to favourably affect the likelihood of teacher collaboration. An obvious policy implication is to have teachers co-teaching a course who know each other well. More generally, policies make sense that facilitate communication and, through communication, the establishment of an appropriate culture of the department. Thus, working at the department should be favoured over working at home and an informal open doors policy should be favoured in the department. Also, it makes sense to take care of common and attractive meeting places at the department such as a common room, by the way not neglecting a high-quality coffee machine (e.g., Verstraten, 2000), as well as common and attractive social activities every now and then.

Quite some of these policy measures are in fact maintained in well-functioning departments. However, it seems that the reasons for such policy measures are often exclusively sought in their *direct effects* on the quality of teaching and research. Indeed, it seems plausible to assume that, for example, complementary skills of teachers do have a positive direct effect on the quality of a course they co-teach. The model presented here shows, however, that there is also an *indirect effect* of the formal and informal institutions sketched, namely, via their incentive effects on voluntary cooperation. These indirect effects should not be overlooked.

Discussion

Incentive problems due to interdependence between teachers who co-teach a course have been analysed. Employing game-theoretic modelling, conditions for cooperation of the teachers and testable predictions have

been derived as well as policy implications. The underlying mechanism that drives the results is the trade-off between long-term and short-term incentives due to repeated interactions of the teachers.

To facilitate exposition, the analysis has been based on a rather simple model. It should be noted that our core results are robust to various modifications of the model. For example, with an eye on the case that a senior scholar co-teaches with a junior, it would be possible to relax our strong assumptions with respect to the 'symmetry' of the game by allowing for differences between the teachers with respect to their budget or by allowing for an unequal distribution of the benefits from co-teaching. Likewise, literature is available (see Buskens & Raub, 2013 for a survey) on the more complex case of interactions that are not repeated indefinitely often but are repeated for a finite number of 'rounds', together with the assumption that teachers are incompletely informed about each other's incentives. Also, one can study the case when teachers cannot monitor each other's behaviour perfectly and observations of the other's behaviour may be mistaken.

An interesting extension of the model would be to include network effects. For example, Ego and Alter are members of a department with quite some other colleagues who can likewise condition their behaviour on Ego's and Alter's contributions to co-teaching. Given such network effects, cooperation based on incentive-guided behaviour is often facilitated (see, e.g., Raub, Buskens, & Frey, 2013 for models of network effects as well as the emergence of networks) and one can show that network effects do indeed facilitate cooperation in the iterated co-teaching game (this is a direct implication of Propositions 1-3 in Raub et al., 2013). Thus, networks between teachers can be seen as social capital (various contributions in Wubbels et al., 2012 discuss how the notion of social capital could be employed in the analysis of relationships in education).

Still another extension of the co-teaching game is needed to account for co-teaching of more than two teachers. The standard version of the (iterated) Public Goods Game could be used as a simple model to study co-teaching by $n \geq 2$ teachers. A new core result is then that the conditions for cooperation in the iterated game become generally more restrictive, the larger the number of teachers involved (see Olson, 1965 as the meanwhile classic contribution on group size effects for cooperation). One would expect that observability of each other's behaviour as well as co-orientation become

more problematic in larger groups. Moreover, one can show that the equivalent of condition (1) for a game with $n \geq 2$ teachers becomes more restrictive when n increases. Obviously, this yields an argument to use 'teacher parades' only with care in higher education.

The iterated co-teaching game highlights that long-term relations can drive cooperation between teachers. This is clearly a benefit of stability in social relations. Of course, such stability also comes with costs. For example, maintaining stable relations often conflicts with integrating new and creative colleagues ('fresh blood') from outside and with introducing innovations (see Coleman, 1990, chapter 5, for a general discussion of this issue). From a policy perspective, thus, a department chair and a Board of Studies have to balance the costs and benefits of inducing and supporting long-term relations between colleagues.

Our analysis shows by way of example that theory construction through formal building need not be '*l'art pour l'art*', neither in research on teaching and education nor elsewhere. Formal models can allow for deriving testable predictions, 'embedding' such predictions in a broader theoretical framework, and can also allow for deriving policy implications, contributing to a theoretical basis for policy making. Much of science is not only about theoretical statements on the one hand and empirical statements as well as policy advice on the other, but is about how these different kinds of statements are logically related to each other, thus providing more 'depth' (Popper, 1973).

Postscript

Theo Wubbels is an outstanding scholar in the field of teaching and learning, Utrecht University's foremost expert in the field and also an able administrator in higher education. Over the years, I have learned a lot from Theo on teaching and learning and have been privileged to have collaborated with him in running the Faculty of Social and Behavioural Sciences. When contemplating how I could contribute a piece to his *Festschrift* based on my own expertise as sociologist and related to the field of teaching and learning and Theo's own scholarly work in this field, it has been helpful that Theo has done quite some research on interpersonal relationships in education (Wubbels et al., 2012, is just one recent item from a much

longer list of publications on this topic in his cv). In a theory course that I taught (and co-taught) for many years in the Sociology Bachelor's program of Utrecht University, I included a module on cooperation in social dilemmas - a core topic of the discipline not only in modern work applying game-theoretic modelling but already since Hobbes, Durkheim, Weber, and Parsons. As a conclusion of this module, I set up a class discussion on what can be learned from models of cooperation for how to induce good co-teaching. I thus asked students to put themselves in the shoes of a member of a Board of Studies and to design policy measures based on implications from models of cooperation, my impression being that students found this more entertaining than the similar task of designing measures that mitigate free-riding of students who work on a group assignment. My contribution to Theo's *Festschrift* has been an opportunity to turn some informal lecture notes into a paper and is therefore a result of research inspired by teaching, including a focus on policy implications for running educational programs. I believe that Theo will enjoy this feature, also because he often stressed, rightly so, the core role of teaching and a balanced perspective on research and teaching in the university.

Appendix

Proof of the Theorem on cooperation in co-teaching. The theorem is an implication of the fundamental theorem on trigger strategy equilibria in indefinitely often repeated games (e.g., Friedman, 1986, pp. 88-89). We sketch the core ingredient of the proof and refer to Friedman (1986) for further details. The core ingredient involves showing that condition (1) is a necessary and sufficient condition for an equilibrium of the iterated co-teaching game such that both teachers employ the trigger strategy.

To show this, it suffices to prove that condition (1) is necessary and sufficient to ensure that a teacher, say, Ego maximizes utility in the iterated co-teaching game by always cooperating, given that the other teacher, Alter, uses a trigger strategy. We show this indirectly and thus assume that Ego could secure a higher utility than by always cooperating. In that case, there must be some round t such that Ego deviates for the first time from own cooperation (otherwise, Ego could not secure a higher utility). Immediately afterwards, Alter will start to defect and will continue to do so in

all future rounds. Thus, the best thing Ego can do is to defect in round *t* and to also defect in all future rounds. We must then have:

$$R + wR + \ldots + w^{t-2}R + w^{t-1}T + w^{t}P + w^{t+1}P + \ldots >$$
$$R + wR + \ldots + w^{t-2}R + w^{t-1}R + w^{t}R + w^{t+1}R + \ldots$$

which is equivalent to:

$$T + w^{1}P + w^{2}P + \ldots + w^{t-1}P + \ldots > R + wR + \ldots + w^{t-1}R + \ldots .$$

Substituting and rearranging yields $w < (2/m) - 1$. Thus, if it is profitable for Ego not to cooperate in some round *t*, it would be likewise profitable to defect already in round 1 which is equivalent with $w < (2/m) - 1$ and thus contradicts condition (1). This completes our sketch of the proof.

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