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Towards a Justification the Principle of Coordination

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Towards a Justification the Principle of Coordination

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Abstract. Different variations of a Principle of Coordination are used in a number of different research traditions. Roughly speaking, one version of the Principle says that if there is a unique Pareto-efficient outcome in a game, then players will choose their part of that outcome. In this paper I will investigate the foundations of the Principle and see to what extent the Principle follows from some axioms regarding rational individual decision-making.

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1. Introduction

On many occasions, individuals are able to coordinate their actions. Empirical evidence to this effect has first been gathered by Schelling (1960) in an informal experiment. His results were corroborated many years later by Mehta et al. (1994a,b) and Bacharach and Bernasconi (1997). From the point of view of mainstream game theory, the success of individuals in coordinating their actions is somewhat of a mistery. If there are two or more strict Nash equilibria, mainstream game theory has no means to explain why people tend to choose their part of one and the same equilibrium. Textbooks (see, e.g., Rasmusen, 1989, Kreps, 1990) refer to the fact that players may use focal points, a term introduced by Schelling (1960), but the notion of focal points cannot itself easily be incorporated into the theoretical framework.

Since Gauthier (1975) many authors have attempted to explain the empirical facts in a way that departs in one way or the other from mainstream game theory. Crawford and Haller (1990) try to explain how rational individuals can use past play to learn to coordinate. Bacharach (1993), Sugden (1995) and Janssen (2000) try to explain how individuals can use the labels of strategies to coordinate their actions.[1] All these papers use variations of the Principle of Coordination, a term introduced by Gauthier (1975). Gauthier (1975: 201) defines the Principle in the following terms: "in a situation with one and only one outcome which is both optimal and a best equilibrium, if each person takes every person to be rational and to share a common coneption of the situation, it is rational for each person to perform that action which has the best equilibrium as one of the possible outcomes". Crawford and Haller (1990: 580) "maintain the working hypothesis that players play an optimal … strategy combination", which is defined as a strategy combination that maximizes both players' repeated-game pay-offs.[2] Similarly, the technical notion Bacharach (1993: 266) employs has players choosing an equilibrium strategy combination that is not strictly pay-off dominated by another equilibrium strategy combination. Finally, Janssen (2000) terms it the Principle of Individual Team Member Rationality, which basically says that if there is a unique Pareto-efficient outcome, then rational players will choose their part of it. The main difference between the alternative uses of the Principle of

[1] An overview of this literature is given in Janssen (1998*a*).

[2] The paper restricts attention to *attainable* strategies. As this concept is not important for my purposes, I have have not mentioned it in the definition introduced in the main text.

Coordination is whether or not it applies only when a game has a unique Pareto-efficient outcome. Crawford and Haller (1990) and Bacharach (1993) interpret the Principle as saying that players can coordinate on one of the Pareto-undominated Nash equilibia. Gauthier (1975) and Janssen (2000), on the other hand, use the Principle more narrowly as appying only to games with a unique Pareto-efficient outcome.

The Principle of Coordination is not uncontroversial. It has been criticized by Gilbert (1989), among others. The purpose of this article is not to take away all controversy. The purpose is rather to clarify the discussion by showing that one version of the Principle follows from some axioms about considerations individual players have when choosing their actions. The discussion about the use of the Principle can then proceed by arguing whether or not these axioms are intuitively appealing and whether or not we should abandon the variations of the Principle that cannot be derived from these axioms. Our analysis provides support for the Principle of Coordination only in so far as there is a unique strict Pareto-efficient outcome and the basic idea of the rationalization is that individual players form a plan specifying for each player how to play the game and which conjecture to hold about their opponent's play. The axioms that are postulated are at the level of these individual plans. We show that these axioms are such that if there is a unique strict Pareto-efficient outcome, there is a unique plan how to play the game. As the plan is unique, both players thinking individually will play according to the same plan and the Pareto-efficient outcome results.

One approach to arguing in favour of the Principle is based on the idea that when playing a (coordination) game individuals should regard themselves as members of a team. Team thinking by individual players has recently been explored by many authors, including Sugden (1991) and Hollis (1998), but a more formal analysis of the concept has not yet been given. Sugden (1991: 776) suggests that the notion of team rationality could be developed in the tradition of regarding game theoretic solution concepts as being written down in a "book of recommendations for playing games which is entirely authorative", the recommendation being addressed to *both* players (rather than to the individual player). The approach I take in this paper can be considered in this light, with the important difference that in many actual coordination problems there is no book of recommendations players can consult. Rather, individual players themselves have to think of a set of recommendations to both players. If there is a unique reasonable recommendation to make, the individual reasoning process of players will result in the same recommendation and players coordinate.

The formal approach that I take in this paper is based on an approach advocated by Jacobson (1996) in this journal. Jacobson (1996) investigates an alternative eductive foundation for the notion of Nash equilibrium. He argues that individual players should make a plan how to play a game. An individual plan specifies for each player a set of pure strategies and a set of conjectures about the opponents' play. The formulation of a plan incorporates the game theoretic idea that each player not only thinks about what he himself is going to play, but also imagines himself in the position of his opponent. Jacobson formulates two requirements a plan has to fulfill. First, *a plan has to be rational* in the sense that given the conjectures the plan should specify an optimal response for each player. Second, a plan has to be *internally consistent* in the sense that a player must not expect the opponent to play a strategy that he himself, according to the same plan, will not play were he in the position of the opponent. The main result of the paper is that if a game has a unique Nash equilibrium, then players will play their Nash equilibrium strategies. Hence, the paper provides an alternative eductive justification for the notion of Nash equilibrium.

In the present note I build on Jacobson by adding one requirement on the set of reasonable plans. I require that a plan be *optimal* in the sense that a player should only consider a particular plan if there does not exist another plan that is strictly better for both players. I show that the uniqueness version of the Principle of Coordination follows from the three requirements taken together. Hence, the paper can be considered as providing a justification for it.[3]

The plan of the paper is as follows. Section 2 present the main axioms. Section 3 gives a formal statement of the result and Section 4 concludes with a discussion.

[3] Another justification has recently been given by Colman and Bacharach (1997). They use a *Stackelberg heuristic* which is defined as a way in which the players can *conceive* the game as being played sequentially (whereas it is played simultaneously). A critique that can be levied against their approach is that coordination games are really simultaneous move games and we know, from the standard game theoretic literature, that simultaneous move games are rather different from sequential games. Hence, it may be difficult to explain why players *conceive* of the game in sequential terms.

2. Game Structure and Axioms of Play

The analysis that follows is build around the following two player game. There is a Row player and a Column player. Each of the two players has a finite strategy space, denoted by S_R, respectively S_C, where S_R={1,..,m} and S_C={1,..,n}. The pay-off to player *i, i=R,C* is given by $\pi(r,c)$, where $r \in S_R$ and $c \in S_C$. The structure of the game, including the pay-offs is common knowledge.

In this section I introduce the four axioms on which the analysis is built. The first three axioms are taken from Jacobson (1996); the fourth axiom is new. The first axiom formulates the idea that a player plans what to do in his own position, but he also imagines himself in the position of the opponent. A plan specifies for each player a set of pure strategies that are motivated by the plan and a conjecture what the other player will choose.

> **A1.** A player proceeds by formulating a plan P with the structure $P=(R,q;C,p)$, $R \subseteq S_R$, $C \subseteq S_C$ $q \in \Delta_C$, and $p \in \Delta_R$, where R and C are the sets[4] of pure strategies motivated by P for the Row and Column player, respectively, while q and p are the conjectures (on the opponent in the other position).

Not every plan is a reasonable plan. First, it seems reasonable to require that a plan be such that the sets of strategies that are motivated by the plan must be best responses to the conjectures that are held about the other player's play. To this end, let us define by $\overline{B}_C(p)$ and $\overline{B}_C(q)$ the set of pure strategies that are a best response to *p*, respectively *q.* A2 now formulates the first condition on reasonable plans.

> **A2.** (Rationality). For a plan $P:=(R,q;C,p)$ of a player, it must be for each position that pure strategies motivated as playable by P for that position are best replies to the conjecture held about the opponent in the other position, i.e., $R \subseteq \overline{B}_R(q)$, and $C \subseteq \overline{B}_C\ (p)$.

[4] Note that the set of pure strategies *R* and *C* that are motivated by a plan need not be singletons.

The third axiom that Jacobson (1996: 77) introduces says that for a plan to be reasonable, "the player holding it must not, according to that plan, expect his opponent to play a strategy that the player himself, according to the same plan, would not possibly play were he in the opponent's position".

> **A3.** (Internal Consistency). A plan $P := (R, q; C, p)$ of a player must be such that if, according to P, there is strictly positive probability that the opponent in some position will play some pure strategy, then the player holding *P* must, according to *P*, himself be ready to play that strategy, were he in the opponent's position, that is, supp $q \subseteq C$, and supp $p \subseteq R$.

Accordingly, a plan of a player is such that the players do not consider the possibility that the other player uses a different plan. Note, once again, that this axiom does not impose a cross-player restriction. The axiom is internal to an individual player's plan and does not require players to look into each other's head. Jacobson motivates the axiom by saying that each player attributes his own kind of "rationality" to his opponent.

Jacobson (1996: 81, proposition 2) shows that if a plan *P=(R,q;C,p)* satisfies A2 and A3, then *(p,q)* is a Nash equilibrium of the game. Hence, we can define the (expected) pay-offs a plan *P* gives to the player *i* as the (expected) pay-off $\pi_i(p,q)$ a player receives in the corresponding Nash equilibrium of the game. Plans that satisfy axioms A2 and A3, I will call internally consistent plans.

Following the same logic, it seems reasonable to require that players only consider a plan to be reasonable if there does not exist another plan that gives both players a strictly larger pay-off.[5] This is the content of A4.

> **A4**. (Optimality). A player's plan *P=(R,q;C,p)* must be such that there does not exist another plan *P'=(R',q';C',p')* such that $\pi_i(p',q') > \pi_i(p,q)$ for *i*=1,2.

Note (again) that A4 is completely internal to the planning process of an individual. It, for example, does not involve knowledge of the expectations the player holds. The reason A4 is a reasonable axiom to impose is precisely because a plan is internal to the thought process of an individual player. Recall that an individual plan is built around the idea that an individual player imagines himself in his own and in the position of the opponent. It specifies the pure strategies he would consider playing in both positions and the conjectures about the other's behavior he would hold in both positions. The plan can be considered a recommendation a player may give to both players. A player wants to give the best possible recommendation, i.e., a recommendation that is feasible (satisfies the axioms of rationality and internal consistency) and that gives the highest pay-off to both players. In this way, a player compares two feasible plans P and P'. If P' would give him in both positions a lower pay-off than P, he would prefer P to P'. Attributing the same kind of rationality to his opponent, he is sure that she also prefers P to P'.

3. Results

In this section I briefly point at the main implications of requiring a reasonable plan to fulfill A1-A4. Before I do so, some terminology is introduced. I will call an outcome *strict Pareto-efficient* if the pay-off to each of the players in this outcome is strictly larger than the pay-off to each of them in any other outcome. The *set of efficient Nash equilibria* is defined as the Nash equilibria that are not Pareto-dominated by another Nash equilibrium.

Proposition 1 below states a relation between the set of efficient Nash equilibria and the set of conjectures supported by axioms A1-A4. It justifies the use of strategies that are part of a Nash equilibrium that itself is a member of the set of efficient Nash equilibria. Note that the justification is at the level of individual plans, rather than at the level of Nash equilibria.

Proposition 1.

(i) If (p,q) is a member of the set of efficient Nash equilibria, and if we define $R = \overline{B}_R(q)$, and $C = \overline{B}_C(p)$, then the plan $P=(R,q;C,p)$ satisfies A2-A4.

[5] Here, I take a conservative view on optimality. If one wishes, one could defend a stronger criterion, namely that a plan is reasonable if there does not exist another internally consistent plan such that both players receive a pay-off that is at least as large and at least one player gets a strictly larger pay-off.

(ii) If the plan *P=(R,q;C,p)* satisfies A2-A4, then (*p,q*) is a member of the set of efficient Nash equilibria.

The proof is omitted . Most of the proof follows immediately from Propositions 1 and 2 in Jacobson (1996: 81). The only thing that is new here relates to the efficiency aspects, but they easily follow from the definitions that are given.

Note that Proposition 1 does not guarantee that an equilibrium results. The proposition only provides a justification for the use of strategies that are part of one of the efficient Nash equilibria. If the set contains more than one member, then it may very well be that one player's plan corresponds to one equilibrium of this class and the other player's plan corresponds to another equilibrium. Hence, an equilibrium may not result. This point is further discussed in Section 4 below.

The main result is then stated in the proposition below. It provides a possible justification for the uniqueness version of the Principle of Coordination.

Proposition 2.[6]

(i) If there exists a unique strict Pareto-efficient outcome, then there exists a unique plan satisfying A2-A4 and players will coordinate on the Pareto-efficient outcome.

(ii) If there exists a unique plan satisfying A2-A4, then players coordinate on the Pareto-dominant Nash equilibrium.

Proof. (*i*) If there exists a unique strict Pareto-efficient outcome, then there are *p* and *q* such that for all *p'* and *q'*, $\pi_i(p,q) > \pi_i(p',q')$ for *i*=1,2. Hence, (p,q) must be a Nash equilibrium and, more, it is the unique element of the set of efficient Nash equilibria. From proposition 1(*i*) it then follows that there exists a (unique) plan that satisfies A2-A4.

(*ii*) Suppose there exists a unique plan satisfying A2-A4. This implies that there exists one plan *P=(R,q;C,p)* such that for all and *p'* and *q'* that are part of a plan *P'=(R',q';C',p')* that satisfies A2 and A3, $\pi_i(p,q) > \pi_i(p',q')$ for *i*=1,2. Hence, both players choose the same plan and from proposition 1(ii) we know that a Nash equilibrium results. Moreover, it must be a Pareto-dominant Nash equilibrium. //

[6] If a stronger version of the optimality axiom A4 is used, then we can asserts a stronger version of this Proposition. In particular, we may then srop the "strictness" requirement in part (*i*).

Note that proposition 2 does not tell us that Axioms A1-A4 guarantee that a Pareto-efficient outcome results. When there are multiple Pareto-efficient outcomes, none of them may be supported as a Nash equilibrium. Hence, the second part of proposition 2 does not guarantee that a Pareto-efficient outcome results if players' plans satisfy A1-A4. (See the discussion below on the Prisoner's Dilemma).

4. Discussion

I realize that the Principle of Coordination is a controversial Principle. In this section I discuss some of the possible critiques along three topics: (*i*) coordination is assumed rather than explained, (*ii*) what is the relation with risk dominance? (*iii*) Does the Principle imply cooperative behavior in the one shot Prisoner's Dilemma? The purpose of the discussion is to make the argument that is made more transparent by arguing what is entailed, and especially, what is not implied. Before discussing the possible objections, I want to argue that the optimality requirement that I introduce below fits the framework of Jacobson (1996) quite nicely.

Jacobson (p. 68) formulates the problem of providing a foundation for the notion of Nash equilibrium in the following terms:

> In a non-cooperative game each player must make up his mind on what to play and expect others to play on a purely individual basis. On the other hand, a Nash equilibrium is by definition something collective, a collection of strategies with a specific cross player property. The problem of justifying the Nash equilibrium concept is the same as explaining how purely individual considerations may lead each player to do his part of such a collective plan.

He continues to argue that it is in the spirit of traditional game theoretic reasoning that players consider themselves in their own position and in the position of their opponents. Each individual player formulates a plan consisting of conjectures and actual strategies for all players. The two requirements formulated loosely above are considered to be assumptions that a reasonable plan has to fulfill.

It is important to realize that even the weakest solution concepts that are employed in non-cooperative game theory, like iterative elimination of dominated strategies (IEDS) or rationalizability, have individual players impose restrictions on the likely behavior of others (cf., Bernheim, 1984, and Pearce, 1984). The common knowledge of rationality assumption on which IEDS is based assumes that all players conjecture (or even: know) other players to be as rational as they are. It is not entirely clear how to categorize this assumption. It is clear that the assumption imposes restrictions beyond the notion of rational individual behavior. However, it is possible to interpret the assumption as being completely internal, in the sense that the assumption only imposes restrictions on the thought processes of individual players (cf. Janssen, 1998*b*). Hence, one may defend the thesis that the considerations that lead to the notion of IEDS are purely individualistic.

The two axioms Jacobson (1996) introduces (see A2 and A3 above) impose restrictions on the behavior expected by the other player that go beyond the restrictions the notion of rationalizability imposes. One way to see this is to present an example from Jacobson (1996: 84). In the game presented below in normal form there is a unique Nash equilibrium and it is in mixed strategies, namely the Row player chooses u with probability 1/3 and c with probability 2/3 and the Column player chooses m with probability 1/3 and r with probability 2/3. Hence, the strategies that are justifiable according to the justification provided by Jacobson are {u,c} and {m,r}. The set of rationalizable strategies is larger, however, and contains all three pure strategies for both players.

	l	*m*	*r*
U	*0,4*	*0,2*	*1,0*
C	*1,0*	*2,3*	*0,4*
R	*5,0*	*0,1*	*0,0*

Figure 1. Not all rationalizable strategies are reasonable strategies

The restriction on the strategies that are justifiable comes from requiring that a plan be internally consistent. A player views his opponent to be like himself in the sense that a player must not expect the opponent to play a strategy that he himself, according to the same plan, will not play were he in the position of the opponent. In other words, a plan of a player does not allow the other player to consider a different plan. Again, one may wonder how to categorize this assumption. It was argued above that the assumption imposes restrictions beyond the notion of rational individual behavior and even beyond the notion of rationalizability. However, it is (again) possible to interpret the assumption as being purely individualistic, in the sense that the assumption only imposes restrictions on the individual thought processes when players are deliberating about which plan to adopt.[7]

The requirement I impose in addition, namely that plans should be optimal, can be justified along the same lines. Each player formulates an individual plan. To be reasonable the plan has to fulfill three requirements (rationality, internal consistency and optimality). The optimality condition can be justified along the following grounds. A plan can be considered a recommendation to both players how to play the game. If I, as a player of the game, have to come up with a recommendation (plan) for both players (the team), then I should give the best recommendation, i.e., one that guarantees the best possible outcome for the team. This consideration, and the others, justifying the three requirements together only impose restrictions on the individual thought processes; not one of the players has to know something that goes on in someone else's head. Hence, the requirements can be justified as being of a purely individualistic nature.

Below I will discuss the three possible objections to the Principle of Coordination.

Coordination

One possible objection to the Principle of Coordination is that it assumes a form of coordination instead of explaining it in terms of individual considerations. The above analysis is, at least partly, able to counter this criticism. To do this consider the game of pure coordination given below.

	L	*R*
L	*1,1*	*0,0*
R	*0,0*	*1,1*

Figure 2: a game of pure coordination

[7] Jacobson (1996: 78) compares his apporach to the one of Aumann and Brandenburger (1991) and he rightly observes that their approach cannot be justified in this way as players are required to know what is going on in the heads of other players.

Axioms A1-A4 do not guarantee in any way that players coordinate in the game of Figure 2. One player's plan may involve both players choosing *L* and conjecturing that the other will play *L*, whereas the second player's plan may specify that both players choose *R* and conjecture that the other will play *R*. As this form of miscoordination is not excluded by A1-A4, I conclude that the Principle of Coordination that follows from A1-A4 does not assume coordination.[8]

More generally, if there are multiple equilibria that cannot be Pareto-ranked then A1-A4 do not guarantee that players coordinate their actions on a Nash equilibrium. This is important as some authors have assumed that players can coordinate on one of the Pareto-efficient equilibria in case of multiplicity. Bacharach (1993: 266), for example, assumes that players choose Pareto-undominated Nash equilibrium strategy combinations. A similar problem arises in the analysis of Crawford and Haller (1990: 575) who assume that players can maintain coordination in an infinitely repeated version of Figure 2 if they have coordinated once. As there are potentially many different ways in which players can maintain coordination and as each of these ways is equivalent in terms of pay-offs, our anaysis does not provide foundations for this assumption (cf. Goyal and Janssen, 1996).

Risk Dominance

A second possible objection to the Principle of Coordination may be that it does not hold when there is a conflict between Pareto-efficiency and risk dominance. An example is given in Figure 3. In that Figure there are two Nash equilibria in pure strategies: (*T,L*) is Pareto-efficient and (*B,R*) is risk dominant.[9]

	L	*R*
L	*10,10*	*4,7*
R	*7,4*	*8,8*

Figure 3: A conflict between Pareto-efficiency and risk dominance

[8] A similar conclusion follows when considering a game like the Battle of the Sexes.

[9] An equilibrium is risk dominant if both players' best response remains unchanged as long as the opponent chooses the equilibrium strategy with a probability at least equal 0.5.

Recent literature in game theory has resulted in conditions under which players are expected to play the risk dominant rather than the Pareto-efficient equilibrium. Carlsson and Van Damme (1993) consider a framework in which players observe pay-offs with some noise and show that (under some conditions) the risk dominant equilibrium survives IEDS. Kandori, Mailath and Rob (1993) and Young (1993), among others, study a population of agents interacting in an evolutionary environment and they show that the risk dominant equilibrium is selected in the long run.

The circumstances I consider in this paper do not fit either one of these environments. This paper provides an *eductive* justification for the Principle of Coordination in case the game structure, including the pay-off, is common knowledge. The literature mentioned above considers other environments and I don't want to argue that the Principle of Coordination should apply in each and every possible situation. Instead when there is enough information and knowledge about each other, players can consider themselves as a team and think individually what is best for the team and its members. This paper argues that in these conditions the Principle of Coordination may hold.

Prisoner's Dilemma

A third issue concerning the Principle of Coordination is whether it enforces players to choose to cooperate in a one-shot Prisoner's Dilemma. The direct response here is that it does not. In a PD game, there is only one internally consistent plan and that is to defect in both positions and to conjecture that the other will defect. Hence, A4 does not impose any further restrictions and cooperative behavior does not follow.

5. Conclusion

This paper has tried to clarify the Principle of Coordination by providing four axioms from which the Principle follows. By doing so, I have been able to tell what the Principle entails and what it does not, making the controversy around the Principle more transparent. For example, the Principle does not tell players in a Prisoner's Dilemma game to cooperate. Also, it does not solve the Battle of the Sexes, nor coordination games where the Nash equilibria have identical pay-offs. In this way the paper discriminates between different versions of the Principle of Coordination. The axioms mentioned here only support a "uniqueness" version of the Pinciple, which says that if there existss a unique Pareto-efficient outcome in a game, then players will choose their part of that outcome.

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