Collaborative innovation: weak commitments and unenforceable contracts

John D. Hanson*

Supply Chain Management Institute,
University of San Diego,
5998 Alcala Park, San Diego, CA 92110-2492, USA
Email: hansonj@sandiego.edu
*Corresponding author

Joachim Henkel

TUM School of Management,
Technical University of Munich,
Arcisstr. 21, 80333 Munich, Germany
Email: henkel@wi.tum.de

Abstract: Innovation that crosses organisational boundaries, such as those between buyers and sellers, requires complementary investments of assets by participants. This creates a contracting problem with the possibility of opportunistic behaviour. We show that this problem can be overcome using the mechanism of weak commitments. In situations where both parties can see a return on their investment in innovation that increases with their partner's investments, there is a bounded range of commitment that can be made unilaterally by either party within which cooperative behaviour becomes the dominant strategy for both parties. This finding is important because it shows that collaborative innovation is possible without the need for elaborate contracts or reliance on intangible constructs such as relational trust or reputational cost. This suggests that collaboration is possible in situations where it was previously considered unlikely and suggests new approaches to research on inter-firm collaborations.

Keywords: collaborative innovation; opportunism; weak commitments; game theory; prisoner's dilemma.

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Biographical notes: John D. Hanson is an Associate Professor of Supply Chain Management and Department Chair for Operations, Supply Chain Management, and Information Technology at the University of San Diego School of Business. His research interests are in new product design for supply chain effectiveness. He has a degree in Aerospace Engineering from the University of Toronto and PhD in Operations Management from the Michigan State University. He previously held executive positions in new product development with AlliedSignal, Siemens, and Eaton Corp (ORCID IDs: 0000-0003-3507-6788).

Joachim Henkel is a Professor of Technology and Innovation Management at TUM School of Management, Technical University of Munich. His research focuses on technology acquisitions, digitisation, open and user innovation, and patent management, and has been published among others in *Harvard Business Review*, *Rand Journal of Economics*, *Research Policy*, and *Strategic Management Journal*. He serves on the editorial review boards of the *Academy of Management Journal and Research Policy*, among others. He received his degree in Physics from the University of Bonn and PhD in Economics from the University of Mannheim (ORCID ID: 0000-0002-6065-0983).

1 Introduction

The field of supply management has long argued that its contributions to firm performance go well beyond the efficient procurement of commodity goods and services and comes from the ability to effectively access complementary supplier capabilities on an as-needed basis. Doing this in a way that creates sustainable competitive advantage (i.e., not easily imitated by competitors), suggests the need for *collaborative* or *non-modular* innovation. Non-modularity implies complementarity and mutual adjustment (i.e., collaboration); meaning that the trading partners must make 'idiosyncratic' investments (Bensaou and Anderson, 1999), either physical or knowledge-based, that are only of value in the presence of a partner's complementary assets.

Collaborative innovation represents a conundrum for researchers. The resource-based view (RBV) of the firm explains how collaborative innovation can create value but not necessarily how it might be managed (Magnan et al., 2017). In the more classical theory of the firm based on transaction cost economics (TCE) one would not expect it to take place. The collaborations with the greatest potential value lack task programmability, have uncertain outcomes, and thus do not lend themselves well to either contracting or to regulation by market forces. From the TCE perspective, transaction costs are very high and the mutual adjustments needed for innovation are better managed within the hierarchy of a single firm.

These transaction costs come from the baseline assumptions of TCE: bounded rationality and opportunism. In plain language, this means that it is not possible to write a contract that covers all possible future states and that when presented with an unanticipated development, the partners will choose to act to their own advantage without regard for their partner's situation. This is the problem of incomplete contracts, on which there is a vast literature but very little in the way of clear 'solutions' that could be employed in a commercial setting.

It has also been shown (Parkhe, 1993) that collaborative innovation can be modelled as a version of the prisoner's dilemma game. The key implication of this is that opportunistic behaviour is the dominant strategy for both players. This further suggests that collaborative innovation is unlikely to take place between partners that are connected only by market forces.

The conundrum is that, in spite of the apparent infeasibility of collaborative innovation, it does exist. In fact, it is fairly common, and the firms involved apparently realise value from these relationships. If we accept that the bounded rationality condition is more or less given, the research question becomes one of how partnering firms can manage opportunism. This is a problem that continues to attract research interest (e.g., Mols, 2017) in attempts to understand what mechanisms or conditions serve to reduce or eliminate opportunism to the extent that parties are willing to go forward with collaborative innovation.

This question has been approached from several directions, with overlapping but distinct frames of reference. Three perspectives that we examine here are social exchange theory (SET), interorganisational trust, and game theory (prisoner's dilemma). We find that the 'solutions' suggested by all of these approaches requires the presence of latent constructs (such as trust) that are doubtless real, but very difficult to characterise for research purposes, or to manage for desired outcomes. In contrast, we find that a re-formulation of the prisoner's dilemma model produces a solution that does not require the presence of any of these constructs to achieve collaboration as an equilibrium solution.

2 Background: trust and SET

There is evidence that firms seek out, engage in, and benefit from collaborative innovation. A well-publicised example of this is Procter & Gamble's 'connect and develop' program (Huston and Sakkab, 2006) that seeks to involve a web of partners in the pursuit of innovation. Although contracts are involved in these collaborations, Panduwawala et al. (2009) noted their limitations in the areas of incentives and ownership of intellectual property, requiring ad hoc solutions on a case-by-case basis. Such contracts have been studied in detail by Gilson et al. (2009), who argue that the firms involved saw them as valuable on the basis that the texts of contracts were included as part of filings with the securities and exchange commission; meaning that the filing companies felt the contracts to be material to their future performance and requiring disclosure.

While contracts exist, if we accept the existence of bounded rationality, then something beyond pure contractual terms must exist for opportunistic behaviour to be suppressed and for effective collaboration to take place. This 'something' has been the subject of much study.

The construct of trust is often invoked to explain why firms may be willing to expose themselves to the possibility of opportunistic behaviour by partners. While trust is widely discussed in the literature, Yam and Chan (2015, p.1070) note that the: "interactive effects (of contract, commitment and trust) on opportunism in inter-firm joint NPD are not addressed adequately in literature." There is broad agreement that *distrust* is a barrier to collaboration (Yunus and Kurniawan, 2015; Dalvi and Kant, 2017), but beyond that there is no clear consensus. To begin with, there are multiple definitions of trust, with Poppo et al. (2016), among others, separating the construct into two parts, and Akrout and Diallo (2017) using three types. It is also unclear which unit of analysis to use in defining and measuring trust – is it an individual, a functional or departmental level, or can it be applied to a firm as a whole? In spite of these difficulties there has been considerable research on the relationship between trust and contractual terms, particularly addressing the question of whether the two are substitutes for each other or complements. There is evidence supporting both positions, for example Fawcett et al. (2012), Bunduchi (2013), Bond-Barnard et al. (2018) and Ruel et al. (2018) suggest that trust is a causal or mediating factor, while Martins et al. (2017), Min et al. (2018), and Pemartín et al. (2018)

find it to be a moderating factor, leaving it somewhat unclear exactly how trust functions. van der Valk et al. (2016) approached this question by asking whether contracts and/or trust are necessary conditions for collaborative innovation. They found both to be necessary conditions, but this finding requires an assumption that trust is causal for cooperation. From the literature we know that trust is something that grows over time (Angle and Perry, 1981; Ring and Van de Ven, 1994) and is enhanced by repeated contact and expectations about the future (Carson et al., 2006; Anderson et al., 2017; Chen et al., 2017; Yen and Hung, 2017), suggesting that trust may be an outcome of collaboration rather than a causal factor, negating the conclusion that it is a necessary condition. Regardless of how trust actually functions, the literature is in general agreement that its presence is dependent on some shared history (the longer the better), which is a restrictive condition that may not be present in the more interesting business cases. How does a company collaborate with another in the absence of shared history, or the expectation of an indefinite future?

This is one of the questions that have led researchers to examine the problem of collaborative innovation from the perspective of SET [generally attributed to Homans (1961)]. In this view, firms derive value from being embedded in 'social' relationships; value that would be damaged (reputational cost) by behaving in ways that deviate from accepted norms. This eliminates the need for a defined future or a history with a specific partner by extending the value judgment to a wider and more stable network that provides the history and the future needed to enforce cooperative behaviour. Schoenherr et al. (2015) use SET as a basis for trust formation, and the same concept underlies the argument of Gilson et al. (2009) in their analysis of collaborative innovation contracts. One of the things that struck them about these contracts was that they contained provisions that were not legally enforceable, begging the question of why such terms would be included. Their explanation is that by formalising these terms in a contract, the parties increased their exposure to reputational cost should they proceed to act opportunistically. While this is a plausible hypothesis, we show that other explanations are possible. Reputational cost, as a component of SET, suffers from many of the same problems as does the construct of trust (definition, unit of analysis, etc.) but has another issue as well. Since the valuation of reputational cost resides within a broader community, we would expect it to be relatively stable. However, there is at least anecdotal evidence that this is not necessarily true. One of the most dramatic examples in modern times was the ascension of Ignacio ('Inaki') Lopez to the head of purchasing for General Motors in 1992. Practically overnight, any restraint attributable to concern for reputational cost vanished. Other examples could be cited, but the key point is that the role of reputational cost is unstable and situation-specific, making it a slippery foundation for either theory or corporate investments.

3 Background: game theory – the prisoner's dilemma

The possibilities for opportunism suggest that collaborative innovation can be modelled as a sequential move prisoner's dilemma game. That is to say, each party obtains a net payoff from its investment in innovation that increases with its partner's investments, but decreases with its own investments. Furthermore, each partner often has repeated opportunities to observe its counterpart's behaviour before taking its next decision, a structure that can be modelled as a sequential move game. In the specific case of inter-firm strategic alliances, there is empirical evidence that the payoff structure for the participating firms is indeed that of a prisoner's dilemma (Parkhe et al., 1993) and, more precisely, of a retaliation type prisoner's dilemma (defined below), and this would seem to be equally applicable to buyer-supplier relationships involving investments in complementary assets.

Potential behaviours are characterised as either cooperative or aggressive (opportunistic) and the analysis follows the conventional prisoner's dilemma format where opportunistic behaviour is a Nash equilibrium, suggesting that cooperation is not inherently feasible. 'Solutions' to the iterated prisoner's dilemma are possible if the game is expected to continue indefinitely, e.g., the 'tit-for-tat' strategy (Telser, 1980; Axelrod, 1984). As long as everyone keeps behaving cooperatively, everyone comes out ahead. If the game is finite however, the rational strategy will be to behave opportunistically in the final round, and by extension, in every prior round.

While the tit-for-tat strategy is rational when the timing of the final round is not known with certainty, it is subject to 'noise' in that imperfect information may cause a move to be misinterpreted. In this sense the game can be thought of as a Markov process where aggressive behaviour is an absorbing state, so that the game would ultimately always devolve to aggressive behaviour. The process can be made robust against noise to some degree by introducing the concepts of *generosity* (forgiveness) and *contrition* (Wu and Axelrod, 1995). These constructs and their functioning are strikingly similar to the roles ascribed to trust or reputational cost in the discussion above. In effect, they are all ways to explain how collaboration can occur when purely 'rational' analysis suggests that it should not. Even when we include such constructs in our models, we still do not have a satisfactory explanation for how collaborative innovation can occur in situations that have neither an extensive history nor an indefinite future.

4 The role of commitments

4.1 Weak commitments

Commitment plays a central role in game theory and although the word is often used in a way that is closely related to trust (Heikkila et al., 2016), in game situations it plays a more mechanistic role. Commitment in this context means a conscious restriction on future actions. The most common example is making irreversible, specialised investments (Williamson, 1985; Ghemawat, 1991), but in a more theoretical sense a firm can, in effect, place a bet with a third party that it will stick to a certain line of activity or pay a penalty (Becker, 1960; Schelling, 1960). Commitments may be strong or weak, depending on how they are implemented. There are numerous business situations in which a strong commitment is beneficial for the committing party. One of many examples is that of the establishing of technical standards for new products [Shapiro and Varian, (1998), p.267]. In this example, two firms propose two distinct technical solutions, and both parties prefer an agreement on one common standard to no agreement. They disagree, however, on which specification should become the standard. The one party that can commit early and strongly to its own proposed solution (by investing in development and infrastructure) has the advantage.

The case of strong commitment has a straightforward game-theoretic explanation. A firm builds commitment to a certain future action by manipulating its payoffs in such a way that all alternative actions yield lower payoffs. Hence, it is later on rational for it to choose the action it committed to. If in addition the commitment is clearly and credibly communicated, then the desired effect on the other firm's behaviour is attained.

The examples above are zero-sum games. In contrast, the case of weak commitment is relevant when partners attempt to achieve cooperation in situations where there is some strategic complementarity. Mutual commitment to this relationship has been the focus of ample research (Dwyer et al., 1987; Morgan and Hunt, 1994). The questions that have been studied most extensively are how commitment is built and sustained (Anderson and Weitz, 1992; Gundlach et al., 1995; Holm et al., 1999) and what its determinants are (Doucette, 1997; de Ruyter et al., 2001; Goodman and Dion, 2001; Kim, 2001). In this type of cooperation, a strong and unilateral commitment of one party to the relationship is generally considered to be detrimental, since it invites the less committed party to engage in opportunistic behaviour (Gundlach et al., 1995; Ross et al., 1997; Achrol and Gundlach, 1999; Poppo et al., 2016).

A mutually beneficial outcome, on the other hand, can be reached by gradually increasing, balanced commitment from both parties (Anderson and Weitz, 1992; Holm et al., 1999). Similarly, it is argued that reciprocal commitments support stable long-term relationships (Williamson, 1985). In this context, "commitment refers to an implicit or explicit pledge of relational continuity between exchange partners" [Dwyer et al., (1987), p.19]. Compared to the case of committing to a single action, additional components come into play – the parties' attitudes towards the relationship and the long-term aspect of this kind of commitment (Meyer and Allen, 1991; Gundlach et al., 1995). Nonetheless, 'commitment' still carries the meaning of 'making alternatives relatively less attractive'. What we wish to show here is that weak commitment can lead to cooperative behaviour when parties are otherwise stuck in a prisoner's dilemma.

A game-theoretic model of the way weak commitment works may not be immediately obvious. A related mechanism that one might consider is the use of *small* commitments by breaking down a large commitment, which would invite opportunism, into several smaller steps [Dixit and Nalebuff, (1991), p.157]. As an example, consider the classic case of a hostage exchange. Instead of having first one party and then the other release all of its hostages at once – inviting opportunism from the second party – the hostages could be exchanged one by one (Williamson, 1983). This way, a breach of the agreement will only yield a small advantage. In addition to reducing the gain attainable by opportunism, this example builds upon repeated interaction, which is well known to foster trust and cooperation (Telser, 1980; Axelrod, 1984; Gundlach et al., 1995; Ingram, 1996). Two problems remain, one of which is end-gaming: in the last round of a series of interactions, one party or both will still be tempted to act aggressively. The other problem is simply that achieving large results by means of many small steps takes an extended period of time. As with other 'solutions', the beneficial impact of finely divided commitments depends on a cumulative history and the expectation of future rounds of the game.

This paper proposes an alternate mechanism by which *weak* commitment leads to improved cooperation without the necessity of multiple steps or the expectation of a future round. It differs in two respects from the approach of breaking down a large commitment into several smaller ones. First, it allows for a large initial commitment, while the strategy of breaking down a large commitment works better the more finely it is divided. Second, it does not reduce the exposure to opportunism, but removes it completely. Mutual cooperation emerges as equilibrium in the game-theoretic sense. For a specific sequence of moves, this mechanism has been described in a formal model by Henkel (1997, 2002).

The central idea here is that one party (or potentially both, but this can be unilateral) makes a commitment to behave collaboratively that is not completely binding. That is, the commitment may be quite large, but is weak in the sense that the firm can subsequently deviate from cooperation, but at a defined cost. This cost measures the strength of the commitment and must fulfil two crucial conditions. First, it must be high enough to make opportunistic behaviour unattractive so long as its partner continues to act collaboratively. On the other hand, it must be low enough that when the partner behaves opportunistically, it must be worthwhile to abandon collaboration as well.

These two conditions imply a restriction on the payoffs in the prisoner's dilemma – there have to be *increasing differences* [Fudenberg and Tirole, (1991), p.490]. That is, the gain from switching to opportunism from collaboration increases when the opponent switches to opportunism from collaboration. Depending on when a player gains more from switching to opportunism – either when retaliating (i.e., the partner behaves opportunistically) or when striking first (i.e., the partner behaves collaboratively) – one can distinguish between a *retaliation* type prisoner's dilemma and a first strike type prisoner's dilemma. In this terminology, it is a precondition for the mechanism of weak commitment to work that the prisoner's dilemma is of the retaliation type. The weak commitment then yields a credible offer of cooperation combined with an equally credible threat of retaliation. This combination makes mutual cooperation an equilibrium outcome. In the context of commercial collaboration, "cooperation [...] is established by the ability of parties to an agreement to reciprocate penalties in the case of competitive behaviour and to reward altruistic behaviour" [Kogut, (1989), p.184].

Partial commitment as defined above is nothing unusual – in fact, it seems to be the rule rather than the exception that a commitment is, at some cost, revocable, leading to the use of an 'irreversibility index' to measure the level of commitment associated with a certain competitive move (Chen and MacMillan, 1992). However, to our knowledge, this has not been pursued in a game theory context.

4.2 Instances of weak commitment

An example of strong commitment was given above, describing win/lose situations: the standard proposed by firm A is good for firm A and comparably disadvantageous for firm B, and vice versa – and they would not both gain by collaborating. Weak commitment, on the other hand, is helpful in win-win situations where there are incentives to shirk; that is, in situations where both actors jointly can improve upon a certain outcome by cooperating but each individually has an incentive to not cooperate. Situations of this kind are ubiquitous. An important approach to formalising them is the prisoner's dilemma, which serves as a basis for the model analysis in next section.

Commitment is a central issue in strategic alliances, the majority of which embed a buyer-supplier relationship. These have emerged as an important form of inter-organisational cooperation (Dyer and Singh, 1998), providing more flexibility than vertical integration, while achieving better results than a pure market solution (which would require *modular* innovation). Strategic alliances require commitment from both parties, which can come from a variety of sources. For example, the commitment between a buyer and a seller or a manufacturer and a distributor may be based on mutual exclusivity or selectivity (Fein and Anderson, 1997). Or, partners in collaborative innovation may invest in tools, machinery, and R&D that are specific to each other's capabilities; a condition described as *asset specificity* (Ebers and Semrau, 2015; Poppo et al., 2016; Chen et al., 2017; Yen and Hung, 2017). For example, a buyer may design its products in a way compatible to the partner's technology or put an emphasis on the partner's input in its marketing (Bensaou and Anderson, 1999; Joshi and Stump, 1999). In this way, manufacturer and supplier 'exchange hostages' to safeguard against opportunism from the other party (Williamson, 1983), which could take on a variety of forms (Wathne and Heide, 2000). The mutual commitment is beneficial for both parties but if one party made its commitment essentially irrevocable, then the other party would be tempted to behave opportunistically and exploit the commitment (Gundlach et al., 1995; Ross et al., 1997; Achrol and Gundlach, 1999). Anticipating this, the first party would not commit and there would be no cooperation, even though it could have benefited both. This prisoner's dilemma is avoided by decreasing the commitment to a safe level and changing it later as needed in response to changes in commitment by the partner. For example, only part of a manufacturer's product range may be initially designed around a supplier's technology, and adoption for the full product range is only considered after the supplier has made some commitment steps, such as building a facility uniquely adapted to supplying that technology. These are weak commitments in that they are revocable: the products can be redesigned around another supplier's technology; the facility can be closed or converted to other uses – but at some cost. Again, a weak commitment is not necessarily a small one.

Even from the limited examples discussed here, it can be seen that the use of weak commitments is actually a very common phenomenon. However, to our knowledge, these have not been much recognised or analysed. In the following, a model is presented which demonstrates rigorously the mechanism behind cooperation via weak commitments and shows that they can be used to create a situation in which mutual cooperation is an equilibrium outcome.

5 The model

5.1 Sequential moves

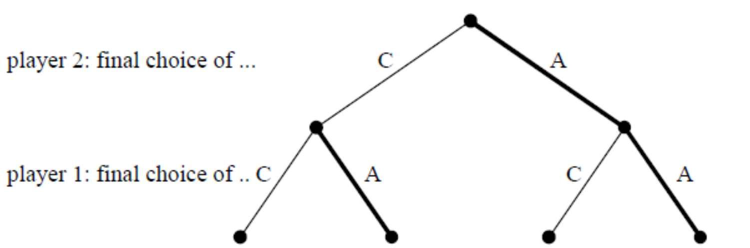
In this section, a model is developed which provides a game-theoretic explanation for the beneficial effect of weak commitment. The analysis starts from a prisoner's dilemma. Figure 1 depicts the decision tree when the actors move sequentially. In order to simplify comparison to the three-stage game below, player 2 moves first. The numerical values given for the payoffs are purely for illustrative purposes.

Since aggression (A) is the dominant strategy for both players, the outcome does not depend on the order of moves, and the final choice of A is the equilibrium action in all sub-games (shown by bold lines). The prisoner's dilemma is characterised by the fact that, whatever the other player does, aggression pays better than ($\Pi^{i}_{AC} > \Pi^{i}_{CC}$ and $\Pi^{i}_{AA} > \Pi^{i}_{CA}$ for player i, where the first subscript denotes player i's action, the second one that of player j, $i \neq j$), but each player's payoff is lower when both choose aggression than when both cooperate ($\Pi^{i}_{AA} < \Pi^{i}_{CC}$). Taken together, these inequalities read as:

$$\Pi^i_{AC} > \Pi^i_{CC} > \Pi^i_{AA} > \Pi^i_{CA} \quad (1)$$

The numerical example in the lower box in Figure 1 illustrates this payoff structure. Now, an announcement stage is added to this game: before player 2 makes a final choice of action, player 1 makes a weak commitment to either aggression or cooperation (see Figure 2). The commitment to the announced action is to the degree c^1. That is, if player 1 deviates in the final stage from the announced action, then the amount c^1 is subtracted from the payoff. This is the case in the second final node from the left: player 2 has returned player 1's weak commitment to cooperation with a binding choice of cooperation, only to be exploited in the last round where player 1 chooses aggression. However, in the numerical example (where $c^1 = 2$) deviating to aggression in the final stage is not rational for player 1, since it would yield a payoff of 5 – 2 = 3 instead of 4. As in Figure 1, the sub-game-equilibrium actions at all nodes are shown by bold lines. With payoffs being as given in the numerical example, it turns out that a weak commitment to cooperation followed by final choices of cooperation by both players is the unique equilibrium outcome, shown by the bold branch on the very left of the tree. The important thing is that, after a weak commitment to cooperation, player 1's best reply in the final stage has changed. As long as player 2 chooses cooperation, then it pays best for player 1 to stick to the announced cooperative behaviour, since 5 – 2 = 3 < 4. On the other hand, when player 2 chooses aggression, then switching to aggression does pay for player 1, since 3 – 2 = 1 > 0. In the right half of the decision tree, where player 1 partly commits to aggression, the equilibrium actions remain unchanged compared to Figure 1. This is obvious, since an additional commitment to the dominant strategy aggression only bolsters this dominance.

Figure 1 Prisoner's dilemma with sequential moves



payoff player 1: payoff player 2:	Π^1_{CC} Π^2_{CC}	Π^1_{AC} Π^2_{CA}	Π^1_{CA} Π^2_{AC}	Π^1_{AA} Π^2_{AA}

payoff player 1: payoff player 2:	4 6	5 1	0 8	3 5

Note: Bold lines: equilibrium paths of the sub-games. Lower box: numerical example.

Turning from the numerical example to the general case, the analysis leads to two conditions. Assume player 1 has made a weak commitment to cooperation in stage 1. First, when player 2 has chosen cooperation, then the cost c1 of deviating (i.e., the degree of commitment) has to be larger than the gain attainable for player 1 by switching from cooperation to aggression: $c^1 > \Pi^1_{AC} - \Pi^1_{CC}$. Second, when player 2 has chosen aggression, then the cost of deviating must be small enough such that switching from C to A does pay for player 1: $c^1 < \Pi^1_{AA} - \Pi^1_{CA}$. The first condition ensures that the promise of cooperation inherent in the weak commitment to cooperation is credible; the second condition keeps player 2 from exploiting player 1's initial commitment, by making retaliation for an aggressive move a credible threat.

Both of these conditions are summarised in inequalities (2).

$$\left(\Pi^1_{AA} - \Pi^1_{CA}\right) > c^1 > \left(\Pi^1_{AC} - \Pi^1_{CC}\right) \tag{2}$$

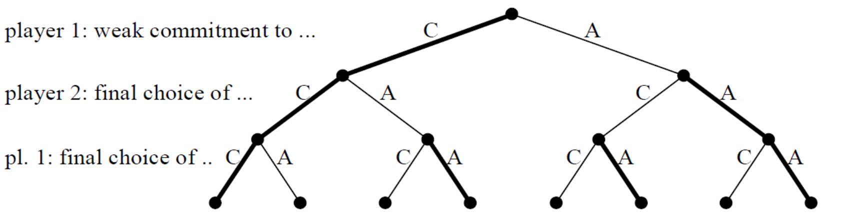
From (2) one immediately obtains inequality (3). It formulates the condition of *increasing differences* [Fudenberg and Tirole, (1991), p.490]: the gain from switching to aggression from cooperation increases when the opponent switches from aggression from cooperation. Phrased differently, aggression pays less when the opponent behaves cooperatively – the prisoner's dilemma is of the retaliation type, as opposed to the first strike type. If this condition is fulfilled, then a degree of commitment c^1 can be found such that the weak commitment leads to mutual cooperation.

$$\left(\Pi^1_{AA} - \Pi^1_{CA}\right) - \left(\Pi^1_{AC} - \Pi^1_{CC}\right) > 0 \tag{3}$$

5.2 Unilateral commitments

An important consequence of this model is that the level of commitment does not have to be negotiated; it can be undertaken unilaterally, provided that it is visible or communicated. To illustrate this: when in stage 1 of the three-stage game (see Figure 2) Player 1 unilaterally chooses the cost c^1 of deviating, simultaneously with the announced action, then the best strategy is to choose c1 such that it fulfils the inequalities (2). To see why, consider first the case where player 1 makes too weak a commitment: $c^1 < \Pi^1_{AC} - \Pi^1_{CC}$. The left-hand part of Figure 3 shows the effect this has on the decision tree, where $c^1 = 0.5$ in the numerical example. Since player 1's announcement of cooperation is not sufficiently binding, player 2 correctly anticipates that player 1 will choose aggression in the final stage. Consequently, player 2 will also choose aggression. The outcome for player 1 would be: $\Pi^1_{AA} - c^1$ (2.5 in the numerical example). Player 1 could have received more by announcing aggression (Π^1_{AA}, 3 in the example) and still more by partly committing to cooperation with a suitable degree of commitment (Π^1_{CC}, 4). The right-hand part of Figure 3 shows the case where player 1's commitment is too strong: $c^1 > \Pi^1_{AA} - \Pi^1_{CA}$ ($c^1 = 4$ in the example). Now, player 1 has lost flexibility in the final stage – should player 2 respond with an aggressive move, retaliation has become prohibitively expensive, such that player 1, after announcing cooperation, will ultimately choose cooperation no matter what the opponent does. Not threatened by retaliation, player 2 chooses aggression. This leaves player 1 with a payoff of Π^1_{CA} (0 in the example). Again, this is less than what player 1 would receive by announcing aggression (Π^1_{AA}, 3) or by partly committing to cooperation with c^1 fulfilling inequalities (2) (Π^1_{CC}, 4). This proves that, with endogenous degree of commitment, the best player 1 can do is to choose c^1 such that $\Pi^1_{AA} - \Pi^1_{CA} > c^1 > \Pi^1_{AC} - \Pi^1_{CC}$. That is, choosing a commitment that is neither too strong nor too weak. (If c^1 is chosen such that one of the inequalities becomes an equality, then the cooperative outcome is still an equilibrium in the game-theoretic sense. The difference is that in this case, one sub-game has multiple optimal decisions, e.g., when $c^1 = \Pi^1_{AC} - \Pi^1_{CC}$, then in the last stage, at the leftmost of the four nodes in Figure 2, player 1 is indifferent between C and A.)

Figure 2 Prisoner's dilemma with weak commitment and sequential moves

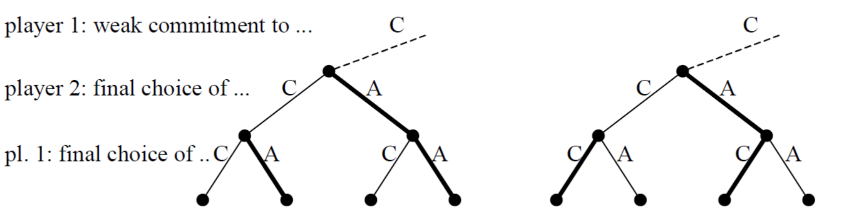


payoff player 1: payoff player 2:	Π^1_{CC} Π^2_{CC}	Π^1_{AC} - c^1 Π^2_{CA}	Π^1_{CA} Π^2_{AC}	Π^1_{AA} - c^1 Π^2_{AA}	Π^1_{CC} - c^1 Π^2_{CC}	Π^1_{AC} Π^2_{CA}	Π^1_{CA} - c^1 Π^2_{AC}	Π^1_{AA} Π^2_{AA}

payoff player 1: payoff player 2:	4 6	3 1	0 8	1 5	2 6	5 1	-2 8	3 5

Notes: $c^1 = 2$ in the numerical example (lower box). In the general case, $\Pi^1_{AA} - \Pi^1_{CA} > c^1 > \Pi^1_{AC} - \Pi^1_{CC}$. Bold lines: equilibrium paths of the sub-games.

Figure 3 Subgame equilibria with too low or too high levels of commitment



payoff pl. 1: payoff pl. 2:	Π^1_{CC} Π^2_{CC}	Π^1_{AC} - c^1 Π^2_{CA}	Π^1_{CA} Π^2_{AC}	Π^1_{AA} - c^1 Π^2_{AA}	Π^1_{CC} Π^2_{CC}	Π^1_{AC} - c^1 Π^2_{CA}	Π^1_{CA} Π^2_{AC}	Π^1_{AA} - c^1 Π^2_{AA}

payoff pl. 1: payoff pl. 2:	4 6	4.5 1	0 8	2.5 5	4 6	1 1	0 8	-1 5

Note: Left half of decision tree in Figure 2, with c^1 too low $(c^1 < \Pi^1_{AC} - \Pi^1_{CC} \,/\, c^1 = 0.5;$ left) resp. c^1 too high $(c^1 > \Pi^1_{AA} - \Pi^1_{CA} \,/\, c^1 = 4;$ right)

5.3 Alternative move sequences

The three-stage structure of the model developed above fits well to examples where the weak commitment is made by one party. In other cases, weak commitments are made by *both* parties, either sequentially or simultaneously. (Decisions that are made without knowledge of the other player's decision can be treated as if they were made simultaneously, even if they are not actually made at the same time.) In the case of inter-firm collaboration, both sequential and simultaneous partial commitments are plausible.

Given that the sequence of moves differs widely between the examples, it would be critical for the model if its predictions depended on the precise order of moves. However, it turns out that this is not the case and a demonstration of this is found in Appendix. For any sensible sequence of moves the possibility of making weak commitments helps the parties to achieve cooperation. The requirement for a 'sensible' order of moves is that a final commitment is only made after the other player has made a move. Otherwise, the other player would be tempted to play aggressively, and the game would effectively remain a prisoner's dilemma. This implies in particular that all partial commitments are made and communicated before any final commitment is made.

6 Summary and discussion

This analysis began with the observation that collaborative innovation between commercially distinct entities is not easily explained. The multiple sources of uncertainty and opportunities for opportunism create a situation where, although the combined benefits to both parties would be greater if they collaborated; opportunistic behaviour is an equilibrium outcome. In the real-life scenarios described, opportunistic behaviour can take many forms, but the clearest case is 'hold-up' (demanding excessive compensation) once the partner is strongly committed. As a result, one would not expect arm's-length entities to enter into collaborative innovation activities in the absence of some additional mechanism. Yet, there is abundant evidence that companies do, in fact, enter into such arrangements and that collaborative innovation is a rich frontier for value creation.

The mechanisms proposed for enabling collaborative innovation are not readily observable. Trust is often invoked as a latent construct that would serve as a deterrent to opportunistic behaviour, but the precise functioning of this mechanism is not totally clear, and the literature is equivocal on its effectiveness (Hoffmann et al., 2010; Bunduchi, 2013; Martins et al., 2017; Min et al., 2018). What is known about trust is that it is strongly associated with a history of repeated interactions and an expectation of continued interaction. Neither of these conditions will necessarily be present in situations that could benefit most from collaborative innovation, particularly those where rapidly evolving technologies are involved.

What we show here is that weak or partial commitments can have a beneficial effect in these prisoner's dilemma-type situations. 'Weak' commitment means that retracting the commitment later on is possible, but at some cost. The key consequences of this finding are as follows:

1. If the situation can be modelled as a retaliation-type prisoner's dilemma game with increasing differences, then there exists a non-zero range of commitment levels within which mutual cooperation is an equilibrium condition – meaning that collaboration becomes the dominant strategy for both parties.
2. The mechanism does not rely on the expectation of future interactions to achieve cooperative behaviour. While it is true that an interaction based on weak commitments will have more than one step, this differs from *repeated* interaction in that payoffs are only due after the last step. In that sense, it is a *single* interaction. In

contrast, the actors receive a payoff *after each round* of the repeated interaction in previously proposed solutions (Telser, 1980; Axelrod, 1984).

3 The weak commitment can be made unilaterally by either party; that is, it does not require any explicit agreement or negotiation.

4 A weak commitment is not necessarily a small commitment, and therefore does not require a sequence of 'building-up' steps.

5 The mechanism is robust with respect to variations in the timing of the steps, as shown in Appendix.

We must acknowledge and examine the basic assumptions and potential criticisms of the model. The model required some simplification. Hence, it is necessary to discuss robustness of the results with respect to changes in the assumptions. First, the interaction was reduced to a simple prisoner's dilemma, with binary strategies, although in many situations actors can choose from continuous strategies (e.g., prices). However, one can consider continuous strategies and still obtain the beneficial effect of partial commitment (Henkel, 1997, 2002). Furthermore, seemingly continuous strategies are often *de facto* discrete, because of focal points (Schelling, 1960). In the case of continuous strategy sets, the property of increasing differences translates into that of *strategic complementarity*, which essentially means that reaction functions are increasing. Considering market competition with substitutive products, this is typically the case when decision variables are prices. When reaction functions are downward sloping, which is usually true in quantity competition, the decision variables are *strategic substitutes* [Bulow et al., 1985; Besanko et al., (2000), p.263].

Another point that has to be checked in each case is whether the prisoner's dilemma really is of the retaliation type, in other words: if the move to opportunism pays more when the partner plays opportunistically than it does when the partner cooperates. It seems though, that this condition is fulfilled in most examples, and Parkhe et al. (1993) found it confirmed in their study of interfirm strategic alliances – thus this does not appear to be a serious limitation.

A more critical objection concerns the assumption of full information. In general, actors know their partner's payoff function approximately at best. The same is true for the level of commitment: perceived and true level generally differ, even though they are closely connected (Anderson and Weitz, 1992). However, this criticism, while justified, is less severe than it may seem. First, participants in the same industry, and in particular firms contemplating collaboration, may have a reasonably good idea of each other's cost structure. Second, an approximate knowledge of payoffs and commitment levels is sufficient for the mechanism to work: all an actor needs to know is that for the partner, the inequalities (2) and (3) are fulfilled.

7 Implications for management

The research presented in this paper has strong implications for managers in how they should approach opportunities for collaborative innovation in buyer-supplier relationships, and it is clear that the principles can be extended to a far wider spectrum of business situations. In the case of a buyer contracting with a supplier in an incompletely specified development agreement, the model shows us that committing unequivocally to the supplier as a sole source may be too strong a commitment, particularly in the case where the buying company has a strong need for the final product. In such a case, the supplier would be encouraged to engage in aggressive pricing actions after completion of the collaborative development. On the other hand, a very weak commitment (e.g., fully funding a parallel development path that would potentially make the supplier's contribution unnecessary) may be insufficient to motivate the supplier to give its best effort or even to cooperate at all. There are multiple strategies that could be employed unilaterally by the buyer to bring the level of commitment into the right range, such as doing only preliminary work on an alternate approach. It is also possible for the supplier to move its level of commitment into the right range through such activities as investing in unique facilities dedicated to the buyer's requirements or by granting an exclusive license to the buyer for use of the final product (Chen et al., 2017). While our analysis has shown that these moves can be made unilaterally, there is of course no reason they cannot be negotiated.

The concept of a 'right' range of strength of commitment implies that attention must be paid to both ends of the scale, strengthening or weakening the commitment as needed. Gilson et al. (2009) found it noteworthy that their examples of collaboration contracts contained terms that were not legally enforceable and attempted to explain their existence. Their proposition (paraphrased) was that the formality of the contracts gave added strength to the commitments through the mechanism of SET even though the terms could not be enforced. If we look at these contracts from a weak commitments perspective, we can see that there might be another rationale for such contracts, and that is to explicitly limit (weaken) the commitments by making it clear that nothing was promised or implied beyond what was stated. In either case, the strength of the commitment must be communicated clearly to be effective, and these contracts could certainly serve this purpose.

The fact that all of these tactics are well-known suggests that the principles described here are understood, at least at an intuitive level. It is suggested however, that weak commitments should be used more deliberately, and that it pays to analyse the cost of deviating and the opponent's gain from aggressive behaviour thoroughly. This means too, that one should identify the nature of the respective prisoner's dilemma – first strike type vs. retaliation type. In the second case, there is an opportunity for cooperation to be attained by weak commitments. Finally, as with commitments in general, weak commitments must be clearly communicated to be effective.

It may be that in everyday strategic interactions, it will not be possible to calculate exact values for weak commitments since they will often be intertwined with other phenomena, including trust and reputational cost. Nonetheless, the analysis presented in this paper shows that weak commitment can and does play an important role in structuring relationships to promote cooperation.

8 Conclusions and recommendations for future research

This paper has shown that under representative conditions, it is possible to structure a relationship in such a way that collaborative innovation can take place without the risk of future opportunistic action by either party. At a minimum, this should cause us to reframe the debate about the role of trust in suppressing opportunism. Specifically, we can see that trust is not a monolithic construct, and Poppo et al. (2016) address this by separating it into *calculative* and *relational* components. Our analysis contributes to the understanding of calculative trust in the sense that if a player analyses the situation and can see that cooperation is the dominant strategy, then that player can 'trust' its supplier, customer, or partner to behave in a cooperative manner, even though there may be no trust in the interpersonal or relational sense. None of this is intended to deny the existence and importance of relational trust – only to demonstrate that they are not necessary conditions. Interestingly, Poppo et al. (2016, p.736) found that: "calculative trust has a stronger effect (on performance) than relational trust (its standardised estimate is almost two times larger than that for relational trust)."

As a result, it is possible for firms to behave in a trusting manner, regardless of whether trust exists or not in the conventional meaning of the term. Although elements of this can be seen in everyday behaviour, it is not clear to what extent managers are consciously aware of the principle of weak commitments or how they evaluate these in the workplace. From a research perspective, the structuring of commitments promises to be a useful theoretical lens through which to study and evaluate managerial behaviour.

An interesting footnote to the mechanism of weak commitments is that because of the effects of unilateral decisions, it can work between competitors as well as collaborators. Given that cooperative behaviour between competitors is generally illegal, proper understanding of the role of weak commitments may have important implications for the wording of anti-trust laws or their enforcement.

Although we have demonstrated that relational trust is not a necessary condition for collaboration, it can certainly exist and now that the role of weak commitments has been formalised as a way to create calculative trust, future research can seek to determine the interactions between the two forms. A plausible finding might be that the presence of relational trust serves to increase the feasible range for c^1.

Finally, an interesting extension of the problem is encountered when there are more than two players involved. Preliminary work suggests that the mechanism is still valid, but that as the number of players increases, at some point it becomes a free rider problem, with different dynamics. Further investigation would help to clarify this.

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Appendix

Alternate timing structures

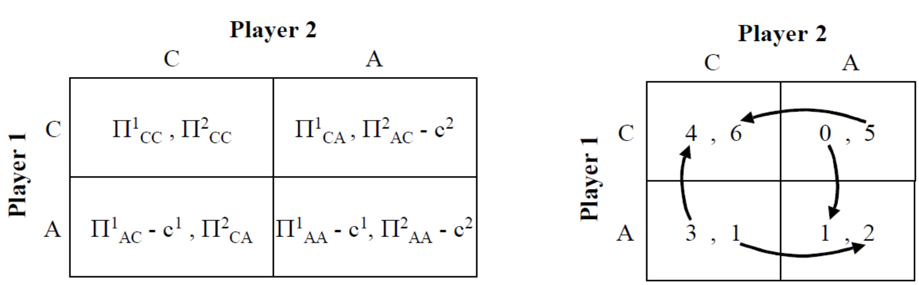
Table A1 shows all sensible timing structures. If only player i makes a partial commitment (A), then the final commitments must be made sequentially with player j leading. Otherwise, player i would have to make a final choice between 'cooperation' and 'aggression' without any information about j's moves. Since j's move would have no effect on i's behaviour, player j would play aggressively. When both make partial commitments with i leading (B, C), then the case that j is first to make the final commitment would be equivalent to A) and is hence left out. After simultaneous partial commitments (D, E), both sequential and simultaneous final commitments are possible.

Table A1 Possible sequences of moves in games with weak commitments ($i \neq j$)

	Partial commitment	*Final commitment*	*Number of stages*
A	Player i only	Player j first, then player i	3
B	Player i first, then player j	Player i first, then player j	4
C	Player i first, then player j	Simultaneously	3
D	Simultaneously	Player i first, then player j	3
E	Simultaneously	Simultaneously	2

The results given above can be generalised as follows: for all timing structures A to E and for degrees c^i of commitment that fulfil inequalities (2), partial commitment(s) to 'cooperation' and final choice of 'cooperation' by both parties is an equilibrium, or more precisely, a 'sub-game perfect equilibrium' [Selten, 1965; Fudenberg and Tirole, (1991), p.72]. That is, no party can improve their outcome by deviating from this strategy.

Figure A1 Payoffs depending on final stage actions in timing structure E, after both players have made a weak commitment to 'cooperation'



(a) (b)

Note: In (b), $c^1 = 2$, $c^2 = 3$. Arrows in (b) denote best responses.

The proof of this result for case A has been given above. All other cases can be solved in the same way by backward induction – solving the final stage for any combination of earlier moves, then the last but one stage, and so on. For illustration, Figure A1 shows the payoff matrix in the final stage of case E, when both players have committed to a suitable degree to 'cooperation' in stage 1. It clearly shows that when the parameters c^i fulfil inequalities (2), then 'cooperation' by both players is a Nash equilibrium in the final stage: when both choose C, then no player has an incentive to choose A instead. (The choice of 'aggression' by both players is also an equilibrium in the final stage, and for the overall game, partial commitment to A and final choice of A is an equilibrium. However, this problem of multiplicity of equilibria is not a serious one since both players will prefer the 'cooperation' equilibrium. Hence, coordination on the latter will be relatively easy.)