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Teamwork as a Self-Disciplining Device

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Abstract

We show that team formation can serve as an implicit commitment device to overcome problems of self-control. In a situation where individuals have present-biased preferences, any effort that is costly today but rewarded at some later point in time is too low from the perspective of an individual's long-run self. If agents interact repeatedly and can monitor each other, a relational contract involving teamwork can help to improve an agent's performance. The mutual promise to work harder is credible because the team breaks up after an agent has not kept this promise – which leads to individual (under-) production in the future and reduces an agent's future utility. This holds even though the standard free-rider problem is present and teamwork renders no technological benefits. Moreover, we show that even if teamwork does render technological benefits, the performance of a team of present-biased agents can actually be better than the performance of a team of time-consistent agents.

JEL-Code: L220, L230.

Keywords: procrastination, hyperbolic discounting, self-control problems, teamwork, relational contracts.

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Remember teamwork begins by building trust. And the only way to do that is to overcome our need for invulnerability.

Patrick Lencioni, The Five Dysfunctions of a Team: A Leadership Fable

1 Introduction

Teams are formed in all kinds of circumstances. They can be found within firms to tackle complicated problems, academics have co-authors to jointly work on research projects, lawyers or doctors form partnerships, and potential entrepreneurs start a firm with friends instead of pursuing their ideas alone.[1] Due to its importance, economists have widely analyzed teamwork, thereby mainly focussing on two conflicting aspects. On the one hand, technological benefits and specialization render teamwork necessary in situations that involve complex or risky tasks. On the other hand, teamwork is associated with a free-rider problem: Because each member's contribution is a public good, an underprovision of contributions can result (see Alchian and Demsetz, 1972). Starting with Holmstrom (1982) – who shows in a static setting that the first-best is impossible to reach if no surplus is destroyed – the literature has tried to identify ways to overcome this public good problem. More recently, non-technological benefits of teamwork have come into focus.[2] For example, internal monitoring and peer pressure can foster cooperation within a team and consequently increase productivity (see Kandel and Lazear, 1992, or Baron and Kreps, 1999).

This paper derives another inherent – and rather intuitive – benefit of teams: Driven by repeated interaction and mutual monitoring, teamwork can help to overcome problems of self-control. In a situation where individuals have present-biased preferences, any effort that is costly today but rewarded at some later point in time is too low from the perspective of an individual's long-run self. As an example, take a scientist's daily work on research projects. Many distractions keep him from being focused and motivated – in particular since most of the rewards of doing research are not realized immediately (it can take long until an article is finally published!). There are ways to increase his commitment, like conference deadlines or tools that temporarily block access to distracting websites. One of the mostly used remedy to tackle motivational issues, though, is the collaboration with co-authors. Besides making use of mutual comparative skills, spurring creativity, and plenty of other advantages, such a cooperation could also serve as a commitment device to overcome self-control problems. Promises made to

[1] Lazear and Shaw (2007) show that almost all US firms use teams in one form or the other.

[2] Outside economics these aspects have been analyzed for much longer.

co-authors are motivating, in particular if one also wants to work with them on future projects. Formally, we show that cooperation in teams can be enforced – even though the standard free-rider problem is present and teamwork renders no technological benefits – because the team breaks up after an agent has not kept his promise of working hard. This leads to individual (under-) production in the future and reduces an agent's future utility. We also show that even if teamwork does render technological benefits, the performance of a team of present-biased agents can actually be better than that of a team of time-consistent agents.

Empirical research on teamwork shows that the free-rider problem indeed is an issue. Encinosa, Gaynor, and Rebitzer (2007) analyze the behavior of medical groups and show that it reduces productivity in teams. Nalbantian and Schotter (1997) compute lab experiments and show that free-riding problems are prevalent in teams and reduce productivity. Erev, Bornstein, and Galili (1993) use real-world experiments involving picking oranges. There, group compensation is associated with a 30% lower production than individual compensation.

However, there also is plenty of evidence that teamwork can be beneficial even in the absence of exogenous technological benefits. Hamilton, Nickerson, and Owan (2003) show that a switch from individual- to team-output contracts in a garment firm improved worker productivity by 14%. Chan, Li, and Pierce (2012) and Pizzini (2010) observe similar results in field experiments. In Jones, Kalmi, and Kauhanen (2010), the introduction of teamwork in a Finnish food-processing plant had a substantially positive impact on workers' efficiency, but only if combined with a group system of performance-related pay.

A potential explanation for inherent benefits of teamwork different from our paper is the existence of peer pressure and internal monitoring in repeated interactions. This is supported by Mas and Moretti (2009), who show that a worker's productivity in a team is increased if he can be seen by another worker, in particular if both interact frequently. Furthermore, the availability of peers might give rise to a competition effect that can help to overcome self-control problems. Gneezy and Rustichini (2004), for example, provide evidence that young boys run races faster when running with another boy than when running alone.

In this paper, we show that the availability of peers helps to overcome self-control problems not only because of intrinsic motivation created by peer pressure, but that internal monitoring can also induce cooperation. Thereby, we develop an infinite-horizon model of two agents who can repeatedly work on individual projects and have present-biased preferences. Since production is costly today but rewards are realized one period later, an agent works less hard than he would have preferred from the perspective of his long-run self. We assume that agents are sophisticated in the sense of Laibson (1997) and O'Donoghue and Rabin (1999), i. e., aware of their time-inconsistency. Furthermore, no exogenous commitment device exists which agents might use to bind their future selves. However, forming a team can serve as an endogenous commitment device to increase individual effort levels. Thereby, agents jointly work on a project, share potential benefits, and make a mutual promise to work harder. Since effort is not verifiable but can only be observed by one's co-worker, the promise to work harder has to be self-enforcing, i. e. optimal from an individual's perspective. This is possible because any deviation from the promise to work harder is followed by a loss of trust between agents and a reversion to individual production in all subsequent periods. Future individual production, though, is regarded as too low from an agent's perspective *today*. It is thus possible to enforce higher effort levels within a team, even though the latter is associated with the standard free-rider problem of team production. Since in the benchmark case teamwork renders a free-rider problem but no technological benefits, teamwork is not possible for time-consistent agents. In this case, individual production is already at its first-best from the perspective of *any* period, and a deviation therefore is not costly. If teamwork is associated with technological benefits (like economies of scale), though – implying that also time-consistent agents would rather work within a team than pursuing individual projects – agents with present-biased preferences might actually perform *better* than agents without. This is again driven by the lower outside option of present-biased agents and holds as long as the technological benefits of teamwork are not too large. Furthermore, we show that even if teamwork yields no technological benefits, an agent with self-control problems can be matched with an agent without. This only works, though, if the agent with self-control problems provides higher effort than the one without; hence, the seemingly lazier agent actually is the one without any self-control problem. Finally, we also allow for agents to be partially naive with respect to their future self-control problems and underestimate their magnitude. This makes it more difficult to enforce team-effort because having to work on individual projects in the future seems to be less unattractive from today's perspective.

Related Literature. This paper contributes and relates to three strands of literature – incentives in teams and professional partnerships, relational contracts and present-biased preferences. Optimal incentive giving in teams has been widely analyzed (starting with Alchian and Demsetz (1972) and Holmstrom (1982)). This literature, though, mainly assumes that teams are formed exogenously and only joint performance schemes are feasible. Recently, a couple of papers have shown that the underlying free-rider problem can be overcome if team members are able to (partially) observe the performance of their peers and hence form relational contracts with each other. Che and Yoo (2001) show that given a team is formed exogenously, joint performance evaluation might be optimal even though the principal observes individual performance signals. The resulting free-rider problem can be overcome by peer pressure and mutual monitoring, arising from repeated interaction and a relational contract formed between agents. Kvaløy and Olsen (2006) extend Che and Yoo's paper, assuming that the (imperfect) signal the principal receives is not verifiable as well, and the relationship between principal and agents is also governed by relational contracts. They identify instances for which relative performance evaluation (compared to joint and independent performance evaluation) is optimal and show that this depends on the interaction between agents' discount factors and their productivities. Furthermore, Rayo (2007) derives optimal asset ownership if a verifiable joint performance scheme exists but relational contracts between agents are feasible.[3]

The literature has also identified instances where the endogenous formation of teams or partnerships can be optimal. Itoh (1991) shows that teamwork may induce agents to help each other. Bar-Isaac (2007) develops a reputational model where it can be optimal to form a team in order to maintain reputational incentives for older workers who want to sell a firm but whose personal reputation is not at stake anymore. Corts (2007) shows that teamwork can help to overcome multitasking problems, by grouping tasks with a lower and those with a higher impact on observable signals. Mukherjee and Vasconcelos (2011) extend Corts' model by assuming that observable signals are not verifiable. Because teamwork requires higher maximum payments, it is also associated with a higher reneging temptation. Hence, teamwork only works if a firm's discount factor is sufficiently large. Finally, Levin and Tadelis (2005) illustrate that proft-sharing partnerships can serve as a signal for better product quality (assuming that product quality is determined by the average productivity of employees): Because partnerships care about a marginal worker's impact on average profits (whereas corporations consider marginal profits), they are more selective as to whom they accept as additional partners. Extending the literature on endogenous team formation, and using relational contracts between team members as well, we show that teamwork can also enhance productivity if individuals have self-control problems.

Furthermore, we contribute to the literature on inconsistent time preferences and self-control problems. Strotz (1955) is the first to formalize this aspect by noting that an individual's discount rate between two periods might depend on the time of evaluation. He further discusses differences between those who recognize this inconsistency – and hence might try to bind their future selves – and those who do not. Phelps and Pollak (1968) state that in particular growth models should take the possibility of inconsistent time preferences into account as this affects savings. Laibson (1997) shows that illiquid assets can serve as a commitment device to bind future selves. O'Donoghue and Rabin (1999) focus on the distinction between individuals who are aware of their time inconsistency and those who are not; they label the former 'sophisticated' and the latter 'naive'.

[3]Several articles derive mechanisms different from peer pressure and mutual monitoring that may render joint performance schemes optimal. Mohnen, Pokorny, and Sliwka (2008) and Bartling (2011) show that if players have social preferences, their preferences for equal outcomes can channel incentives in a way to overcome the free-rider problem. Kim and Vikander (2013) show that if teamwork renders *decreasing* returns to scale and relational contracts are used to motivate employees, joint-performance systems can be optimal because they help to smooth payments over time.

A huge amount of evidence confirms that people make decisions that are not consistent over time, for example when using credit cards or signing up for health clubs (DellaVigna and Malmendier, 2004, 2006). Ashraf, Karlan, and Yin (2006) conduct a field experiment with customers of a Philippine bank, allowing individuals to choose a commitment device that restricts access to their savings. More than 25% of customers opt for this device and subsequently increase their savings substantially . More recently, experimental evidence from the field and the lab uses real-effort tasks to directly identify self-control problems. Kaur, Kremer, and Mullainathan (2010, 2013) perform a field experiment involving full-time workers in an Indian data entry firm. Quantity and quality of output can be easily measured, and workers receive a piece rate. The existence of self-control problems is supported by the observation that workers increase effort as the payday gets closer. In addition, many workers select an offered commitment device that would be dominated for individuals with exponential preferences. Furthermore, Augenblick, Niederle, and Sprenger (2013) perform a real-effort task lab experiment. There, participants show a significant present-bias as well, and many of them demand a binding commitment device if it is offered. We contribute to this literature showing that by forming a team, individuals can create an *implicit* commitment device.[4] Thereby, they use the benefits of future cooperation as a collateral to overcome self-control problems. In addition, we show that people with present-biased preferences can actually perform better than those without and – to our knowledge – are the first to derive such a result. It is driven by individuals with self-control problems being hurt more by a breakdown of teamwork.

Finally, we relate to the literature on relational contracts. Relational contracts are implicit arrangements based on observable but non-verifiable information. Theoretical foundations have been laid by Bull (1987) and MacLeod and Malcomson (1989) and later extended for the case with imperfect public monitoring by Levin (2003). This triggered various developments of the baseline model, thereby providing many explanations for real-world phenomena. As in Che and Yoo (2001), we do not analyze relational contracts between a principal and one or many agents, but assume that two identical individuals interact. There, we show that adding behavioral assumptions to relational contracting framework can yield new and interesting implications.

[4]Several other implicit commitment devices to overcome self-control problems, in particular to enforce optimal consumption and savings decisions, have been identified. Bond and Sigurdsson (2013) show that contractual arrangements restricting an individual's intertemporal consumption choice can help to solve the tradeoff between inducing future commitment and reacting flexibly to stochastic and non-verifiable shocks. Basu (2011) derives a justification for so-called rotational savings and credit associations, which many people in the developing world join. Although clearly restricting an individual's flexibility, they can foster commitment to accumulate savings.

2 Basic Model – Individual Production

2.1 The Economy

Consider two risk-neutral agents $i = \{1, 2\}$ who live for infinitely many periods, $t \in \{0, 1, \ldots\}$. Each agent has access to an inexhaustible amount of projects. At each date, an agent chooses a total effort level e_t and how to allocate it among projects (we add an index for the agent when necessary).

Each project returns V in the following period $(t+1)$ with probability identical to the effort allocated to this project. The aggregate expected return from a total effort e_t is thus $e_t\,V$, independent of the concrete allocation of effort among projects. Hence, an agent can influence his payoff in period $t+1$ by increasing his effort in period t. Effort leads to an immediate cost $c\,e_t^2/2$ at date t, with $c > 0$, where e_t is an agent's total effort.[5] To make sure that we always have an interior solution, we assume for the remainder of this paper that $\delta\,V/c < 1/2$. As discussed above, the agents could be researchers carrying out experiments or writing papers. Effort increases the probability of a publication, yielding V (not necessarily monetary).

There are no technological linkages of projects across periods. The effort spent on a project in period t does not affect the likelihood that the project is successful in any later period. If an agent finishes one project, or abandons it, he can start a new project.

2.2 Discounting

Agents discount future costs and future utilities in a quasi-hyperbolic way according to Laibson (1997) and O'Donoghue and Rabin (1999). Immediate utilities are not discounted. Utilities after t periods are discounted with a factor $\beta\,\delta^{\mathrm{T}}$, with β and δ in $(0; 1]$. Hence, the discounted value of a utility stream evaluated in period t is $u_t + \beta\,[\delta u_{t+1} + \delta^2 u_{t+2} + \ldots]$, where u_t is the agent's period-t utility. Consequently, an agent's preferences are dynamically inconsistent. At date $t = 0$, an agent would pay $\beta\,\delta$ for a dollar at date $t = 1$, and at date $t = 1$ he would pay $\beta\,\delta$ for a dollar at date $t = 2$. However, at date $t = 0$, he would give up $\beta\,\delta^2$ instead of $\beta^2\,\delta^2$ for a dollar at date $t = 2$. In addition, we assume that agents are sophisticated in the sense that they are fully aware of their time-inconsistency and hence take their future time-inconsistency into account when taking actions. Throughout the paper, we assume that there is no formal device for an agent to commit to any specific effort level.

[5] Hence, an agent's effort cost and expected payoff is the same, no matter whether he just works on one or allocates total effort among an arbitrary number of different projects. Therefore, the number of projects an agent works on in a given period can be normalized to 1.

2.3 Individual Production and Self-Control Problems

Now, we derive effort levels if agents work on their own. Since there is no commitment on any effort level, an agent decides how much he wants to work at the beginning of any period t, maximizing his discounted utility[6]

$$\beta\,\delta\,e_t\,V - \frac{c\,e_t^2}{2}. \tag{1}$$

The solution to individual production, e^{I}, is the same in every period and equals

$$e^{\mathrm{I}} = \frac{\beta\,\delta\,V}{c}. \tag{2}$$

In each period, the agent will spend this effort e^{I}. However, reasoning over how much effort he wants to spend in the future, he would come to a different result. Thinking at date t how much he wants to work at a future date $\hat{t} > t$, he would like to maximize

$$\beta\,\delta^{\hat{t}-t}\left(\delta\,e_{\hat{t}}\,V - \frac{c\,e_{\hat{t}}^2}{2}\right). \tag{3}$$

For any period $\hat{t} > t$ this is maximized by first-best effort e^{FB}, i. e., by

$$e^{\mathrm{FB}} = \frac{\delta\,V}{c}. \tag{4}$$

Informally speaking, the agent is lazy. Since $e^{\mathrm{I}} < e^{\mathrm{FB}}$ for $\beta < 1$, he works less than he would originally have liked to work, from the perspective of earlier periods. This does not come as a surprise, though, since the agent is sophisticated and fully aware of his self-control problem.

This time-inconsistency problem is not present in period $t = 0$, the first period of the game. There, no past plans do yet exist from which current behavior can deviate. Hence, first-best effort in period $t = 0$ is equal to e^{I}. This phenomenon – that optimal behavior in period $t = 0$ differs from optimal behavior in all subsequent periods – will also manifest in the description of equilibrium team arrangements.

[6]We exclude the possibility of an agent conditioning his current behavior on past effort levels. Otherwise, we would have equilibria where an agent punishes himself for "wrong" behavior (like too low effort levels) in the past; for an analysis of such equilibria see Laibson (1994) or Bernheim, Ray, and Yeltekin (1999). Formally, the equilibrium we derive for the game played by the different selves of a single agent is the unique Markov-perfect equilibrium, which implies that the game is stationary given *any* history (like in Krusell and Anthony A. Smith (2003) or Basu (2011)).

3 Teamwork

3.1 Framework

In this section, we discuss exactly the same economic setting as before. We show that – instead of working on their own – agents can do better by forming a team, using relational contracts. At the beginning of every period agents can form a team. This implies that both agents jointly work on some projects, and that the payoff V from these projects – if successful – is shared equally. In the case of researchers, both would define a joint research topic. In case of successful publication, both names appear on the paper. The value of the publication for the two co-authors would be the same.

Equivalently to footnote 5, the number of projects pursued in a team at each date can – without loss of generality – be normalized to 1. Agents make their effort choices simultaneously, where effort is mutually observable but not verifiable. Given agent 1 chooses effort $e_{1,t}$ and agent 2 chooses $e_{2,t}$, the joint expected payoff – realized in period $t+1$ – is $(e_{1,t}+e_{2,t})\ V$, and each expects to receive $(e_{1,t}+e_{2,t})\ V/2$. Hence, we assume that there are no economies (or diseconomies) of scale (or scope) from teamwork[7] – the same amount of work can get done and costs of effort are the same.

Even after agents have formed a team in a period t, they are always able to revert to individual production in *future* periods. In other words, we rule out exclusivity contracts with profit-sharing agreements involving all future projects.[8]

Our definition of teamwork – that agents jointly work on a project – is solely made for concreteness. Any arrangement where one agent uses part of his effort in order to benefit the other agent would yield the same qualitative results. For example, one agent might directly spend some of his working time on one of the other agent's projects, and vice versa. Agents could also focus on different topics and explain their insights to each other. Plain profit sharing would also be feasible, as well as any combination of these aspects (like sharing the outputs of two projects and alternate working on it).

3.2 Relational Contracts and Equilibrium Concept

Agents can form a relational contract specifying effort levels within the team. Since both agents can observe each other's effort, mutual monitoring is feasible.

[7] In section 4, we introduce economies of scale in a team.

[8] Thinking of researchers, one researcher could abandon the project with one co-author and start working on a new project.

This relational contract is formed at the beginning of the game. For any period t, it specifies the actions both agents are supposed to take along the whole path of the game – contingent on the realized history up to period t. The relational contract implicitly determines when a team is supposed to be formed, as well as each agent's effort level on and off the equilibrium path. Both agents' contingent action plans, i. e. their strategies, have to be optimal for any feasible history, i. e., form a subgame perfect equilibrium of the dynamic game. However, given agents' time inconsistency, we require a subgame perfect equilibrium to constitute a Nash equilibrium at each subgame, given agents' preferences once a respective subgame is reached, and given each agent's continuation play.

As explained above, the time-inconsistency problem does not exist in period $t = 0$ (there, first-best effort is identical to e^{I}). Thus, teams can only potentially add value in periods $t \geq 1$. For those periods, relational contracts can be stationary, i. e., team-effort is the same in every period,[9] allowing us to omit time subscripts.

3.3 Team Production

Assume each agent is supposed to exert team-effort e^{T} in period t. For tractability, we focus on symmetric equilibria where effort e^{T} is the same among agents. To support team-effort e^{T}, we have to specify what happens after a deviation. In principle, there are two possibilities for an agent to deviate in any period. First, an agent could refuse to form a team-project as specified by the relational contract. Second, after forming the team, the agent could provide an effort level different from e^{T}. The first possibility to deviate, though, is not relevant: Because an agent can always work on his own projects, agreeing to form a team but then choosing $e^{\mathrm{T}} = 0$ is associated with no costs. Therefore, we can restrict our attention to deviations from equilibrium team-effort e^{T}. Given any such deviation, we follow Abreu (1988) who shows that any observable deviation should be responded by the strongest feasible punishment. In our case, that means that cooperation within the relational contract breaks down for good, and agents could either resume to individual production or stick to teamwork – with effort levels determined by the static Nash equilibrium. Due to the free-rider problem of teamwork which is also present in our setting, static Nash effort is one half of indivdiual production. Hence, individual production is preferred by agents compared to teamwork when the static Nash equilibrium is played by both of them.[10]

In the following we analyze whether such a relational contract can be sustained

[9]This is because agents are risk-neutral and information is symmetric. For a further elaboration on this issue see Levin (2003).

[10]This is formally shown below, in Lemma 3, and holds as long as teamwork renders no technological benefits. With technological benefits, teamwork – with both agents exerting effort determined by the static Nash equilibrium – might be chosen even after a deviation.

as a subgame perfect equilibrium, and in particular whether team effort e^{T} can exceed the effort level of individual production, e^{I} or might even reach e^{FB} – the first-best effort as regarded from the point of view of earlier periods. There, note that e^{FB} also is an agent's preferred symmetric future effort level given a team is formed: In a period t and thinking about his preferred effort level (exerted by both agents) at a future date $\hat{t} > t$, he maximizes

$$\beta\,\delta^{\hat{t}-t}\,\left[\delta\,\left(e^{\mathrm{T}}_{\hat{t}} + e^{\mathrm{T}}_{\hat{t}}\right)\,V/2 - c\,\left(e^{\mathrm{T}}_{\hat{t}}\right)^2/2\right], \tag{5}$$

which is solved by e^{FB}.

Once a team has been formed and given agents stick to their agreement, an agent's expected discounted utility stream in a period $t \geq 1$ is

$$\begin{aligned} U^{\mathrm{T}} &= \beta\,\delta\,e^{\mathrm{T}}\,V - \frac{c\,(e^{\mathrm{T}})^2}{2} + \sum_{t=1}^{\infty}\beta\,\delta^{\mathrm{T}}\left(\delta\,e^{\mathrm{T}}\,V - \frac{c\,(e^{\mathrm{T}})^2}{2}\right) \\ &= \beta\,\delta\,e^{\mathrm{T}}\,V - \frac{c\,(e^{\mathrm{T}})^2}{2} + \frac{\beta\,\delta}{1-\delta}\left(\delta\,e^{\mathrm{T}}\,V - \frac{c\,(e^{\mathrm{T}})^2}{2}\right). \end{aligned} \tag{6}$$

U^{T} can only be enforced by a relational contract if a deviation is never optimal. Because an agent only gets 0.5 of the outcome of his own effort within the team and because *any* deviation triggers a breakdown of future cooperation, if the agent deviates, he should optimally provide zero team-effort and instead completely work on his individual projects. Then, he would still enjoy the benefits of the other agent's team effort. After a deviation, both agents work on individual projects from then on. Hence, an agent's expected discounted utility stream given he joins the team but then underprovides effort is

$$\begin{aligned} U^{D} &= \beta\,\delta\,e^{\mathrm{T}}\,\frac{V}{2} + \beta\,\delta\,e^{\mathrm{I}}\,V - \frac{c\,(e^{\mathrm{I}})^2}{2} + \sum_{t=1}^{\infty}\beta\,\delta^{\mathrm{T}}\left(\delta\,e^{\mathrm{I}}\,V - \frac{c\,(e^{\mathrm{I}})^2}{2}\right) \\ &= \beta\,\delta\,V\,\left(\frac{e^{\mathrm{T}}}{2} + e^{\mathrm{I}}\right) - \frac{c\,(e^{\mathrm{I}})^2}{2} + \frac{\beta\,\delta}{1-\delta}\left(\delta\,e^{\mathrm{I}}\,V - \frac{c\,(e^{\mathrm{I}})^2}{2}\right). \end{aligned} \tag{7}$$

To sustain teamwork, an agent's equilibrium utility stream within the team has to be larger than given any possible deviation. Hence, an incentive compatibility (IC) constraint must be satisfied, $U^{\mathrm{T}} \geq U^{D}$, or

$$\begin{aligned} &\left(\beta\,\delta\,e^{\mathrm{T}}\,\frac{V}{2} - \frac{c\,(e^{\mathrm{T}})^2}{2}\right) - \left(\beta\,\delta\,e^{\mathrm{I}}\,V - \frac{c\,(e^{\mathrm{I}})^2}{2}\right) \\ &+\frac{\beta\,\delta}{1-\delta}\left[\left(\delta\,e^{\mathrm{T}}\,V - \frac{c\,(e^{\mathrm{T}})^2}{2}\right) - \left(\delta\,e^{\mathrm{I}}\,V - \frac{c\,(e^{\mathrm{I}})^2}{2}\right)\right] \geq 0 \end{aligned} \tag{IC}$$

Here, the first line captures the standard free-rider problem of teamwork (and is negative for $e^{\mathrm{T}} \neq e^{N}$); the second line gives the value of future cooperation, evaluated today. Only if the second line dominates, teamwork is feasible. If (IC) is not satisfied, no team is formed, and both agents have utilities U^{I}.

Note that the (IC) constraint must hold in every period t. This implies that – different from many other (formal) commitment devices analyzed in the literature – teamwork has to be optimal for every future self of an agent (taking every future self's continuation utility into account), not only for the period-0 self.

3.4 Results

In the following, we analyze what can be achieved within a team and what is not feasible, without making any claim which equilibrium is actually chosen (with the exception that we focus on symmetric equilibria). As a first result, we can show that if agents do *not* exhibit inconsistent time preferences, forming a team is not feasible.

Lemma 1 *For $\beta = 1$, no positive effort level can be enforced within a team.*

Obviously, a team is not needed if $\beta = 1$. We show that forming a team even is not possible in that case. This is driven by two aspects. On the one hand, the standard free-rider problem of team production is present, making an underprovision of effort optimal in the short run. On the other hand, an agent's outside option is already at the first best. Hence, a breakdown of the team is associated with no costs and a deviation always more tempting than working for the joint project. Furthermore, teamwork is only (potentially) feasible for effort levels above e^{I}.

Lemma 2 *No effort level $e^{T} \leq e^{I}$ can be enforced within a team.*

The intuition of Lemma 2 is similar to the one driving Lemma 1. For $e^{\mathrm{T}} \leq e^{\mathrm{I}}$, continuation utilities of individual production are higher than those of teamwork. Together with the free-rider problem, this indicates that teamwork is not only not worthwhile, but not even feasible for $e^{T} \leq e^{I}$. Lemma 2 also implies that if a team can be formed, the associated effort is higher than e^{I}, and teamwork can help agents to overcome their self-control problems.

In a next step, we show that forming a team teamwork is indeed feasible for $\beta < 1$ and that first-best effort e^{FB} might eventually be reached if δ is sufficiently large.

Proposition 1 *For every $\beta < 1$ and any effort level $e^{T} \in (e^{I}, e^{FB}]$, e^{T} can be enforced within a team if δ is sufficiently close to 1.*

For δ sufficiently large, today's value of future cooperation becomes so large that it necessarily dominates today's deviation gain. Proposition 1 establishes our first main result – that teamwork can help to overcome self-control problems. The next proposition makes the feasibility of teamwork more precise.

Proposition 2 *Positive effort within a team can be enforced if and only if*

$$\delta \geq \underline{\delta} = \frac{2\sqrt{4 - 6\beta + 3\beta^2} - 1}{5 - 8\beta + 4\beta^2}. \tag{8}$$

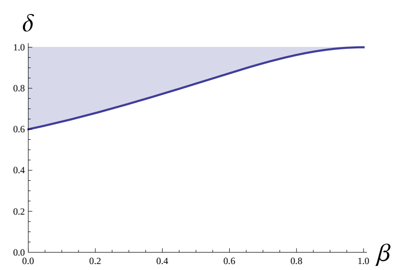
Furthermore, $d\underline{\delta}/d\beta \geq 0$.

To obtain $\underline{\delta}$, we derive the level of team-effort that maximizes the left-hand-side of the (IC) constraint, denoted $\underline{e}^{\mathrm{T}}$. Since it is unique, teamwork is only feasible if the (IC) constraint holds for $\underline{e}^{\mathrm{T}}$. Two aspects are important. First of all, $\underline{\delta} < 1$ for $\beta < 1$, hence agents with self-control problems can generally form productive teams. Furthermore, $d\underline{\delta}/d\beta \geq 0$ implies that a lower β generally makes it *easier* to enforce any effort within a team.

The latter point is not that straightforward, since a lower β generally has two countervailing effects. On the one hand, it reduces e^{I} and an agent's outside option, thereby relaxing the (IC) constraint. On the other hand, the future becomes less valuable, which tightens the (IC) constraint. However, at the threshold $\underline{\delta}$ only effort $\underline{e}^{\mathrm{T}}$ can just be enforced, which is increasing in β (furthermore, $\underline{e}^{\mathrm{T}} \to 0$ for $\beta \to 0$). Therefore, a lower β implies that the critical threshold of δ above which a team can be formed is reduced, however the enforceable effort at this threshold goes down.

The blue line in the following Figure 1 gives $\underline{\delta}$ as a function of β; the shaded region gives all combinations of δ and β for which positive effort within a team can be enforced.

Figure 1: Region where Positive Team-Effort is Feasible



We are particularly interested in the conditions for which a given effort level e^{T} can be enforced, especially for first-best effort $e^{\mathrm{FB}} = \delta V/c$. In this case, the (IC) constraint becomes

$$-\left(1 - \beta\,(1-\beta)\right) + \delta\,\left(1 - \beta^2\,(1-\beta)\right) \geq 0. \tag{9}$$

Since the term $\delta^2 V^2/2c$ cancels out, the value of the fundamentals V and c has no effect on the enforceability of team-effort. Only the ratio V^2/c determines the size of the left hand side, however does not affect whether it is positive. This implies

Proposition 3 *First-best effort e^{FB} within a team can be enforced if*

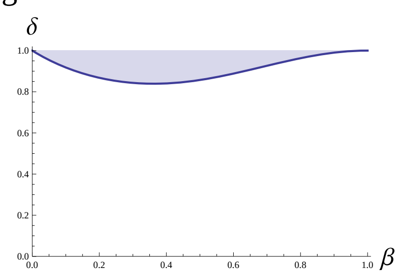
$$\delta \geq \delta^{FB} = \left(1 - \beta\ (1-\beta)\right) / \left(1 - \beta^2\ (1-\beta)\right). \tag{10}$$

Note that $\delta^{\mathrm{FB}} < 1$ for $\beta \in (0,1)$. Furthermore, δ^{FB} increases in β for large initial values of β and decreases for small initial values of β.[11] Therefore, more severe self-control problems of team members can make it easier to sustain first-best effort within a team.

For a given effort level e^{T}, a lower β generally has two effects. On the one hand, it directly tightens the (IC) constraint because the future becomes less valuable. On the other hand, it relaxes the (IC) constraint by decreasing off-equilibrium individual effort levels in the future (i. e., e^{I} is reduced) and consequently agents' outside options (from today' perspective). Starting from $\beta = 1$ and reducing β, the second effect initially dominates if $e^{\mathrm{T}} = e^{\mathrm{FB}}$. For rather low values of β, the first effect dominates.

In the following Figure 2, the blue line gives δ^{FB}, and the shaded region shows all combinations of δ and β for which e^{FB} can be enforced.

Figure 2: Region where the First-Best can be Attained



Concluding, more severe self-control problems can help to improve the performance of a team (which – if feasible – always yields higher effort than e^{I}, see Lemma 2). This is a general feature of relational contracts, which work better if agents are vulnerable. Someone who is locked in a relationship because their outside option is unattractive is willing to sacrifice more in order to maintain cooperation. An agent's vulnerability might be more pronounced if finding an adequate replacement for one's partner is impossible or – as in our case – if being thrown back on one's own is particularly bad.

[11] Formally, $\frac{d\delta^{\mathrm{FB}}}{d\beta} = -\left[(1-\beta)\ \left(1 - 3\,\beta + \beta^2\ (1-\beta)\right)\right] / \left(1 - \beta^2\ (1-\beta)\right)^2$.

4 Extensions

In the following, we extend our setup along three lines and show that a couple of further interesting results can be obtained. First, we assume that teamwork is associated with exogenous technological benefits. Then, we analyze what happens if an agent with self-control problems is matched with an agent without. Finally, we explore the implications of agents not being (fully) aware of their future self-control problems.

4.1 Teamwork with Exogenous Benefits

We have shown that teamwork can help to overcome an agent's self-control problems. For time-consistent agents, teamwork is not possible – however also not needed. Here, we show that even if teamwork renders technological benefits, implying that also time-consistent agents would rather work within a team than on individual projects, time-inconsistent agents can perform better than time-consistent ones. This is true as long as the exogenous benefits of teamwork are not too large. The mechanism driving this result is equivalent to the one underlying our previous analysis: A lower β not only reduces continuation utilities in equilibrium, but also agents' off-equilibrium utilities. As long as the latter aspect dominates, a lower β can induce a higher performance within the team.

We focus on one particular case of exogenous team-benefits and assume that if both agents work on a joint project, the probability to generate the payoff V in period $t+1$ is $e_1 + e_2 + 2\,\alpha\min\{e_1, e_2\}$, with $\alpha \geq 0$ (and impose the assumption $\delta\, V\,(1+\alpha)/c < 1/2$ to always guarantee an interior solution). Therefore, the exogenous benefits of teamwork are only realized if both actually work on the joint project. A value $\alpha = 0$ yields the situation analyzed above; a value $\alpha > 0$ could be generated by discussions of the team members about the joint problems which deepens each agent's understanding, or by heterogeneities in the agents' abilities to tackle different aspects of a project. If both agents exert team effort e^{T}, the probability to generate the payoff V in period $t+1$ is $2\,e^{\mathrm{T}}\,(1+\alpha)$.

Before analyzing the feasibility of teamwork, we have to be precise about the definition of first-best effort in this section. First-best effort – as regarded from earlier periods – now is different under individual production than within a team. Here, we focus on the highest feasible payoff an agent can possibly expect, which implies that the technological benefits of teamwork are enjoyed. Hence, we define first-best effort levels e_1^{FB} and e_2^{FB} as maximizing the joint team payoff as regarded from earlier periods, i. e.

$$-\frac{c\,e_1^2}{2} - \frac{c\,e_2^2}{2} + \delta\ (e_1 + e_2 + 2\,\alpha\min\{e_1, e_2\})\ V. \tag{11}$$

Since a potential output V is shared equally, no other definition of first-best effort could make both agents better off. The symmetric first-best effort level e^{FB} is thus

$$e^{\text{FB}} = \frac{\delta\,(1+\alpha)\,V}{c}. \tag{12}$$

Furthermore, an agent's equilibrium utility stream is

$$U^{\text{T}} = -c\,\frac{(e^{\text{T}})^2}{2} + \beta\,\delta\,e^{\text{T}}\,(1+\alpha)\,V + \beta\,\frac{\delta}{1-\delta}\,\left(\delta\,e^{\text{T}}\,(1+\alpha)\,V - c\,\frac{(e^{\text{T}})^2}{2}\right). \tag{13}$$

Individual production is not affected by the existence of technological team benefits. It yields a per-period utility $u^{\text{I}} = -c\,(e^{\text{I}})^2/2 + \beta\,\delta\,e^{\text{I}}\,V$, and optimal effort for each agent is $e^{\text{I}} = \beta\,\delta\,V/c$. Absent cooperation, i. e. if agents solely maximize their stage payoffs (this situation determines the outside option in a relational contract), it might now still be optimal for agents to form a team if α is sufficiently large. In this case, the static Nash equilibrium is played, the per-period utility of agent i is $u_i^N = -c\,(e_i^N)^2/2 + \beta\,\delta\,\left(e_1^N + e_2^N\right)\,(1+\alpha)\,V/2$, and optimal static effort for both agents is $e^N = \beta\,\delta\,(1+\alpha)\,V/2c$.

Off equilibrium, agents will work within a team if the marginal value of individual effort in the team is higher than under individual production. Since agents can always deviate and work on individual projects, it is *not* sufficient that $u^N \geq u^{\text{I}}$ for teamwork to constitute the off-equilibrium outcomes. Hence,

Lemma 3 *If agents solely maximize their stage payoffs, teamwork is chosen for $\alpha > 1$ and individual production is chosen for $\alpha \leq 1$.*

Due to the free-rider problem induced by teamwork, the exogenous technological benefits of teamwork have to make up for the fact that one half of an agent's effort directly benefits the other agent. Given our production technology, α has to exceed 1 for this condition to hold.

An agent's deviation utility is hence given by

$$U^D = \begin{cases} -c\,\frac{(e^{\text{I}})^2}{2} + \beta\,\delta\,e^{\text{T}}\,\frac{V}{2} + \beta\,\delta\,e^{\text{I}}\,V + \beta\,\frac{\delta}{1-\delta}\,\left(\delta\,e^{\text{I}}\,V - c\,\frac{(e^{\text{I}})^2}{2}\right) & \text{for } \alpha \leq 1 \\ -c\,\frac{(e^N)^2}{2} + \beta\,\delta\,2\,e^N\,\frac{V}{2}\,(1+\alpha) + \beta\,\delta\,\frac{V}{2}\,\left(e^{\text{T}} - e^N\right) + \beta\,\frac{\delta}{1-\delta}\,\left(\delta\,e^N\,(1+\alpha)\,V - c\,\frac{(e^N)^2}{2}\right) & \\ & \text{for } \alpha > 1 \end{cases}$$

The second and third term in the second line stem from our assumption that exogenous benefits of teamwork are only enjoyed for the effort levels both put into the team project. Given the deviating player optimally chooses e^N, and given $e^{\text{T}} \geq e^N$, $e^{\text{T}} + e^N + 2\,\alpha\,\min\{e^{\text{T}}, e^N\} = e^{\text{T}} - e^N + 2\,(1+\alpha)\,e^N$.

In the following, we treat both cases separately to precisely analyze the impact of an agent's time inconsistency on cooperation within a team.

Outside Option is Individual Production. If the outside option is individual production, i. e. if $\alpha \leq 1$, the (IC) constraint boils down to

$$\left(\beta\,\delta\,e^{\mathrm{T}}\left(\frac{1}{2}+\alpha\right)V-c\,\frac{(e^{\mathrm{T}})^2}{2}\right)-\left(\beta\,\delta\,e^{\mathrm{I}}\,V-c\,\frac{(e^{\mathrm{I}})^2}{2}\right)$$
$$+\beta\,\frac{\delta}{1-\delta}\left[\left(\delta\,e^{\mathrm{T}}\,(1+\alpha)\,V-c\,\frac{(e^{\mathrm{T}})^2}{2}\right)-\left(\delta\,e^{\mathrm{I}}\,V-c\,\frac{(e^{\mathrm{I}})^2}{2}\right)\right]\geq 0. \qquad \text{(IC')}$$

Generally, a lower α helps to enforce cooperation within a team, irrespective of whether agents exhibit time-inconsistencies or not. Hence, a larger α lets potential extra benefits of a lower β diminish. As long as α is not too large, though, the performance of teams with time-inconsistent agents can still be better than of teams without inconsistencies. To see, we focus on first-best effort e^{FB} and the conditions under which it can be enforced. For e^{FB}, the (IC') constraint becomes

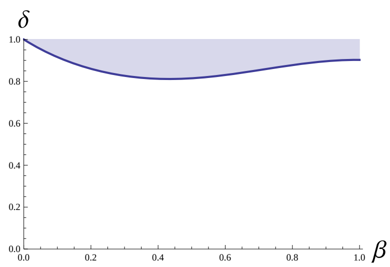
$$-(1+\alpha)^2-\beta^2+\beta\,(1+\alpha)\,(2\alpha+1)+\delta\,\left((1+\alpha)^2-\beta\,(1+\alpha)\,\alpha-\beta^2\,(1-\beta)\right)\geq 0,$$

and first-best effort is feasible for

$$\delta \geq \delta'^{FB}=\frac{(1+\alpha)^2+\beta^2-\beta\,(1+\alpha)\,(2\alpha+1)}{\left[(1+\alpha)^2-\alpha\,\beta\,(1+\alpha)-\beta^2\,(1-\beta)\right]}. \qquad (14)$$

As an example, assume that $\alpha = 0.05$, i. e. teamwork boosts total productivity by 5 % compared to indivdiual production. Then, the blue line in the following Figure 3 gives δ'^{FB} as a function of β; the shaded region gives all combinations of δ and β for which positive effort within a team can be enforced for $\alpha = 0.05$.

Figure 3: Region where the First-Best can be Attained for $\alpha = 0.05$



Hence, there exist values of δ such that first-best effort cannot be enforced when $\beta = 1$, but that this is feasible for values of β.

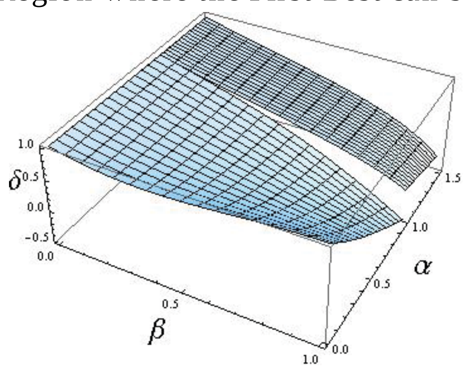
Outside Option is Teamwork. If the outside option is teamwork, i. e. if $\alpha > 1$, the (IC) constraint to enforce first-best effort becomes

$$\left(-(1+\alpha)^2-\frac{\beta^2\,(1+\alpha)}{4}\,(1+3\alpha)+\beta\,(1+\alpha)\,(2\alpha+1)\right)$$
$$+\delta\left((1+\alpha)^2+\frac{\beta^2\,(1+\alpha)}{4}\,(-3+\beta-\alpha+\beta\,\alpha)-\beta\,\alpha\,(1+\alpha)\right)\geq 0. \qquad (15)$$

Now, a higher β always improves team performance, and agents without self-control cannot perform worse than agents with self-control problems. This is driven by the difference between utilities in and out-of equilibrium already being quite large when agents choose teamwork in the stage game. Therefore, if α is large enough to render teamwork the optimal off-equilibrium choice, the additional commitment by a lower β is not needed. Then, the negative effect – driven by a larger discounting of future utilities – dominates.

Concluding, even in the presence of exogenous technological benefits of teamwork, teams of agents with self-control problems can perform better than teams of agents without – however only if α is not too large. The following Figure 4 gives δ^{FB}. The region above the curve shows all combinations of δ, β and α for which e^{FB} can be enforced, for the two cases analyzed before.

Figure 4: Region where the First-Best can be Attained



4.2 Asymmetries

Our previous analysis restricts agents to be identical. In this section, we briefly present one example of asymmetric agents, returning to the case where teamwork renders no exogenous technological benefits. We show that an agent *without* self-control problems (where in the symmetric setting teamwork is not feasible) can be part of a productive team if matched with an agent *with* self-control problems – and that such a setting can be mutually beneficial.

Consider a situation with two agents $i = \{1, 2\}$, where $\beta_1 = 1$ and $\beta_2 = \beta < 1$. We know from above that two agents without self-control problems cannot form a team. However, a team of agents 1 and 2 is potentially feasible and helps to relax the self-control problem of the latter. To see this, note that agent 1's (IC) constraint is

$$\left(\delta\, e_1^{\mathrm{T}}\, \frac{V}{2} - \frac{c\,(e_1^{\mathrm{T}})^2}{2}\right) - \frac{\delta^2\, V^2}{2\,c} + \frac{\delta}{1-\delta}\, \left[\left(\delta\, \left(e_1^{\mathrm{T}} + e_2^{\mathrm{T}}\right)\, \frac{V}{2} - \frac{c\,(e_1^{\mathrm{T}})^2}{2}\right) - \frac{\delta^2\, V^2}{2\,c}\right] \geq 0. \tag{16}$$

There, a solution is only feasible for $e_2^{\mathrm{T}} > e_1^{\mathrm{T}}$ (for $e_2^{\mathrm{T}} = e_1^{\mathrm{T}}$, the situation is the same as under symmetric matching). Hence, given a team consisting of one agent with and one without self-control problems is feasible, the one with self-control problems works harder than the one without. Therefore, the seemingly more diligent agent is actually the lazy one who only works hard in order to not lose the other one's goodwill.

Several effort-combinations e_1^{T} and e_2^{T} are potentially feasible. As a particular case, suppose we want to enforce $e_1^{\mathrm{T}} = e^{\mathrm{FB}}$. Then, agent 1's (IC) constraint becomes

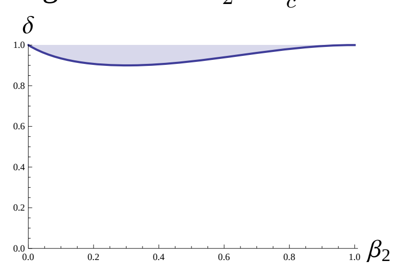
$$e_2^{\mathrm{T}} \geq \frac{V}{c} \tag{17}$$

Plugging $e_2^{\mathrm{T}} = \frac{V}{c}$ (which would maximize the joint surplus in this situation, further assuming an interior solution) – as well as $e_1^{\mathrm{T}} = e^{\mathrm{FB}}$ – into agent 2's (IC) constraint yields

$$-1 + \delta\,\left(1 + \beta_2\,\delta\,\left(\delta - \beta_2 - \beta_2\,\delta + \beta_2^2\,\delta\right)\right) \geq 0. \tag{18}$$

It can be shown that there are combinations of β_2 and δ that satisfy this condition. All these respective combinations are depicted in the following Figure 5, constituting the shaded region.

Figure 5: Region where $e_2^{\mathrm{T}} = \frac{V}{c}$ can be Attained



There, note that – given it can be enforced – such an arrangement would naturally be preferred by both agents compared to individual production (this is implied by the (IC) constraints). Agent 1 would naturally prefer such a match to one with another agent with $\beta = 1$ (where teamwork would not be feasible): he contributes first-best effort, whereas agent 2's effort is inefficiently high – hence 1's costs are the same as under individual production but the success probability is higher. He therefore receives an extra rent for serving as a commitment device for agent 2 (who would be willing to pay for a costly commitment device). Agent 2, on the other hand, would rather prefer to be matched with an agent who also has self-control problems, since then the required "mark-up" on e^{FB} would be lower.

4.3 Naive and Partially Naive Agents

The agents in our setup are sophisticated in a sense that they can perfectly anticipate their future self-control problems and hence their future behavior. In this section, we extend our model and also allow for (partially) naive agents in the sense of O'Donoghue and Rabin (2001): An agent's *actual* self control problems in every period are characterized by β. An agent's belief concerning his self-control problems in all future periods, though, is given by $\hat{\beta}$, with $\beta \leq \hat{\beta} \leq 1$. Previously, we had $\hat{\beta} = \beta$, and an agent could perfectly anticipate his behavior. A fully naive agent has $\hat{\beta} = 1$ and believes he will have no self-control problems in the future. A partially naive agent has $\hat{\beta} \in (\beta, 1)$ and is aware of having self-control problems in the future, but underestimates their degree.

To keep the analysis simple, we assume β and $\hat{\beta}$ to remain constant over time and exclude learning. Hence, although an agent's true β is the same in every period, he thinks that the value in future periods is $\hat{\beta}$. This has a direct impact on an agent's perceptions of future individual production. Although he would choose effort $e^{\mathrm{I}} = \beta\delta V/2$ in every period working on his own, he expects to work harder in the future and then choose $\hat{e}^{\mathrm{I}} = \hat{\beta}\delta V/c \geq e^{\mathrm{I}}$. Therefore, it becomes more difficult to enforce team-effort, and the (IC) constraint becomes

$$\left(\beta\,\delta\,e^{\mathrm{T}}\,\frac{V}{2} - \frac{c\,(e^{\mathrm{T}})^2}{2}\right) - \left(\beta\,\delta\,e^{\mathrm{I}}\,V - \frac{c\,(e^{\mathrm{I}})^2}{2}\right)$$
$$+\frac{\beta\,\delta}{1-\delta}\left[\left(\delta\,e^{\mathrm{T}}\,V - \frac{c\,(e^{\mathrm{T}})^2}{2}\right) - \left(\delta\,\hat{e}^{\mathrm{I}}\,V - \frac{c\,(\hat{e}^{\mathrm{I}})^2}{2}\right)\right] \geq 0. \qquad \text{(IC)}$$

Whereas the first line is unaffected by an agent's belief concerning his future self-control problems, the second line is reduced – because having to work on individual projects in the future (incorrectly) seems to be less unattractive for partially naive agents. In the extreme case of fully naive agents ($\hat{\beta} = 1$), no team-effort at all can enforced, for the same reason that made teamwork impossible for agents without self-control problems (Lemma 1): Because agents expect to exert first-best effort if working on their own in the future, they perceive a breakdown of the team to be costless.

Concluding, a higher degree of naiveté (higher $\hat{\beta}$) makes cooperation within teams harder to sustain. If a naive agent is matched with a sophisticated one, the former can benefit from his naiveté, for the same reason as an agent without self-control problems can benefit from being matched with a time-inconsistent agent (as worked out in section 5.1): Because his perceived future benefit from teamwork (the second line of the (IC) constraint) is low, he is only willing to cooperate given the other's effort is higher than his own.

5 Conclusion

We have shown that teamwork can serve as an implicit commitment device to overcome problems of procrastination and self-control. Even if teamwork renders technological benefits, the team-performance of “lazy” agents can actually be better than of agents without self-control problems.

A Appendix – Proofs

Proof of Lemma 1. Note that in this case, $e^{\mathrm{I}} = e^{\mathrm{FB}}$; the (IC) constraint becomes

$$\left(\delta\, e^{\mathrm{T}}\, \frac{V}{2} - \frac{c \cdot (e^{\mathrm{T}})^2}{2}\right) - \left(\delta\, e^{\mathrm{FB}}\, V - \frac{c\,(e^{\mathrm{FB}})^2}{2}\right)$$
$$+\frac{\delta}{1-\delta}\left[\left(\delta\, e^{\mathrm{T}}\, V - \frac{c\,(e^{\mathrm{T}})^2}{2}\right) - \left(\delta\, e^{\mathrm{FB}}\, V - \frac{c\,(e^{\mathrm{FB}})^2}{2}\right)\right] \geq 0 \tag{19}$$

Now e^{FB} maximizes $\delta e V - c\, e^2/2$, hence $\left(\delta e^{\mathrm{T}} V - c\,(e^{\mathrm{T}})^2/2\right) - \left(\delta e^{\mathrm{FB}} V - c\,(e^{\mathrm{FB}})^2/2\right) \leq 0$; furthermore, $\left(\delta\, e^{\mathrm{T}}\, \frac{V}{2} - c\,(e^{\mathrm{T}})^2/2\right) - \left(\delta\, e^{\mathrm{FB}}\, V - c\,(e^{\mathrm{FB}})^2/2\right) < 0$. Therefore, the left hand side of the (IC) constraint is strictly negative for any $e^{\mathrm{T}} \geq 0$. ■

Proof of Lemma 2. The proof is almost equivalent to that of Lemma 1: Assume that $e^{\mathrm{T}} \leq e^{\mathrm{I}}$. Because $e^{\mathrm{I}} \leq e^{\mathrm{FB}}$ and $\delta\, e\, V - \frac{c\, e^2}{2}$ is increasing for effort levels below e^{FB}, the second line of the (IC) constraint, $\left(\delta e^{\mathrm{T}} V - c\,(e^{\mathrm{T}})^2/2\right) - \left(\delta e^{\mathrm{I}} V - c\,(e^{\mathrm{I}})^2/2\right) \leq 0$ for $e^{\mathrm{T}} \leq e^{\mathrm{I}}$; because e^{I} maximizes $\beta\delta e V - c\, e^2/2$ the first line of the (IC) constraint, $\beta\, \delta\, e^{\mathrm{T}}\, \frac{V}{2} - c\,(e^{\mathrm{T}})^2/2 - \left(\beta\, \delta\, e^{\mathrm{I}}\, V - c\,(e^{\mathrm{I}})^2/2\right)$, is strictly negative. Therefore, the left hand side of the (IC) constraint is strictly negative for $e^{\mathrm{T}} \leq e^{\mathrm{I}}$. ■

Proof of Proposition 1. The second line of the (IC) constraint, $\left(\delta\, e^{\mathrm{T}}\, V - c\,(e^{\mathrm{T}})^2/2\right) - \left(\delta\, e^{\mathrm{I}}\, V - c\,(e^{\mathrm{I}})^2/2\right)$, is strictly positive for any $\beta < 1$ and $e^{\mathrm{I}} < e^{\mathrm{T}} \leq e^{\mathrm{FB}}$. Following Lemmas 1 and 2, the first line of the (IC) constraint is negative, however it is bounded. Hence, for $\delta \to 1$, the (IC) constraint is satisfied for any e^{T} with $e^{\mathrm{I}} < e^{\mathrm{T}} \leq e^{\mathrm{FB}}$. ■

Proof of Proposition 2. First, we derive the level of e^{T} that maximizes the left-hand-side of the (IC) constraint. Only if (IC) holds for this effort level, positive effort within a team can at all be enforced.

The first derivative of the left-hand-side of (IC) with respect to e^{T} is $\beta\, \delta\, \frac{V}{2} - c\, e^{\mathrm{T}} + \frac{\beta\, \delta}{1-\delta}\, \left(\delta\, V - c\, e^{\mathrm{T}}\right)$, hence the left-hand-side of (IC) is maximized for $\underline{e}^{\mathrm{T}} = \frac{\beta\, \delta\, \frac{V}{2}\, (1+\delta)}{c\,(1-\delta+\beta\, \delta)}$ (the second-order condition holds since the second derivative of the left-hand-side of (IC) with respect to e^{T} equals $-c\, \frac{1-\delta+\beta\, \delta}{1-\delta} < 0$). Plugging this value into (IC) and re-arranging gives

$$-3 + 2\, \delta + 5\, \delta^2 + 4\, \beta\, \delta^2\, (\beta - 2) \geq 0. \tag{20}$$

Solving for δ yields $\underline{\delta}$. Finally,

$$\frac{d\underline{\delta}}{d\beta} = 2\,(1-\beta)\, \frac{5 + 12\,(1-\beta)^2 - 4\sqrt{4\,(1-\beta)^2 + 2\,\beta - \beta^2}}{\sqrt{4 - 6\,\beta + 3\,\beta^2}\,(5 - 8\beta + 4\beta^2)^2}. \tag{21}$$

The sign of $d\underline{\delta}/d\beta$ is determined by the sign of its nominator, where $5+12\,(1-\beta)^2-4\sqrt{4\,(1-\beta)^2+2\,\beta-\beta^2} > 5+12\,(1-\beta)^2-4(1-\beta)\sqrt{5} \geq 5-12\beta(1-\beta) \geq 5-12\,(1/2)^2=2$, thus the nominator is positive. ■

Proof of Lemma 3. Take a symmetric equilibrium where agents maximize their stage payoffs. Then, agent 1 chooses e_1^N and e_1^{I} in order to maximize $-c\,(e_1^N+e_1^{\mathrm{I}})^2/2+\beta\,\delta\,\left(e_1^N+e_2^N\right)\,(1+\alpha)\;V/2+\beta\,\delta\,e_i^{\mathrm{I}}\,V$, subject to $e_i^N,\,e_i^{\mathrm{I}}\geq 0$. This gives first-order conditions $-c\,(e_i^N+e_i^{\mathrm{I}})+\beta\,\delta\;(1+\alpha)\;V/2\leq 0$ and $-c\,(e_i^N+e_i^{\mathrm{I}})+\beta\,\delta\,V\leq 0$. For values $a>1$, effort put into the joint project (given a symmetric equilibrium, i. e. the other puts the same amount of effort into the joint project) yields strictly higher marginal benefits than individual production, making it optimal to set $e^{\mathrm{I}}=0$. For $\alpha<1$, effort put into individual production yields strictly higher marginal benefits than individual production, making it optimal to set $e^N=0$. For $\alpha=1$, agents are indifferent, and we can assume without loss that individual production is selected in that case. ■

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