Overcoming Overconfidence: Teamwork and Self-Control

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December 18, 2015

Abstract: This paper analyzes interactions between agents who are overconfident regarding their own future self-control relative to others. The paper considers the problem of incentivizing several such agents, and compares two methods: assigning work individually to each agent or jointly to pairs of agents. If the agents are homogenous in their preferences and beliefs, then the joint assignment method dominates individual assignments. In the case of heterogenous agents, the effects of the joint assignment are twofold: teamwork mitigates the efficiency loss from overconfidence, but introduces inefficiency by disincentivising the more patient members of the team. The results in the paper suggest that team-based incentives are more effective when employees are relatively overconfident and when teams are formed based on similarity in present-bias and beliefs.

Keywords: behavioral economics, incentives, teamwork, overconfidence

JEL classification: C70, D03, J41

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1 Introduction

This paper analyzes interactions between present-biased agents, and considers how present-bias, naïveté, and awareness of the present-bias of others affect optimal task design. Addressing the problem of incentivizing two present-biased agents either individually or jointly, the paper highlights one channel through which team-based assignments can increase efficiency: fear of their teammates' future procrastination makes both agents more willing to complete the joint work early on. When partially naïve present-biased agents face individual tasks, imperfect awareness of their future present-bias leads them to postpone the work early on, overestimating the likelihood of completion in later periods. When working in a team, however, expectations of each other's future present-bias make the agents reluctant to postpone, curbing their procrastination. The strength of this effect increases in the degree of the agents' present-bias, their overconfidence regarding their own present-bias relative to others, and the similarity in the agents' preferences and beliefs. The results of this paper suggest that optimal team formation involves assortative matching based on present-bias and overconfidence.

The paper features a two-period model with stochastic effort costs, where the principal has two indivisible tasks to assign to two agents to be completed over the two periods. I consider the profit-maximization problem of a principal who has the following tools at her disposal: the monetary reward for successful task completion and the assignment method, which can be either individual or joint. Under the individual task assignment, each agent decides in which period to complete his task. Under the joint task assignment, the two agents must complete their tasks in the same period. The agents have present-biased preferences modeled in a long tradition of research on time-inconsistency (see Laibson (1997) and O'Donoghue and Rabin (1999a), among others). Following a growing body of empirical and experimental evidence,[1] the present paper assumes that the agents are not fully aware of the extent of their own present-bias. Furthermore, following the experimental evidence in Fedyk (2015), I model the agents as holding more critical beliefs about the present-bias of others than of their own present-bias. The resulting wedge in beliefs regarding own and others' present-bias is a form of relative overconfidence, analogous to the patterns of overconfident beliefs documented in other aspects of everyday life.[2]

The model in the paper does not impose any further structure on beliefs or the process

[1]See Ariely and Wertenbroch (2002), DellaVigna and Malmendier (2006), Skiba and Tobacman (2009), Acland and Levy (2015), and Augenblick and Rabin (2015).

[2]For example, Svenson (1981) provides evidence of relative overconfidence about driving abilities, while Weinstein (1980) documents overconfidence and overoptimism regarding a host of potential life events, and Alicke (1985) documents that subjects deem positive (negative) adjectives to be more (less) characteristic of themselves than of their average peer.

of their formation, relying only on the wedge in beliefs driven by the relatively more optimistic perception of self versus other. The present paper also circumvents the limitedly understood issue of biased agents' higher-order beliefs by focusing on a particular form of teamwork (where the two agents perform their portions of work simultaneously, and each can costlessly convey his willingness to work to the other) and adopting a weakly dominant strategy equilibrium concept.

For two homogenous agents, present-bias and relative overconfidence create an intuitive benefit to team-based assignments, even in the absence of repeated interactions or reputation concerns. Under the individual task assignment, overconfidence leads individual agents to overestimate the likelihood with which they will complete their tasks in the second period. This increases the perceived option value form postponing, and makes the agents less willing to complete the tasks in the first period. Under the joint assignment method, agents must both agree to complete their individual tasks simultaneously either in the first or in the second period. Each agent anticipates his teammate's future procrastination, so that the option value from postponing in the first period declines, and it becomes individually rational to complete the work in the first period for a larger space of potential task-cost realizations. The weakly dominant strategy equilibrium among two equally present-biased peers then features a higher likelihood of task completion under the joint assignment than under the individual assignment, for any monetary reward.

The unconditionality of the benefits of teamwork breaks down, however, when teams consist of agents with sufficiently diverse self-control problems. Intuitively, it is the agent with the most severe self-control problem that ultimately determines whether or not the work is completed. In the case of heterogenous agents, teamwork has two effects: the curbing of overconfidence expands the space of first-period cost realizations for which the work is completed, but the spread of present-bias parameters shrinks the completion range of cost realizations for both periods. The former effect dominates when heterogeneity is relatively small, but the latter dominates when the agents' present-bias parameters are sufficiently different. The effects of agent heterogeneity on efficacy of the joint assignment method can be formalized by the notion that the production function under the joint assignment is supermodular in both, the agents' present-bias parameters and their relative overconfidence. As a result, the joint assignment delivers maximal profits when agents are paired with their most similar peers based on present-bias and beliefs.

This paper builds on the growing literature on time-inconsistent preferences, by providing a parsimonious model of interactions between present-biased agents working on a joint assignment and the effects such teamwork might have on their productivity. Most prior studies of present-bias have restricted their attention to behavioral agents in isolation.[3] Those models that do consider the effects of present-bias on strategic interactions typically focus on behaviorally biased agents and rational principals.[4] Models such as O'Donoghue and Rabin (1999b) and DellaVigna and Paserman (2005) investigate the effects of individual workers' present-bias in the labor markets, but ignore the effects of the interactions of several present-biased agents within a single workplace.

The conclusions of this paper point to present-bias coupled with relatively overconfident beliefs as one driver for effectiveness of joint work assignments. Existing models of advantages of joint or transferable control, such as Aghion, Dewatripont, and Rey (2002), focus on reputation-based mechanisms. The present model highlights that if the agents are present-biased and overconfident, then collaboration between them may be desirable even in absence of repeated interactions and reputation concerns. The paper also contributes to the teamwork and task design literature (see Hackman, Brousseau, and Weiss (1976), Holmstrom (1982), Holmstrom and Milgrom (1991), and Hollenbeck, DeRue, and Guzzo (2004), among others), with testable predictions regarding when the joint assignment is most likely to dominate the individual assignment method: when the employees are similar, when the employees are relatively overconfident, and when the teams are formed based on similarity in present-bias and beliefs.

The rest of the paper proceeds as follows. Section 2 outlines the model. Section 3 presents the results for the case of homogenous agents. Section 4 extends the results to the case of workers with heterogenous present-bias parameters, weighing the advantages of the joint assignment in mitigating the adverse effects of individual overconfidence against the disadvantages that come from diverse present-bias. These effects are illustrated with simulations. Section 5 concludes.

2 Model

Let us consider a setting with a firm assigning tasks to employees, either individually or in groups. The tasks must be completed within a preset length of time, but the employees are free to decide when exactly they will complete the tasks. This setup mirrors situations such as students dividing the work for a joint class assignment, co-authors splitting the writing of a book, or consultants performing parts of a joint project. Each member of the team has

[3] See, for example: Kirby and Herrnstein (1995), O'Donoghue and Rabin (1999a), Gul and Pesendorfer (2001), DellaVigna and Paserman (2005), Ashraf, Karlan, and Yin (2006), Houser, Schunk, Winter and Xiao (2010), Augenblick, Niederle, and Sprenger (2015).

[4] See Della Vigna and Malmendier (2004), Gottlieb (2008), Heidhues and Koszegi (2010), Herweg and Müller (2011), among others.

a clearly delineated portion of work to perform, and can be assigned to complete his task either individually or in conjunction with his teammate.

2.1 *Model Setup*

Consider a two-period model, where an employer has two employees and two indivisible tasks to assign them. The employer derives a benefit B from the completion of each task. She can assign at most one task to each employee, and has two tools at her disposal:

- The monetary incentive, as captured by the reward R;
- The method of the task assignment: individual (I) or joint (J).

Under the individual assignment, each of the two agents is assigned one task and receives the reward R conditional on task completion. The joint assignment assigns two tasks to two agents, and pays R to each upon successful completion of the entirety of the assignment.

The cost of performing each task in each period, incurred by the workers and capturing any disutility they may experience from task completion, is stochastic, and differs from period to period. A natural interpretation of this is that the workers cannot fully anticipate each period's conditions (economic, weather, etc.), the amount of other work they might be required to complete in a given period, or a number of other potential complications. For simplicity, I assume that within each period t, all workers face the same cost c_t.[5] The stochastic cost in each period t is drawn from an absolutely continuous distribution with full support on an interval $C_t \subset \mathbb{R}_+$ and cumulative distribution function $F_t(\cdot)$ (with associated density function $f_t(\cdot)$). The distributions are common knowledge.

The timing of the model, displayed graphically in Figure 1, is as follows.

- **Period 0:** The employer chooses the incentive contract, which consists of the assignment method (I or J) and the monetary incentive R.
- **Period 1**: The workers observe the first period cost c_1, and decide (individually or in a team, depending on the assignment method) whether to complete the assigned work. Each employee incurs an immediate disutility of c_1 if he (or his team) chooses to complete the work in this period.

[5]Section 4 introduces agent heterogeneity in the form of differing present-bias parameters. Heterogeneity in the form of idiosyncratic task completion costs would deliver similar insights, and would not further enlighten the analysis. For ease of exposition, I adhere to common costs throughout the paper, and provide a brief analysis of the case with heterogenous task completion costs in Appendix B.

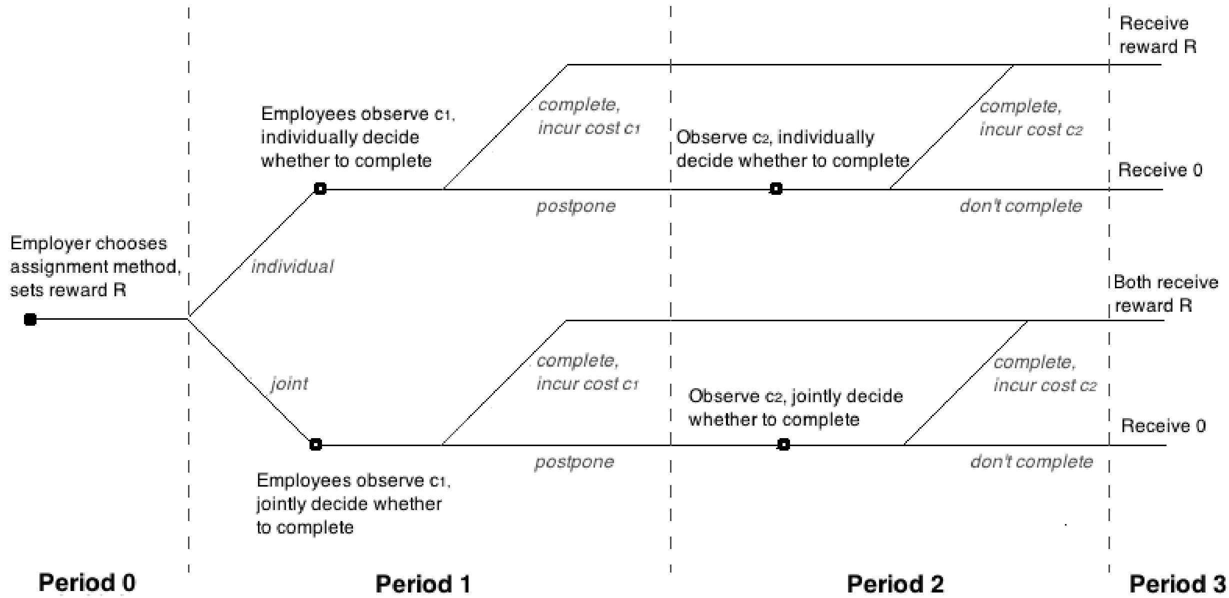

Figure 1: Model Timeline.

- **Period 2**: The workers observe the second period cost c_2. If they have not already completed the work in period 1, then they have the option of completing it now, incurring the disutility of c_2 in period 2.

- **Period 3**: The employees are compensated. If a worker had been assigned an individual task, he receives the reward R if and only if he has completed the assignment. If a group of workers had been assigned joint work, each agent in the group receives R if and only if the entirety of the assignment has been completed.

Note that the reward R is received in the last period if the agents complete the work, regardless of when they complete it. This is consistent with setups in both theoretical and experimental literature (see O'Donoghue and Rabin (1999b), Kaur, Kremer, and Mullainathan (2010), Augenblick, Niederle, and Sprenger (2015)), and reflects key features of many real-life work settings, where a salary or performance bonus is paid at a predetermined date, regardless of when the employees choose to complete the assignment.

The model assumes that there are no complementarities in task completion; the joint assignment is modeled as a literal combination of individual assignments. The present paper aims to highlight one particular channel that may make team-based assignments useful: the indirect cross-motivation created by the wedge in beliefs due to individual overconfidence. To the extent that there are other task complementarities involved, teamwork would be even more effective. The present model, however, abstracts away from those other potentially beneficial effects of team incentives. The only sense in which the joint assignment is indeed a team assignment is that the employees are required to complete their tasks in the same period, and are paid only if both of them complete the assignment. These restrictions along with the equilibrium concept I use (weakly dominant strategy perception-perfect equilibrium) are designed to circumvent the issue of the agents' higher-order beliefs. There is, at present, a dearth of work on biased agents' higher-order beliefs,[6] and understanding of how those beliefs are formed and updated is limited. Since the extension of the model to other paradigms of joint assignments requires further assumptions on the agents' higher order beliefs, it will be left to future work.

Let Π denote the employer's profit. Then her profit-maximization problem is given by:

$$\max_{R,\ \text{method} \in \{I, J\}} \Pi(R, \text{method}) = \max_{R,\ \text{method}} (B - R)\mathbb{E}\{\#\ \text{completed tasks}\ \mid R,\ \text{method}\} \quad (2.1)$$

where the expected number of completed tasks is consistent with optimizing behavior on the employees' part. I take each employee's reservation utility to be 0, so that the participation constraints are satisfied since each agent can attain a utility of 0, regardless of R and the assignment method, by not completing his task.

Solving the employer's problem requires a characterization of how the interaction between the two agents under the joint assignment affects their willingness to compete their tasks. This is the primary focus of the present paper.

2.2 *Preferences and Beliefs*

Before proceeding to analyze the employees' behavior under the two assignment schemes, I first define their preferences and beliefs.

Employees have time-inconsistent preferences, expressed following the standard model in the literature (see Phelps and Pollak (1968); Laibson (1997); O'Donoghue and Rabin (1999a)). Namely, in addition to the time-consistent discount factor $\delta \in (0, 1]$, each employee i in period t is subject to what I term the "present-bias parameter" $\beta_t^{(i)} \in (0, 1]$. So in any period t, employee i's intertemporal preference is:

$$U_t = u_t + \beta_t^{(i)} \sum_{s=t+1}^{\infty} \delta^{(s-t)} u_s \quad (2.2)$$

where u_t is the immediate per-period utility in period t, and U_t is the overall utility at time t.

[6]One exception is Danz, Madarasz, and Wang (2014), who investigate higher order beliefs in the context of information projection.

Consistent with the literature, the present paper models the present-bias parameter $\beta_t^{(i)}$ as time-invariant. For each employee i, $\beta_t^{(i)} = \beta_s^{(i)} = \beta^{(i)}$ for any two periods t and s. However, the employees may underestimate the extent of their own future time-inconsistency.

Following O'Donoghue and Rabin (2001), the partial naïveté of an employee regarding his future present-bias is modeled as follows. In any given period, employee i is subject to the present-bias parameter $\beta^{(i)}$, but mispredicts his future present-bias to be $\hat{\beta}^{(i,i)} \in (\beta^{(i)}, 1]$. Formally, this can be summarized in the following definition:

Definition 1. (Partial Naïveté):

Employee i is **partially naïve** *about his future self-control if in each period t, he overestimates his future present-bias parameter $\beta_s^{(i)}$: $\forall s > t, i$ believes that $\beta_s^{(i)} = \hat{\beta}^{(i,i)} > \beta^{(i)}$ almost surely.*

Partial naïveté regarding future present-bias has received extensive support from empirical studies focusing on time-inconsistent preferences and behaviors. For example, DellaVigna and Malmendier (2006) document that customers of U.S. health clubs overestimate their future attendance, while Acland and Levy (2015) find partial naïveté in an experimental investigation of gym attendance. Augenblick and Rabin (2015) document present-bias and naïveté in the context of real effort tasks.

Partial naïveté regarding one's future self-control problems is often attributed to overconfidence (see, for example, DellaVigna and Malmendier (2004, 2006)). Moreover, the ongoing experimental investigation in Fedyk (2015) suggests that subjects engaging in a real effort task tend to be more aware of the time-inconsistency in other subjects' preferences than in their own. This type of relative overconfidence receives theoretical support from the motivation theory of overconfidence (see Bénabou and Tirole (2002)), since motivational benefits of optimism are much stronger for beliefs about self than for beliefs regarding others.

Let $\hat{\beta}^{(i,j)}$ denote agent i's beliefs regarding agent j's present-bias. This paper captures the idea of relative overconfidence with the following structure of agents' first-order beliefs about each other:

Definition 2. (Relative Overconfidence):

Employee i with beliefs $\hat{\beta}^{(i,i)}$ about his own present-bias parameter is **relatively overconfident** *if $\forall s \geq t, j \neq i, i$ believes that $\beta_s^{(j)} = \hat{\beta}^{(i,j)} < \hat{\beta}^{(i,i)}$ almost surely.*[7]

Note that Definition 1 considers an individual who is overconfident in an absolute sense, believing himself to be better than he actually is. Definition 2, on the other hand, posits

[7] In most of the analysis below, I implicitly make a further conservative assumption that $\hat{\beta}^{(i,j)} \geq \beta^{(i)}$, so that beliefs about others are not unduly harsh. All results are qualitatively unchanged for $\hat{\beta}^{(i,j)} < \beta^{(i)}$, and, in fact, the modeled benefits of teamwork are strengthened in this case.

relative overconfidence: the agent believes himself to be better than others. Throughout the present paper, an employee's overconfidence is taken to be a combination of these two effects. It is the inefficiency arising from this form of absolute-and-relative overconfidence that team-based assignments can mitigate.

3 Teamwork among Homogenous Agents

This section considers homogenous workers; i.e., all employees have identical present-bias parameters β. It is also assumed that the degree of overconfidence in the workers' beliefs $\hat{\beta}^{(i,i)}$ and $\hat{\beta}^{(i,j)}$ is likewise homogenous.

Formally, consider the following assumption:

Assumption 1. (Employee homogeneity):

For any two workers i and j:

$$\beta^{(i)} = \beta^{(j)} = \beta, \hat{\beta}^{(i,i)} = \hat{\beta}^{(j,j)} = \hat{\beta}^{(s)} \text{ and } \hat{\beta}^{(i,j)} = \hat{\beta}^{(j,i)} = \hat{\beta}^{(o)}$$

Throughout this section, $\hat{\beta}^{(s)}$ denotes beliefs regarding oneself, and $\hat{\beta}^{(o)}$ captures beliefs about others. Recall that, by Definition 2, $\hat{\beta}^{(o)} < \hat{\beta}^{(s)}$; i.e., the employees have more critical beliefs regarding the present-bias of others than their own present-bias, due to overconfidence.

Let us now compare the likelihoods with which the agents complete the assigned tasks under the individual and joint assignment methods.

3.1 *Individual Assignment*

Suppose that the employer has chosen the individual method of assignment, and set the completion reward at R.

Consider a worker who has been assigned an individual task to complete in either period 1 or period 2, and who anticipates a reward of R in period 3 in the event of successful completion of the task. In the computations that follow, I introduce the following notation and make use of the following technical condition, which ensures non-degeneracy of results.

Notation 1. *Let* $H(\beta, \hat{\beta}) = \beta\delta^2 R - \beta\delta \int_0^{\hat{\beta}\delta R} (-c_2 + \delta R) f_2(c_2) dc_2$.

Condition 1. *The monetary incentive R is set such that* $F_1(H(\beta, \hat{\beta}^{(s)})), F_2(\beta\delta R) \in (0, 1)$.

Condition 1 states that the monetary incentive R is set in such a way that there is some nonzero but also not certain chance that the employee is willing to perform the task in either period under the individual assignment. It does not materially affect any of the results, except to ensure that task completion regions are non-degenerate.

The game form is straightforward: in each period t, the worker observes the cost realization c_t, and decides whether to complete the task, if such is still outstanding. Formally, the game G_I of individual task assignment can be represented as follows:

- A single player has the strategy space $S = \mathcal{S}_1 \times \mathcal{S}_2$, where $\mathcal{S}_t$ (with $t \in \{1, 2\}$) denotes the set of all Lebesgue-measurable subsets of C_t. Then $(\sigma_1, \sigma_2) \in S$ corresponds to completing the task in period 1 if and only if $c_1 \in \sigma_1$ and completing it in period 2 if and only if $c_1 \notin \sigma_1$ and $c_2 \in \sigma_2$.

- Due to partial naïveté, the agent may mispredict his own future behavior. Let $\hat{\sigma}_2 \in \mathcal{S}_2$ denote the agent's belief, in period 1, regarding the strategy he will follow in period 2. If $\hat{\sigma}_2 \neq \sigma_2$, then the agent holds incorrect beliefs in period 1 regarding his period 2 strategy. Let $\sigma = (\sigma_1, \sigma_2; \hat{\sigma}_2)$ denote the agent's actual strategy augmented with period 1 beliefs regarding period 2 behavior.

- The payoff function P denotes the stream of the agent's per period utility, and depends on the agent's strategy profile σ and the cost realizations (c_1, c_2). Letting (u_1, u_2, u_3) denote the agent's payoffs in periods 1, 2, and 3, respectively, we have:

$$P(\sigma; c_1, c_2) = \begin{cases} (-c_1, 0, R) & \text{if } c_1 \in \sigma_1 \\ (0, -c_2, R) & \text{if } c_1 \notin \sigma_1 \text{ and } c_2 \in \sigma_2 \\ (0, 0, 0) & \text{otherwise} \end{cases}$$

The equilibrium concept used throughout the paper is that of perception-perfect equilibrium (PPE), as introduced by O'Donoghue and Rabin (1999a). A perception-perfect equilibrium is an extension of the subgame-perfect equilibrium concept to the case of erroneous beliefs. In each period, the agent is able to perform backward induction and optimize across the currently available options, but bases his backward induction procedure on incorrect beliefs regarding his future preferences. The following proposition characterizes the unique (up to sets of measure zero)[8] PPE $s = (s_1, s_2; \hat{s}_2)$ of G_I.

Proposition 1. *For any monetary reward R satisfying Condition 1, the unique Perception-Perfect Equilibrium of G_I is given by:*

$$s_1 = [0, H(\beta, \hat{\beta}^{(s)})] = [0, \beta\delta^2 R - \beta\delta \int_0^{\hat{\beta}^{(s)}\delta R} (-c_2 + \delta R) f_2(c_2) dc_2]$$

[8]Throughout the paper, uniqueness of equilibria is established up to sets of measure zero.

$$s_2 = [0, \beta\delta R]$$

$$\hat{s}_2 = [0, \hat{\beta}^{(s)}\delta R]$$

Proof. See Appendix A. □

Note that for every reward R, the space of task-cost realizations for which the task is successfully completed in each period increases in β. Furthermore, the likelihood of task completion in the first period decreases in $\hat{\beta}^{(s)}$. Hence, the principal's profit, as given by (2.1), decreases from the introduction of both present-bias and partial naïveté. The following result characterizes this efficiency loss from the employer's perspective in terms of likelihood of task completion, holding fixed the monetary incentive R.

Result 1. (Efficiency with Individual Tasks):

Suppose the principal chooses the individual task assignment method, and sets any monetary incentive R satisfying Condition 1.

1. *Efficiency loss due to present-bias (relative to exponential discounters):*

   Agents afflicted with present-bias end up failing to complete the task in the first period if $c_1 \in (H(\beta, \beta), H(1, 1)]$. In the second period, they fail to complete the task if $c_2 \in (\beta\delta R, \delta R]$.

2. *Efficiency loss due to overconfidence about future present-bias (relative to fully sophisticated present-biased agents):*

   Partial naïveté causes the employees to fail to complete the task in the first period if $c_1 \in (H(\beta, \hat{\beta}^{(s)}), H(\beta, \beta)]$.

Figure 2 presents a graphical representation of the two forms of efficiency loss in the case of individually-assigned tasks.

3.2 *Joint Assignment*

Consider the case of the employer choosing the joint assignment method with monetary incentive R for two workers with identical discounting parameters (β, δ), beliefs regarding their own future self-control $\hat{\beta}^{(s)}$, and beliefs regarding others given by $\hat{\beta}^{(o)}$. The two employees must jointly decide whether to complete their two tasks in period 1 or in period 2, with each employee incurring the cost c_1 or c_2, respectively. If the entirety of the assignment is successfully completed, then each employee receives the reward R.

The game G_J of joint task assignment is the two-player extension of G_I. Each player's strategy profile $\sigma^{(i)} = (\sigma_1^{(i)}, \sigma_2^{(i)}; \hat{\sigma}_2^{(i,i)}, \hat{\sigma}_2^{(i,j)})$ consists of his first- and second-period actions

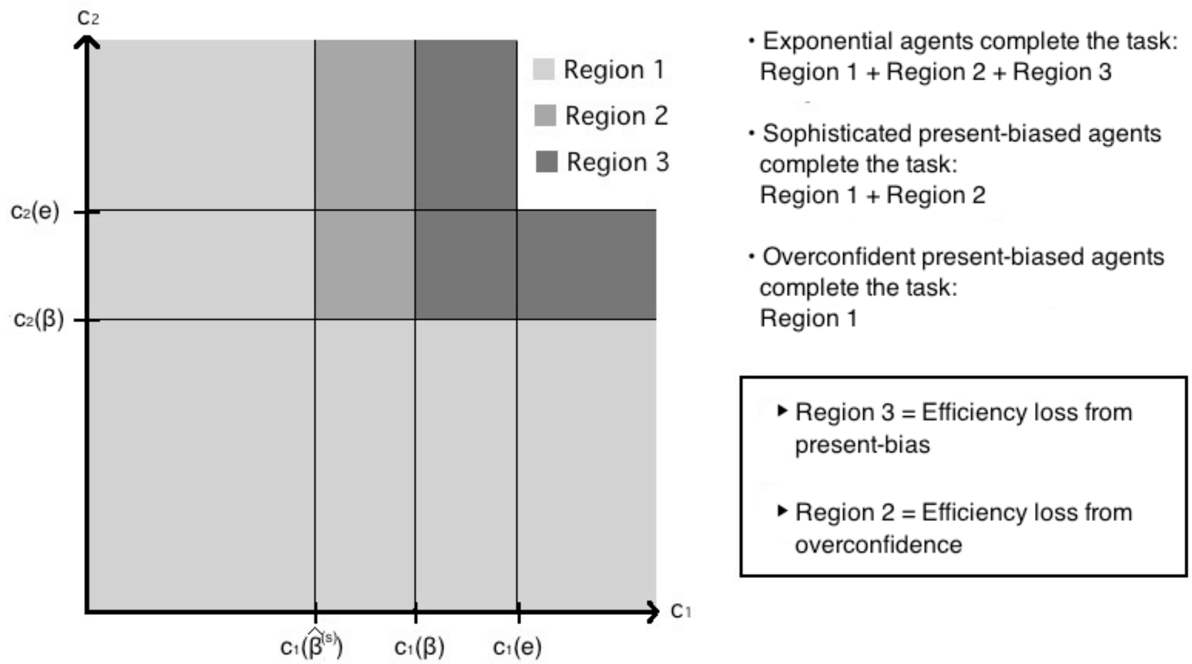

Figure 2: Efficiency loss from present-bias and partial naïveté when an employee is assigned an individual task. Realizations of the first-period task-cost c_1 are marked on the x-axis; second-period task-costs c_2 are on the y-axis. Note that $c_t(e)$ denotes the threshold for the cost realization in period t below which an exponential discounter would be willing to perform the task immediately in period t. Similarly, $c_t(\beta)$ is the cost realization threshold below which a sophisticated present-biased agent would be willing to perform the task in period t. And $c_1(\hat{\beta}^{(s)})$ is the highest cost-realization for which a partially naïve present-biased employee would be willing to complete the task in the first period.

$(\sigma_1^{(i)}, \sigma_2^{(i)})$ and his expectations of his own and the other agent's second-period actions $(\hat{\sigma}_2^{(i,i)}, \hat{\sigma}_2^{(i,j)})$. The payoff function P now depends on both agents' strategy profiles:

$$P(\sigma^{(1)}, \sigma^{(2)}; c_1, c_2) = \begin{cases} (-c_1, 0, R) & \text{if } c_1 \in \sigma_1^{(1)} \cap \sigma_1^{(2)} \\ (0, -c_2, R) & \text{if } c_1 \notin \sigma_1^{(1)} \cap \sigma_1^{(2)} \text{ and } c_2 \in \sigma_2^{(1)} \cap \sigma_2^{(2)} \\ (0,0,0) & \text{otherwise} \end{cases} \tag{3.1}$$

Note that, since the work has to be completed by both agents during the same period, completion occurs at t if and only if both agents are willing to complete the work at that time. If one agent is willing and the other is not – nothing happens. The form of G_J above is agnostic regarding the particular method of communication used by the agents to convey their willingness to work on the assignment. The communication can be taken to be a simultaneous exchange of messages such that joint production occurs only if both agents send a positive message: for example, the message can be turning up to work, coming to a meeting, or bringing materials necessary for the assignment. This follows Hart and Moore (1988), where trade between a buyer and a seller occurs if and only if both parties turn a switch “on”, and neither party can be punished for causing the lack of action. This setup – where two parties each costlessly signal their willingness to cooperate, and cooperation occurs only if both signal positively – is analogous to the business unit coordination decision modeled by Hart and Holmstrom (2010).

Depending on the particular structure of the team, communication can also be more sequential. For example, one of the agents might be designated as a team leader who proposes whether to complete the work in each period, and the other agent can either accept or reject the proposal. Task completion then occurs if the team leader suggests to complete the work and the other agent accepts. In such a case, the game becomes entirely sequential. In the more general setup allowing for simultaneous-move decisions that may result in multiple perception-perfect equilibria, I solve G_J using the Weakly Dominant Strategy PPE concept defined as follows.

Consider two agents 1 and 2 with present-bias parameters $\beta^{(1)}$ and $\beta^{(2)}$, and beliefs $\{\hat{\beta}^{(1,1)}, \hat{\beta}^{(1,2)}\}$ and $\{\hat{\beta}^{(2,2)}, \hat{\beta}^{(2,1)}\}$. Let $\mathbb{E}\{U_2^{(i)}(\sigma_2^{(i)}, \sigma_2^{(j)} \,|\, \beta^{(i)})\}$ denote agent i's expected utility at $t = 2$ from following strategy $\sigma_2^{(i)} \in \mathcal{S}_2$, given that player $j \neq i$ follows $\sigma_2^{(j)}$. Similarly, let $\mathbb{E}\{U_1^{(i)}(\sigma_1^{(i)}, \sigma_1^{(j)} \mid \beta^{(i)}; \hat{\sigma}_2^{(i,i)}, \hat{\sigma}_2^{(i,j)})\}$ be agent i's expected utility at $t = 1$ from following strategy $\sigma_1^{(i)} \in \mathcal{S}_1$ when $j \neq i$ follows $\sigma_1^{(j)}$ and i believes that the strategies to be played at $t = 2$ are $(\hat{\sigma}_2^{(i,i)}, \hat{\sigma}_2^{(i,j)})$.

Definition 3. (Weakly Dominant Strategy Perception-Perfect Equilibrium of G_J):

A pair of strategy-belief profiles $s^{(1)} = (s_1^{(1)}, s_2^{(1)}; \hat{s}_2^{(1,1)}, \hat{s}_2^{(1,2)})$ *and* $s^{(2)} = (s_1^{(2)}, s_2^{(2)}; \hat{s}_2^{(2,2)}, \hat{s}_2^{(2,1)})$ *forms a* **Weakly Dominant Strategy Perception-Perfect Equilibrium (WDSPPE)** *of* G_J *if and only if:*

1. *For each player* i, $s_2^{(i)}$ *is a weakly dominant strategy in the second-period subgame:*

$$\forall i, j \neq i, \nexists \sigma_2^{(i)}, \sigma_2^{(j)} \in \mathcal{S}_2 \ s.t. \ \mathbb{E}\{U_2^{(i)}(\sigma_2^{(i)}, \sigma_2^{(j)} \mid \beta^{(i)})\} > \mathbb{E}\{U_2^{(i)}(s_2^{(i)}, \sigma_2^{(j)}) \mid \beta^{(i)})\}$$

2. *For each player* i, $\hat{s}^{(i,i)}$ *and* $\hat{s}^{(i,j)}$ *are weakly dominant strategies for players* i *and* j*, respectively, in the perceived second-period subgame according to player* i*'s beliefs* $(\hat{\beta}^{(i,i)}, \hat{\beta}^{(i,j)})$*:*

   (a) $\forall i, j \neq i, \nexists \sigma_2^{(i)}, \sigma_2^{(j)} \in \mathcal{S}_2 \ s.t. \ \mathbb{E}\{U_2^{(i)}(\sigma_2^{(i)}, \sigma_2^{(j)} \mid \hat{\beta}^{(i,i)})\} > \mathbb{E}\{U_2^{(i)}(\hat{s}_2^{(i,i)}, \sigma_2^{(j)} \mid \hat{\beta}^{(i,i)})\}$

   (b) $\forall i, j \neq i, \nexists \sigma_2^{(i)}, \sigma_2^{(j)} \in \mathcal{S}_2 \ s.t. \ \mathbb{E}\{U_2^{(j)}(\sigma_2^{(j)}, \sigma_2^{(i)} \mid \hat{\beta}^{(i,j)})\} > \mathbb{E}\{U_2^{(j)}(\hat{s}_2^{(i,j)}, \sigma_2^{(i)} \mid \hat{\beta}^{(i,j)})\}$

3. *For each player i,* $s_1^{(i)}$ *is a weakly dominant strategy in the first period, given player i's expectations regarding second period play,* $(\hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)})$*:*

$$\forall i, j \neq i, \nexists \sigma_1^{(i)}, \sigma_1^{(j)} \in \mathcal{S}_1 \text{ s.t. } \mathbb{E}\{U_1^{(i)}(\sigma_1^{(i)}, \sigma_1^{(j)} | \beta^{(i)}; \hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)})\} > \mathbb{E}\{U_1^{(i)}(s_1^{(i)}, \sigma_1^{(j)} | \beta^{(i)}; \hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)})\}$$

The perception-perfection restriction is a generalization of the single-agent perception-perfect equilibrium, and serves to exclude non-credible threats of second period behavior. The restriction is implemented in weakly dominant strategies. Point 1 ensures that the agents play out a weakly dominant strategy equilibrium once the second period arrives. Point 2(a) states that at $t = 1$, each agent expects himself to play a weakly dominant strategy at $t = 2$, under his erroneous beliefs regarding his future present-bias. Similarly, 2(b) states that each agent expects the other to play a weakly dominant strategy at $t = 2$, under the mistaken beliefs regarding the other's present-bias. Point 3 specifies that, given their beliefs regarding second period behavior, the agents play weakly dominant strategies in period 1.

I adopt the weakly dominant strategy approach for several reasons. First, coupled with restrictions on the game form discussed above, it provides a way to circumvent the limitedly understood issue of higher-order beliefs. Second, a single round of calculation of weakly dominant strategies does not require coordination among agents, and thus offers an easily accessible solution concept. Given that the considered agents not only have biased (time-inconsistent) preferences, but are also imperfectly aware, it is intuitive to adopt an equilibrium concept that requires only a relatively weak form of individual rationality. Lastly, under any incentive scheme satisfying Condition 1, the proposed equilibrium concept rules out unintuitive equilibria such as $s_1^{(1)} = s_1^{(2)} = s_2^{(1)} = s_2^{(2)} = \emptyset$.

Solving for the WDSPPE of G_J yields the following result.

Proposition 2. *For homogenous employees and any monetary incentive R satisfying Condition 1, the unique Weakly Dominant Strategy Perception-Perfect Equilibrium of G_J is given by:*

$$\forall i \in \{1, 2\} : s_1^{(i)} = [0, H(\beta, \hat{\beta}^{(o)})] \tag{3.2}$$

$$\forall i \in \{1, 2\} : s_2^{(i)} = [0, \beta\delta R]$$

$$\forall i \in \{1, 2\}, j \neq i : \hat{s}_2^{(i,i)} = [0, \hat{\beta}^{(s)}\delta R] \text{ and } \hat{s}_2^{(i,j)} = [0, \hat{\beta}^{(o)}\delta R]$$

Proof. See Appendix A. □

Thus, if the principal sets the monetary incentive at R and chooses the joint assignment method, the overall space of cost realization pairs (c_1, c_2) for which the two workers successfully complete the work is:

$$(c_1, c_2) \in ([0, H(\beta, \hat{\beta}^{(o)})], C_2) \cup (C_1, \beta\delta^2 R])$$

Note that, for $\hat{\beta}^{(o)} \in (\beta, \hat{\beta}^{(s)})$, this result is between the case of an individual overconfident agent (replacing $\hat{\beta}^{(o)}$ with $\hat{\beta}^{(s)}$) and the case of an individual sophisticated agent (with $\hat{\beta}^{(o)}$ replaced with β). Thus, while assigning the two tasks to two identical employees at once does not help mitigate the negative effects of their present-bias, it does diminish the additional efficiency loss arising from individual overconfidence. If the workers believe their own future present-bias to be less severe than the present-bias of others, then for any incentive R that satisfies Condition 1, the joint assignment yields a nontrivial gain in the likelihood of task completion in the first period.

This is summarized in Result 2 below, and visually displayed in Figure 3.

Result 2. (Efficiency with Joint Tasks for Homogenous Workers):

Suppose that the principal chooses the joint assignment method, and sets a monetary incentive R satisfying Condition 1.

1. *Efficiency loss due to present-bias (relative to exponential discounters):*

   This efficiency loss is the same as under the individual task assignment method.

2. *Efficiency effects of imperfect awareness (relative to fully sophisticated present-biased agents):*

   In the case of joint tasks assigned to homogenous workers, the efficiency loss due to overconfidence in the first period is replaced by efficiency loss due to erroneous beliefs regarding each other, which is strictly smaller (and potentially negative).

3. *Efficiency gain from joint assignment method (relative to individual assignment method):*

   The efficiency gain from the joint assignment comes from both agents being willing to complete their tasks for additional first-period task-cost realizations $c_1 \in (H(\beta, \hat{\beta}^{(s)}), H(\beta, \hat{\beta}^{(o)})]$.

The intuition behind Result 2 is quite simple. Overconfident workers are less likely to complete individually-assigned tasks, since they are prone to postponing to the last moment, overestimating the probability that they will complete the tasks at that later time. However, such overconfidence poses less of a problem for identical employees working in teams. While they still overestimate their own propensity to complete the work at the later time, they are more critical of their teammates, and therefore understand that postponing early on might result in the work never getting completed. This makes both agents more willing to complete the joint assignment early on.

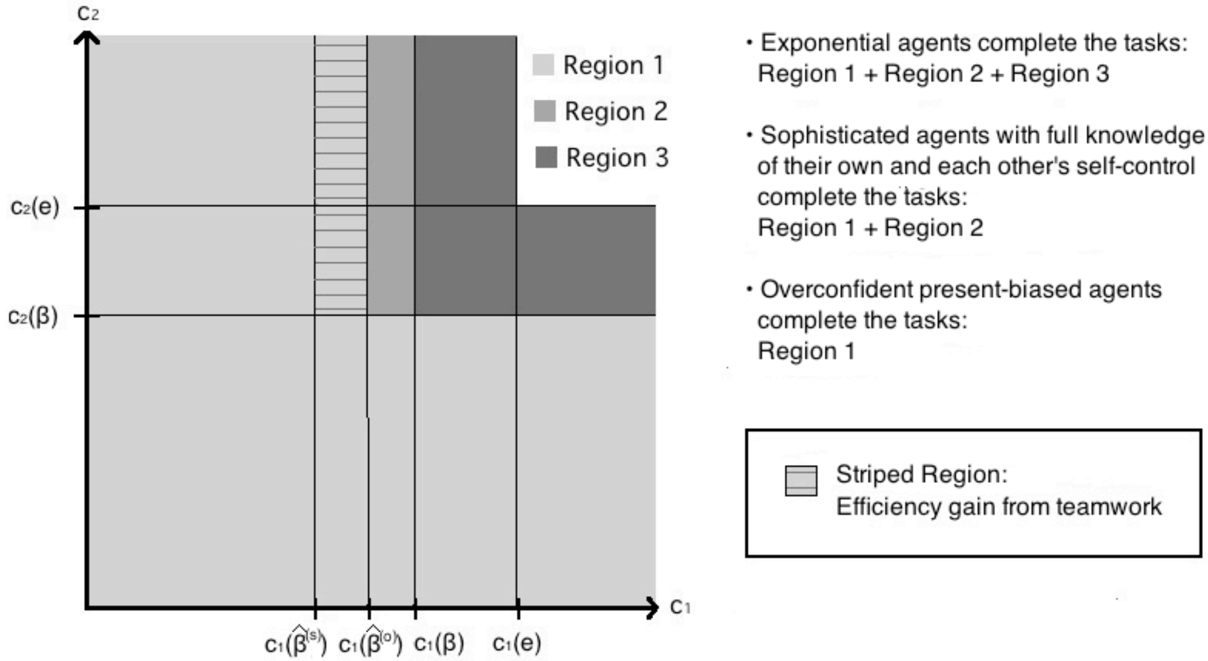

Figure 3: Efficiency loss from present-bias and overconfidence when two identical employees are given a joint assignment. Note that $c_i(\hat{\beta}^{(o)})$ is the threshold below which the employees agree to complete the jointly assigned tasks. Contrast with Figure 1. Note that region 1 has expanded, while region 2 has narrowed. Teamwork among identical overconfident employees enhances productivity.

Thus, for any fixed monetary incentive R, the joint assignment method yields at least as high a probability of task completion as the individual assignment method. Hence, the principal's profit function Π satisfies:

$$\forall R, \Pi(R, \text{individual}) \leq \Pi(R, \text{joint})$$

When employees are homogenous, the joint assignment method is at least as effective as the individual assignment method, with inequality strict for some values of the parameters.

Result 2 characterizes the likelihood that the work is completed within the allotted time under the individual and joint assignment methods and a fixed monetary incentive R. However, it is instructive to observe not only how likely the tasks are to be finished, but also *when* they are completed. If the two agents are homogenous, the joint task assignment induces earlier completion, as seen from the following Result.

Result 3. (Expected Delays under Individual and Joint Assignments):

For homogenous employees and any monetary reward R satisfying Condition 1, the expected delay to task completion, $\mathbb{E}\{\#\text{ periods to completion} \mid \text{tasks are completed}\}$, is lower *under the joint task assignment than under the individual task assignment.*

Result 3 follows immediately from Result 2, which indicates that the likelihood of task completion in the first period is greater under the joint assignment method, while the likelihood of task completion in the second period is the same under the two assignment methods. Result 3 is especially interesting for cases where delay is costly to the principal, but the task completion costs are known only to the agents. In such cases, it may not be feasible for the employer to dictate when exactly the employees complete the work, but the joint task assignment serves as a useful tool for inducing earlier completion.

4 Heterogenous Present-Bias

Let us now turn our attention to the case of heterogenous workers. In particular, this section relaxes Assumption 1.

4.1 *Heterogenous Agent Equilibrium*

Consider two workers, each with parameters $(\delta, \beta^{(i)}, \hat{\beta}^{(i,i)}, \hat{\beta}^{(i,j)})$ $(i \in \{1,2\}, j \neq i)$, where $\beta^{(i)}$ expresses the severity of worker i's present-bias, $\hat{\beta}^{(i,i)} \in (\beta^{(i)}, 1]$ denotes the extent of his naïveté, and $\hat{\beta}^{(i,j)}$ (with $\hat{\beta}^{(i,j)} < \hat{\beta}^{(i,i)}$) captures agent i's beliefs regarding agent $j \neq i$. Contrary to the case considered in the previous section, I do not require that any of $\beta^{(1)} = \beta^{(2)}$, $\hat{\beta}^{(1,1)} = \hat{\beta}^{(2,2)}$, or $\hat{\beta}^{(1,2)} = \hat{\beta}^{(2,1)}$ hold.

For non-degenerate results, consider the following modified version of Condition 1:

Condition 1′. *The monetary incentive R is set such that $\forall i \in \{1,2\} : F_1(H(\beta^{(i)}, \hat{\beta}^{(i,i)}))$, $F_2(\beta^{(i)}\delta R) \in (0,1)$.*

Let us first recall the predictions that Section 3 makes for the chances that the two workers successfully complete their tasks if the employer chooses the individual assignment method and sets the monetary incentive at R. Proposition 1 provides that Employee i completes his task for any cost realization pair in

$$C^{(i)} = ([0, H(\beta^{(i)}, \hat{\beta}^{(i,i)})] \times C_2) \cup (C_1 \times [0, \beta^{(i)}\delta R]) \tag{4.1}$$

Consider now the joint task assignment method.

The game form is identical to the game G_J studied in Section 3.2. The only features that alter are the preference and belief parameters of the two agents. Under the joint assignment method, the work is again completed in period t if and only if it is still outstanding and both agents are willing to complete it at that time. The agents' undiscounted payoffs are identical and still given by (3.1), although their discounting parameters can now differ. Agent i's beliefs regarding his own and agent j's second-period behavior are again denoted by $\hat{s}_2^{(i,i)}$ and $\hat{s}_2^{(i,j)}$, respectively, but now informed by $\hat{\beta}^{(i,i)}$ and $\hat{\beta}^{(i,j)}$.

As before, I focus on WDSPPE as the solution concept. The WDSPPE of the considered game is given in Proposition 3:

Proposition 3. *Consider any monetary incentive R satisfying Condition 1′. The unique WDSPPE of the game G_J with agent preference and belief parameters $\{(\beta_i; \hat{\beta}^{(i,i)}, \hat{\beta}^{(i,j)})\}_{i\in\{1,2\}, j\neq i}$ is given by:*

$$\forall i \in \{1,2\}, j \neq i : s_1^{(i)} = [0, H(\beta^{(i)}, \hat{\beta}^{(i,j)})]$$

$$\forall i \in \{1,2\} : s_2^{(i)} = [0, \beta^{(i)}\delta R]$$

$$\forall i, j \in \{1,2\} : \hat{s}_2^{(i,j)} = [0, \hat{\beta}^{(i,j)}\delta R]$$

Proof. See Appendix A. □

Recall that in each period, the joint assignment is completed if and only if both agents are willing to undertake the work in that period. Thus, under the joint assignment with monetary incentive R, both employees complete the work if the cost realizations (c_1, c_2) fall within $C^{(1,2)}$, and neither employee completes the work otherwise; where

$$C^{(1,2)} = ([0, \min_{i\in\{1,2\}}\{H(\beta^{(i)}, \hat{\beta}^{(i,j)})\}] \times C_2) \cup (C_1 \times [0, \min_{i\in\{1,2\}}\{\beta^{(i)}\delta R\}]) \tag{4.2}$$

In order to assess the effects of the joint assignment method on task completion, let us compare the region in equation (4.2) to the individual completion regions specified in (4.1).

In the second period, conditional on the work not having already been completed, introduction of teamwork (the joint assignment method) unambiguously decreases the likelihood of successful task completion for workers with differing self-control problems ($\beta^{(1)} \neq \beta^{(2)}$). In particular, for cost realizations c_2 that fall within $[\min_{i\in\{1,2\}}\{\beta^{(i)}\delta R\}, \max_{i\in\{1,2\}}\{\beta^{(i)}\delta R\}]$, exactly one employee (the one with the higher $\beta^{(i)}$) would successfully complete his task under the individual assignment, but neither employee completes the jointly assigned work. Intuitively, under the joint assignment, since both agents get compensated only if the entirety of the assignment is completed, there is no incentive for the high type (employee with better self-control) to complete his share of the work when the low type is not willing to do the same.

The effect of the assignment method on the employees' willingness to complete the work in the first period is less straightforward. On the one hand, the joint assignment again leads to some exacerbation of the effects of present-bias, since *neither* worker completes his task if the more present-biased one is unwilling to complete his portion. On the other hand, teamwork continues to offer the advantage of overcoming inefficiency arising from overconfidence, analogously to the effect observed in the previous section. Conceptually, the likelihood that the work is completed in the first period in the case of a joint assignment is analogous to the likelihood that an individually-assigned task is completed when assigned to a single worker whose present-bias is the more severe of the two, but whose naïveté is made less severe.

In the limit of $\beta^{(1)} = \beta^{(2)}$ but $\hat{\beta}^{(i,i)} > \hat{\beta}^{(i,j)}$ for $i \in \{1,2\}$, we are in the homogenous agents case discussed in Section 3, and teamwork is purely beneficial. In the limit case of $\hat{\beta}^{(1)} = \beta^{(1)}, \hat{\beta}^{(2)} = \beta^{(2)}$ but $\beta^{(1)} \neq \beta^{(2)}$, there is heterogeneity but no overconfidence, and the joint assignment is entirely harmful. But in cases between those two limits – where there is some degree of both heterogeneity and overconfidence – benefits of teamwork are more ambiguous, as summarized by the following Result, and displayed graphically in Figure 4.

Result 4. (Effects of Teamwork on Efficiency for Heterogenous Workers):

Suppose the principal sets the monetary incentive at any R satisfying Condition 1$'$.

1. *Efficiency loss due to present-bias:*

   Assigning tasks jointly to two employees with $\beta^{(1)} \neq \beta^{(2)}$ may exacerbate the efficiency loss from present-bias. The potentially negative effect spans realizations of $c_1 \in [\min_{i\in\{1,2\}}\{H(\beta^{(i)}, \hat{\beta}^{(i,j)})\}, \max_{i\in\{1,2\}}\{H(\beta^{(i)}, \hat{\beta}^{(i,i)})\}]$ and realizations of c_2 in $[\min_{i\in\{1,2\}}\{\beta^{(i)}\delta R\}, \max_{\in\{1,2\}}\{\beta^{(i)}\delta R\}]$. Instead of one employee completing his task at these cost realizations, neither employee completes his task.

2. *Efficiency loss due to overconfidence:*

   Assigning tasks jointly (rather than individually) reduces the inefficiency from overconfidence, leading both employees (rather than only one of them) to complete their tasks in the cost-realization region of $c_1 \in [\min_{i\in\{1,2\}}\{H(\beta^{(i)}, \hat{\beta}^{(i,i)})\}, \min_{i\in\{1,2\}}\{H(\beta^{(i)}, \hat{\beta}^{(i,j)})\}]$.

3. *The relative strengths of 1. and 2. above depend on the extent of the employees' overconfidence and the similarity in the two employees' present-bias. In particular, the positive effect in 2. will dominate for sufficiently similar or sufficiently overconfident employees.*

4.2 *Optimal Team Composition*

The results thus far suggest that heterogeneity in preference and belief parameters decreases the effectiveness of the joint assignment method. While with homogenous agents

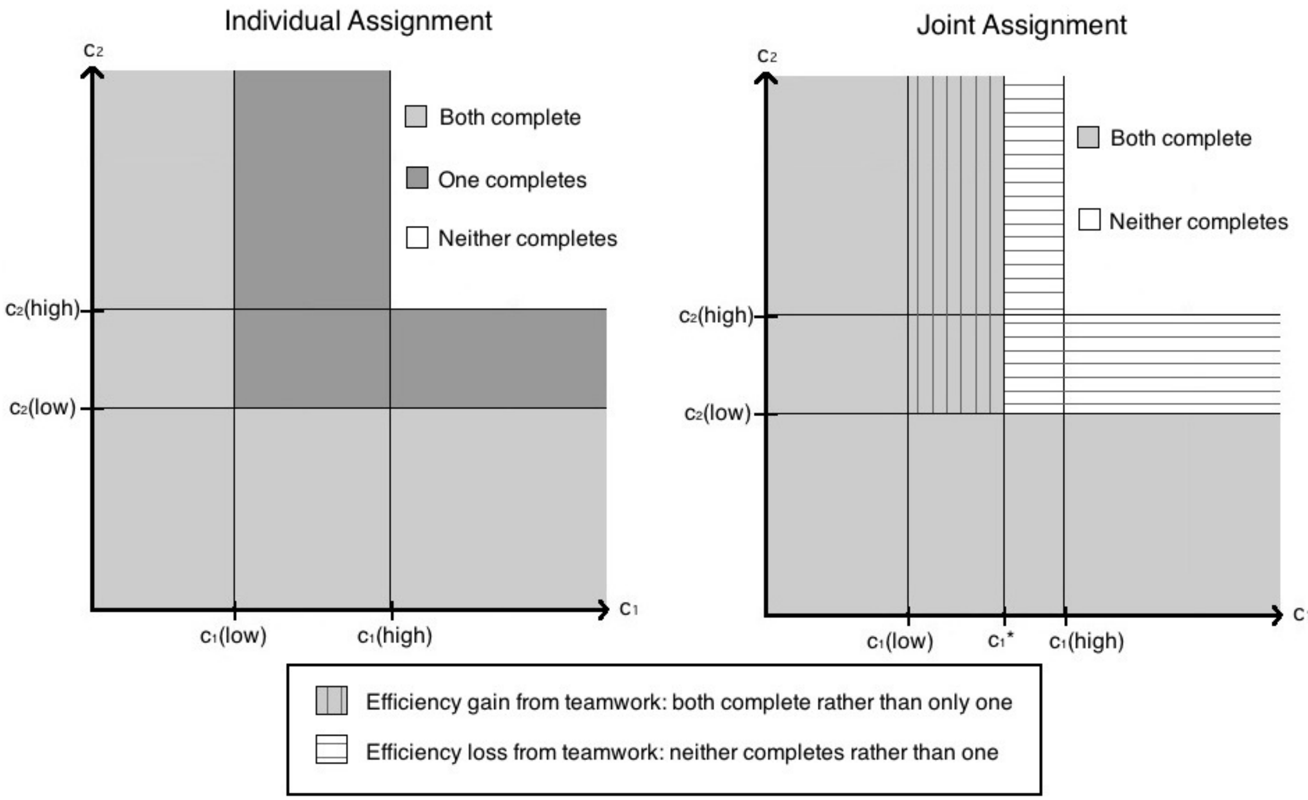

Figure 4: Efficiency gains and losses from teamwork among heterogenous agents. For each period t, $c_t(low)$ and $c_t(high)$ denote the thresholds of the task completion costs below which the lower-type and higher-type, respectively, are willing to complete the individual task at t; c_1^* denotes the threshold below which the two employees complete the joint tasks at $t = 1$. When agents have heterogenous propensities to procrastinate, teamwork can either increase or reduce efficiency. For workers with similar self-control problems, the region with horizontal stripes (efficiency loss region) will be small. The more overconfident the employees, the larger will be the region with vertical stripes (efficiency gain region).

studied in Section 3 the joint assignment unambiguously dominates the individual assignment method for any monetary incentive R, this is not necessarily true for heterogenous agents studied in the current section. To formalize the effects of heterogeneity on efficacy of the joint assignment, consider any two agents i and j, and recall from (2.1) that the principal's expected profit under the joint assignment method and monetary incentive R is given by:

$$\Pi(\mathrm{R}, \text{joint}|\{\beta^{(i)}, \hat{\beta}^{(i,j)}\}_{i\in\{1,2\},j\neq i}) =$$

$$= (B - R)\mathbb{E}\{\#\text{ completed tasks} \mid \mathrm{R}, \text{joint}, \{\beta^{(i)}, \hat{\beta}^{(i,j)}\}_{i\in\{1,2\},j\neq i}\}$$

Fix any monetary incentive R satisfying Condition 1′, and define $X(\beta^{(i)}, \beta^{(j)})$ and $Y(\beta^{(i,j)}, \beta^{(j,i)})$

as follows:

$$X(\beta^{(i)}, \beta^{(j)}) = \Pi(\text{R, joint} \mid \hat{\beta}^{(i,j)} = \hat{\beta}^{(j,i)} = \hat{\beta}^{(o)})$$

$$Y(\hat{\beta}^{(i,j)}, \hat{\beta}^{(j,i)}) = \Pi(\text{R, joint} \mid \beta^{(i)} = \beta^{(j)} = \beta)$$

In words, $X(\beta^{(i)}, \beta^{(j)})$ denotes the principal's expected profit as a function of the two agents' present-bias parameters $\beta^{(i)}$ and $\beta^{(j)}$ when their beliefs are identical, while $Y(\hat{\beta}^{(i,j)}, \hat{\beta}^{(j,i)})$ gives the expected profit as a function of beliefs about each other, $\hat{\beta}^{(i,j)}$ and $\hat{\beta}^{(j,i)}$, under identical present-bias parameters. Thus, varying the inputs to $X(\cdot)$ isolates the effects of heterogeneity in the agents' actual self-control problems, while varying the inputs to $Y(\cdot)$ captures the effects of heterogeneity in the agents' beliefs. The Proposition below shows that both $X(\cdot)$ and $Y(\cdot)$ are supermodular in the sense of Grossman and Maggi (2000) (see also Topkis (1978) and Milgrom and Roberts (1990)).

Proposition 4. *$X(\cdot)$ and $Y(\cdot)$ are both supermodular. I.e., $\forall i, i', j, j'$:*

$$X(\beta^{(i)}, \beta^{(j)}) + X(\beta^{(i')}, \beta^{(j')}) \leq X(\min\{\beta^{(i)}, \beta^{(i')}\}, \min\{\beta^{(j)}, \beta^{(j')}\}) +$$

$$+ X(\max\{\beta^{(i)}, \beta^{(i')}\}, \max\{\beta^{(j)}, \beta^{(j')}\})$$

$$Y(\hat{\beta}^{(i,j)}, \hat{\beta}^{(j,i)}) + Y(\hat{\beta}^{(i',j')}, \hat{\beta}^{(j',i')}) \leq Y(\min\{\hat{\beta}^{(i,j)}, \hat{\beta}^{(i',j')}\}, \min\{\hat{\beta}^{(j,i)}, \hat{\beta}^{(j',i')}\}) +$$

$$+ Y(\max\{\hat{\beta}^{(i,j)}, \hat{\beta}^{(i',j')}\}, \max\{\hat{\beta}^{(j,i)}, \hat{\beta}^{(j',i')}\})$$

Proof. See Appendix A. □

Proposition 4 implies that if an employer wishes to incentivize a group of agents to each complete a unit task, and chooses the joint assignment method to do so, then the best results are achieved by pairing the agents based on similarity of their present-bias and beliefs: the most present-biased agent should be paired with the second-most present-biased, the least present-biased with the second-least present-biased, and so on (and similarly for optimism regarding others, $\hat{\beta}^{(i,j)}$).

Supermodularity of the production function in the agents' preferences and beliefs is driven by the structure of the joint assignment, where both agents must complete their shares of the joint work in order to succeed. When one agent is much more present-biased than the other, he effectively precludes his teammate's productivity. Similarly, if one agent is much more optimistic about his peer, he does not perceive the need to work early on in oder to curb his peer's procrastination, and hence prevents the team from completing the work early.

Assortative matching on present-bias and beliefs is effective by aligning the agents both in their willingness to work and in their wariness of each other's procrastination. This suggests that when agents are heterogenous in their preferences or beliefs, the efficacy of teamwork such as the considered joint assignment method depends on the principal's ability to sort the agents based on present-bias and beliefs about others. While it is unlikely that an employer would be able to accurately estimate each worker's $\beta^{(i)}$ and $\hat{\beta}^{(i,j)}$, she may have access to signals correlated with the relative values of the agents' parameters that would enable better-than-random sorts. The effects of the granularity in the principal's knowledge of the relative rankings of the agents' present-bias parameters are explored in the simulations below.

4.3 *Simulations*

In order to illustrate the efficiency effects of teamwork, let us consider numerical simulations of an economy with 1,000 present-biased agents, who can each be assigned a task to complete. There is a single principal, and the setup can be thought of as a firm. The principal sets the monetary incentive R and chooses between the individual and the joint task assignment. Under the individual assignment, each agent plays the game G_I from Section 3.1. Under the joint assignment, the principal splits the agents into pairs and assigns two tasks to each pair; the agents then play out the game G_J from Section 3.2.

Let each period last a month, with the time-consistent discount factor of $\delta = 0.997$ (corresponding to an annualized discount factor of 0.96, consistent with calibrations in the literature[9]). Let the costs c_1 be uniformly distributed on $[0, 1]$. To have similar likelihood of task completion in the first and the second periods, let costs $c_2 \sim U[0, 2]$. Set the principal's profit from successful task completion at $B = 2$.

There is less consensus regarding estimates of present-bias β than those of time-consistent discounting δ. Laibson, Repetto, and Tobacman (2007) report an estimate of $\beta = 0.7$ and Shui and Ausubel (2005) obtain $\beta = 0.8$, while Augenblick, Niederle, and Sprenger (2015) find $\beta = 0.9$. Augenblick and Rabin (2015) estimate β to be between 0.8 and 0.85. Paserman (2008) obtains estimates of $\beta = 0.4$ for low-wage workers and $\beta = 0.9$ for high-wage workers. Skiba and Tobacman (2009) find $\beta = 0.5$. In the present simulations, each agent's $\beta^{(i)}$ parameter is randomly drawn from a uniform distribution on $[0.65, 0.75]$, which is broadly consistent with the empirical findings in the literature.

In order to model partial sophistication and overconfidence, the simulations use calibration findings from Acland and Levy (2015), who estimate $\hat{\beta}^{(i,i)}$ as a weighted average between 1 and $\beta^{(i)}$, with 2/3 of the weight on 1. Given estimates of $\beta^{(i)} \in [0.65, 0.75]$, this yields $\hat{\beta}^{(i,i)} \in [0.88, 0.92]$, consistent with the findings in Skiba and Tobacman (2009), who estimate $\hat{\beta}^{(i,i)} = 0.9$.

[9] For example, Laibson, Repetto, and Tobacman (2007) estimate annualized δ at 0.96 using lifecycle accumulation data.

Lastly, I take the following form for relative overconfidence: $\hat{\beta}^{(i,j)} = \frac{1}{2}\hat{\beta}^{(i,i)} + \frac{1}{2}\overline{\beta}$, where $\overline{\beta}$ denotes the average population present-bias parameter (for the considered parameters, $\overline{\beta} = 0.7$). Thus, each employee presumes that others are more present-biased than he is. This is in line with the preliminary experimental evidence in Fedyk (2015), who documents beliefs about others that are between rational beliefs and the naïveté displayed in beliefs about self.

To summarize, the baseline specification considers an economy of 1,000 agents with the following parameters:

Completion costs	$c_1 \sim U[0,1], c_2 \sim U[0,2]$
Principal's profit	$B = 2$
Time-consistent discount factor	$\delta = 0.997$
present-bias parameters	$\beta^{(i)} \sim U[0.65, 0.75]$
Partial naïveté	$\hat{\beta}^{(i,i)} = 1/3\beta^{(i)} + 2/3$
Beliefs about others	$\hat{\beta}^{(i,j)} = 1/2\hat{\beta}^{(i.i)} + 1/2\overline{\beta}$

I simulate the principal's expected profit as a function of the monetary incentive R, under both individual and joint assignment methods. As observed in Section 4.2, the joint assignment is more effective when the principal teams relatively more similar agents with each other. In the present simulations, I consider the following types of joint assignment:

- Perfectly matched joint assignment: the agents are perfectly sorted, and the agent with the lowest present-bias is matched with the agent who has the second-lowest present-bias, etc.

- Joint assignment within top/bottom half: the principal knows which of the agents are in the "top half" of the distribution of present-bias parameters, and which are in the "bottom half". However, the principal cannot tell the rankings within the top and bottom half, so assignment is random within each half of the population.

- Random joint assignment: the agents are assigned to teams randomly.

The results from 100 simulations of the above economy are aggregated in Panel 1 of Figure 5, which depicts the principal's expected profit as a function of the monetary incentive R, under the individual assignment method and the joint assignment method with varying degrees of sorting. For each assignment method, the corresponding thick line spans from the 10th to the 90th percentiles of the simulation results. The profit as a function of the monetary reward is equal to zero when $R = 0$ (no tasks are completed) and when $R = B = 2$ (all benefits from task completion accrue to the agents). The profit function (given by (2.1)) is concave between these two points, and achieves a single interior maximum.

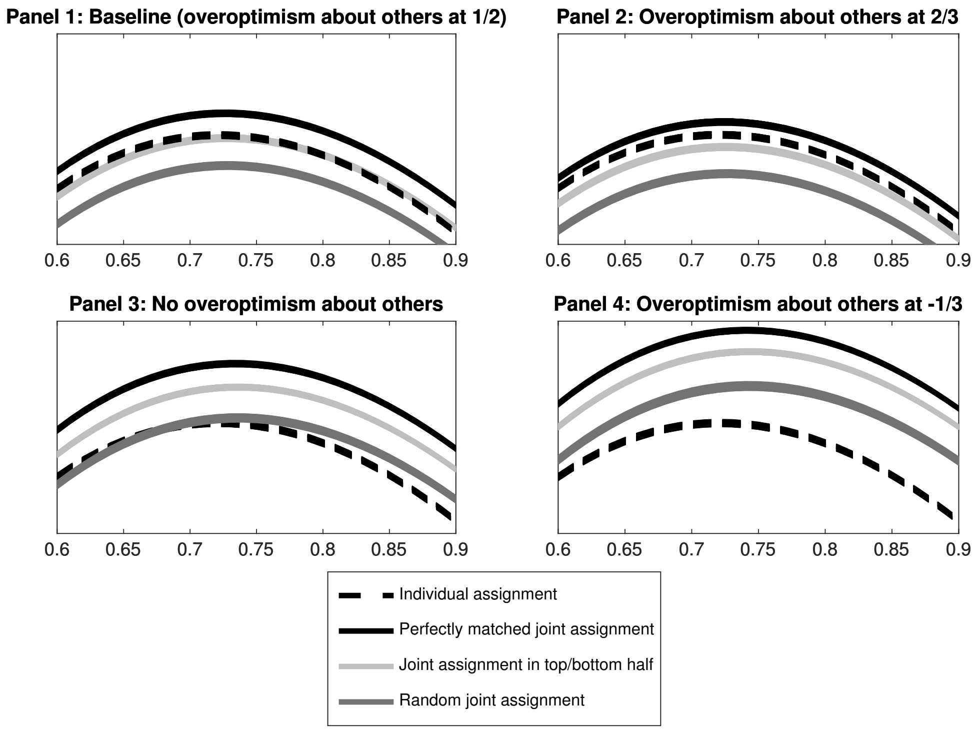

Figure 5: Expected profit as a function of monetary reward R for the individual assignment method and the joint assignment method with varying degrees of sorting, under different assumptions on beliefs about others. Panel 1 uses baseline parameter values: $\delta = 0.997$, $c_1 \in U[0,1], c_2 \in U[0,2]$, $\beta^{(i)} \sim U[0.65, 0.75]$, $\hat{\beta}^{(i,i)} = 1/3\beta^{(i)} + 2/3$, and $\hat{\beta}^{(i,j)} = 1/2\hat{\beta}^{(i,i)} + 1/2\overline{\beta}$. Panels 2, 3, and 4 consider the specification for beliefs about others $\hat{\beta}^{(i,j)} = \alpha\hat{\beta}^{(i,i)} + (1-\alpha)\overline{\beta}$ with $\alpha = 2/3, 0$, and $-1/3$, respectively.

As can be seen from the graph, the random joint assignment performs worse than the individual assignment method, due to the heterogeneity in agents' present-bias parameters – relatively patient types who are matched with relatively impatient agents get discouraged from completing their work. However, if the principal can perfectly sort the agents on their present-bias and assign them to matched teams, the joint assignment yields superior profits to the individual assignment for any incentive R. The two assignment methods perform similarly if the principal observes only whether each agent's self-control is above- or below-average.

The efficacy of the joint assignment depends not only on the agents' heterogeneity, but also on the extent of their relative overconfidence. To explore the effects of the wedge in beliefs regarding own and others' present-bias, I fix beliefs regarding self at $\hat{\beta}^{(i,i)} = 1/3\beta^{(i)} + 2/3$, consistent with existing empirical literature, and vary beliefs regarding others as follows:

$$\hat{\beta}^{(i,j)} = \alpha\hat{\beta}^{(i,i)} + (1-\alpha)\overline{\beta}, \text{ where } \overline{\beta} = \text{population average present-bias and } \alpha \in \{1/2, 2/3, 0, -1/3\}$$

Thus, beliefs about others are a weighted average of the population average present-bias and the individual's optimistic beliefs about his own future self-control. The weight on the latter – which can be negative – is termed "optimism about others." The baseline value of $\alpha = 1/2$ corresponds to beliefs about others that are half as optimistic as beliefs about oneself. The effects of optimism about others on the relative performance of the individual and joint assignment methods are displayed in Panels 2-4 of Figure 5. Panel 2 considers a higher optimism value of $\alpha = 2/3$. Panel 3 displays the case of no optimism about others, where beliefs are informed purely by the population average. Panel 4 displays the case of severe relative overconfidence, where beliefs about others are actually pessimistic. Once again, all shaded lines represent results spanning from the 10th to the 90th percentile of the simulations run. As can be seen from the Figure, the less optimistic are beliefs about others, the more effective is the joint assignment method relative to the individual assignment. In the case of rational beliefs about others, displayed in Panel 3, even the randomly matched joint assignment performs slightly better than the individual assignment method. This highlights one of the model's key predictions: that the benefits of teamwork are higher when the wedge in beliefs regarding self and other is larger.

5 Conclusion

The present paper revisits the issue of task assignment in organizations when agents are subject to present-bias and overconfidence. Endowing the principal (employer) with the ability to choose between the individual and joint task assignments, the paper highlights one potential benefit of teamwork: that the wedge in employees' beliefs regarding their own future present-bias and that of others allows joint work assignments to partially combat inefficient procrastination arising from individual overconfidence.

The results in this paper outline conditions under which teamwork among present-biased employees increases their aggregate efficiency. In particular, teamwork is optimal when the employees are sufficiently similar in the extent of their self-control problems, and sufficiently overconfident regarding their own self-control abilities relative to those of others. If employees differ too much in their individual propensities to procrastinate, however, it may be best to incentivize them individually, preventing the self-control problems of the more present-biased workers from spilling over to their more patient peers. These results are relatable and intuitive: it makes sense to place workers in teams so that they would incentivize each other, but only if they are compatible. The conclusions of the present paper suggest present-bias as one metric on which to evaluate compatibility of potential teammates.

The present paper suggests several avenues for future research. It may be interesting to consider the possibility of employees splitting the work unevenly, as may happen frequently in real work environments where the employee with better self-control might be willing to complete a portion of his peer's work in addition to his own, so as not to forego the reward. The effectiveness of tournament incentive schemes along the lines of those discussed in Lazear and Rosen (1981) and Green and Stokey (1983) in the case when agents are individually overconfident offers another intriguing direction for future study. Most extensions, however, require assumptions on the agents' higher order beliefs. As such, empirical and experimental investigation of the full structure of present-biased agents' beliefs would in itself constitute a fruitful direction for future research.

Appendix A Proofs

A.1 Proof of Proposition 1

Suppose that agent i has not completed the work before the second period, and consider any cost realization c_2. The agent's total utility from completing the task at this point is given by $-c_2+\beta\delta R$. His utility from not completing the task is 0. Hence, the agent's optimal strategy (determined uniquely up to sets of measure zero) in the second period is $s_2 = \beta\delta R$.

In period 1, agent i anticipates himself completing the task at $t = 2$ for any cost $c_2 < \beta_2^{(i)}\delta R$, where $\beta_2^{(i)}$ is his second-period present-bias parameter. By Definition 1, the agent fails to recognize that $\beta_2^{(i)} = \beta$, believing instead that $\beta_2^{(i)} = \hat{\beta}^{(s)}$ almost surely. Thus, he mispredicts his second period strategy to be $\hat{s}_2 = \hat{\beta}^{(s)}\delta R$.

Hence, at $t = 1$, when deciding whether to complete the task immediately at a given task-cost realization c_1, the agent compares the following expected utilities:

$$\textit{Expected utility from completing at } c_1\textit{:} - c_1 + \beta\delta^2 R$$

$$\textit{Expected utility from postponing given cost } c_1\textit{: } \beta\delta\int_0^{\hat{\beta}^{(s)}\delta R}(-c_2+\delta R)f_2(c_2)dc_2$$

The expected utility from postponing is higher than that from completing if and only if $c_1 > \beta\delta^2 R - \beta\delta\int_0^{\hat{\beta}^{(s)}\delta R}(-c_2+\delta R)f_2(c_2)dc_2$. Thus, the agent's perception-perfect equilibrium strategy in period 1 is $s_1 = [0, \beta\delta^2 R - \beta\delta\int_0^{\hat{\beta}^{(s)}\delta R}(-c_2+\delta R)f_2(c_2)dc_2] = [0, H(\beta, \hat{\beta}^{(s)})]$.

■

A.2 Proof of Proposition 2

Recall that by Assumption 1, $\beta^{(1)} = \beta^{(2)} = \beta$, $\hat{\beta}^{(1,1)} = \hat{\beta}^{(2,2)} = \hat{\beta}^{(s)}$, and $\hat{\beta}^{(1,2)} = \hat{\beta}^{(2,1)} = \hat{\beta}^{(o)}$.

Let us first consider the second period, and establish the following result:

Lemma 1. *In the second period, for agent i with present-bias β, $s_2^{(i)} = [0, \beta\delta R]$ is a unique (up to sets of measure zero) weakly dominant strategy.*

Proof. Agent i's second-period expected utility from playing strategy $\sigma_2^{(i)}$ when agent j plays $\sigma_2^{(j)}$ is given by:

$$\mathbb{E}\{U_2^{(i)}(\sigma_2^{(i)}, \sigma_2^{(j)}|\beta)\} = \int_{c_2 \in \sigma_2^{(i)} \cup \sigma_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2$$

Note that the integrant, $-c_2 + \beta\delta R$, is positive for any $c_2 \in [0, \beta\delta R)$ and negative for any $c_2 \in (\beta\delta R, \infty)$.

To see that $s_2^{(i)} = [0, \beta\delta R]$ is a weakly dominant strategy, consider any other strategy $\sigma_2^{(i)} \in \mathcal{S}_2$ and any $\sigma_2^{(j)} \in \mathcal{S}_2$. Let $A = s_2^{(i)} \backslash \sigma_2^{(i)}$ and $B = \sigma_2^{(i)} \backslash s_2^{(i)}$, where the notation $a \backslash b$ denotes the set $\{x \in a \text{ s.t. } x \notin b\}$. Then:

$$\mathbb{E}\{U_2^{(i)}(\sigma_2^{(i)}, \sigma_2^{(j)} \mid \beta)\} = \int_{c_2 \in s_2^{(i)} \cup \sigma_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2 - \int_{c_2 \in A \cup \sigma_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2 +$$

$$+ \int_{c_2 \in B \cup \sigma_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2$$

Note that, since $A \subset s_2^{(i)} = [0, \delta\beta R]$, the integral $\int_{c_2 \in A \cup \sigma_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2$ is positive whenever $A \cup \sigma_2^{(i)}$ has positive measure, and zero otherwise. Similarly, since $B \subset \mathbb{R}_+ \backslash s_2^{(i)} = (\beta\delta R, \infty)$, the integral $\int_{c_2 \in B \cup \sigma_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2$ is negative whenever $B \cup \sigma_2^{(i)}$ has positive measure, and zero otherwise. Hence:

$$\mathbb{E}\{U_2^{(i)}(\sigma_2^{(i)}, \sigma_2^{(i)} \mid \beta)\} \leq \int_{c_2 \in s_2^{(i)} \cup \sigma_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2 = \mathbb{E}\{U_2^{(i)}(s_2^{(i)}, \sigma_2^{(j)} \mid \beta)\},$$

and $s_2^{(i)}$ is a weakly dominant strategy.

To see that there is no other weakly dominant strategy, consider any other strategy $\sigma_2^{(i)} \in \mathcal{S}_2$ that differs from $s_2^{(i)}$ on a positive-measure subset of $\mathcal{S}_2$. As before, define $A = s_2^{(i)} \backslash \sigma_2^{(i)}$ and $B = \sigma_2^{(i)} \backslash s_2^{(i)}$. Since $s_2^{(i)}$ and $\sigma_2^{(i)}$ differ on a positive-measure subset, at least one of A and B must have positive measure.

Consider the following strategy of agent j: $s_2^{(j)} = [0, \beta\delta R]$.

Then we have:

$$\mathbb{E}\{U_2^{(i)}(\sigma_2^{(i)}, s_2^{(j)} \mid \beta)\} = \int_{c_2 \in s_2^{(i)} \cup s_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2 - \int_{c_2 \in A \cup s_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2 +$$

$$+ \int_{c_2 \in B \cup s_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2$$

If A has positive measure, then $\int_{c_2 \in A \cup s_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2$ is strictly positive. If B has positive measure, then $\int_{c_2 \in B \cup s_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2$ is strictly negative. In both of these cases:

$$\mathbb{E}\{U_2^{(i)}(\sigma_2^{(i)}, s_2^{(j)} \mid \beta)\} < \int_{c_2 \in s_2^{(i)} \cup s_2^{(j)}} (-c_2 + \beta\delta R) f_2(c_2) dc_2 = \mathbb{E}\{U_2^{(i)}(s_2^{(i)}, s_2^{(j)} \mid \beta)\},$$

so that $\sigma_2^{(i)}$ is not a weakly dominant strategy.

□

By Lemma 1, in the second period, WDSPPE dictates that $s_2^{(1)} = s_2^{(2)} = [0, \beta\delta R]$ (uniquely up to measure-zero sets). Note that this is identical to the equilibrium second-period strategy in the individual task completion game analyzed in Section 3.1.

Let us now turn to the first period. Applying Lemma 1 with erroneous beliefs regarding the agents' future self-control, I obtain that in period 1, each agent i expects that he will play $\hat{s}_2^{(i,i)} = [0, \hat{\beta}^{(s)}\delta R]$ almost surely and the other agent will play $\hat{s}_2^{(i,j)} = [0, \hat{\beta}^{(o)}\delta R]$.

To complete the proof, it remains only to establish the following fact.

Lemma 2. *In the first period, for agent i with present-bias β and expectations of second-period strategies given by $(\hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)})$ based on beliefs $(\hat{\beta}^{(s)}, \hat{\beta}^{(o)})$, the unique (up to sets of measure zero) weakly dominant strategy is $s_1^{(i)} = [0, H(\beta, \hat{\beta}^{(o)})]$.*

Proof. Agent i's first-period expected utility from playing strategy $\sigma_1^{(i)} \in \mathcal{S}_1$ when agent j plays $\sigma_1^{(j)} \in \mathcal{S}_1$ is given by:

$$\mathbb{E}\{U_1^{(i)}(\sigma_1^{(i)}, \sigma_1^{(j)} \mid \beta; \hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)})\} = \int_{c_1 \in \sigma_1^{(i)} \cup \sigma_1^{(j)}} [-c_1 + \beta\delta^2 R] f_1(c_1) dc_1 +$$

$$+\beta\delta \int_{c_1 \notin \sigma_1^{(i)} \cup \sigma_1^{(j)}} \left(\int_{c_2 \in \hat{s}_2^{(i,i)} \cup \hat{s}_2^{(i,j)}} [-c_2 + \delta R] f_2(c_2) dc_2 \right) f_1(c_1) dc_1 =$$

$$= \int_{c_1 \in \sigma_1^{(i)} \cup \sigma_1^{(j)}} \left[-c_1 + \beta\delta^2 R - \beta\delta \int_0^{\hat{\beta}^{(o)}\delta R} (-c_2 + \delta R) f_2(c_2) dc_2 \right] f_1(c_1) dc_1 + K, \tag{A.1}$$

where the constant $K = \beta\delta \int_0^\infty \left(\int_0^{\hat{\beta}^{(o)}\delta R} [-c_2 + \delta R) f_2(c_2) dc_2 \right] f_1(c_1) dc_1$. Note that the last equality in (A.1) uses the fact that $\hat{\beta}^{(o)} < \hat{\beta}^{(s)}$.

Recall that $H(\beta, \hat{\beta}^{(o)}) = \beta\delta^2 R - \beta\delta \int_0^{\hat{\beta}^{(o)}\delta R} (-c_2 + \delta R) f_2(c_2) dc_2$. Note that the integrand in (A.1) is positive whenever $c_1 < H(\beta, \hat{\beta}^{(o)})$, and negative whenever $c_1 > H(\beta, \hat{\beta}^{(o)})$.

Now, consider the strategy $s_1^{(i)} = [0, H(\beta, \hat{\beta}^{(o)})]$ and any other strategy $\sigma_1^{(i)}$. Let $A = s_1^{(i)} \backslash \sigma_1^{(i)}$ and $B = \sigma_1^{(i)} \backslash s_1^{(i)}$. Suppose agent j plays an arbitrary strategy $\sigma_1^{(j)}$. Then we have:

$$\mathbb{E}\{U_1^{(i)}(\sigma_1^{(i)}, \sigma_1^{(j)} \mid \beta; \hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)}\}) = \int_{c_1 \in \sigma_1^{(i)} \cup \sigma_1^{(j)}} \left[-c_1 + H(\beta, \hat{\beta}^{(o)}) \right] f_1(c_1) dc_1 + K = \tag{A.2}$$

$$= \int_{c_1 \in s_1^{(i)} \cup \sigma_1^{(j)}} \left[-c_1 + H(\beta, \hat{\beta}^{(o)}) \right] f_1(c_1) dc_1 - \int_{c_1 \in A \cup \sigma_1^{(j)}} [-c_1 + H(\beta, \hat{\beta}^{(o)})] f_1(c_1) dc_1 +$$

$$+ \int_{c_1 \in B \cup \sigma_1^{(j)}} [-c_1 + H(\beta, \hat{\beta}^{(o)})] f_1(c_1) dc_1 \le$$

$$\le \int_{c_1 \in s_1^{(i)} \cup \sigma_1^{(j)}} \left[-c_1 + H(\beta, \hat{\beta}^{(o)}) \right] f_1(c_1) dc_1 = \mathbb{E}\{U_1^{(i)}(s_1^{(i)}, \sigma^{(j)} \mid \beta; \hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)})\},$$

which establishes that $s_1^{(i)}$ is indeed a weakly dominant strategy.

Furthermore, setting $\sigma_1^{(j)}$ equal to $s_1^{(j)} = [0, H(\beta, \hat{\beta}^{(o)})]$, inequality (A.2) becomes strict for any $\sigma_1^{(i)}$ that differs from $s_1^{(i)}$ on a subset of positive measure. Hence, $s_1^{(i)}$ is a unique (up to measure zero sets) weakly dominant strategy.

□

This completes the proof that the strategy profiles given by $s^{(i)} = (s_1^{(i)}, s_2^{(i)}; \hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)})$ constitute a unique WDSPPE of G_J.

■

A.3 Proof of Proposition 3

Consider two agents, with preferences and beliefs given by $\{\beta^{(i)}; \hat{\beta}^{(i,i)}, \hat{\beta}^{(i,j)}\}_{i \in \{1,2\}, j \neq i}$.

Let us first consider the second period. By Lemma 1, for each agent i, the unique weakly dominant strategy is $s_2^{(i)} = [0, \beta^{(i)}\delta R]$.

Furthermore, since in the first period each agent i believes agent j's future present-bias to be $\hat{\beta}^{(i,j)}$, Lemma 1 also dictates that $\forall i, j \in \{1, 2\}, \hat{s}_2^{(i,j)} = [0, \hat{\beta}^{(i,j)}\delta R]$.

Now consider the first period. Take any agent i. His present-bias is $\beta^{(i)}$, and his expectations of the second-period strategies are given by $(\hat{s}^{(i,i)}, \hat{s}^{(i,j)})$ (for $j \neq i$), based on beliefs $(\hat{\beta}^{(i,i)}, \hat{\beta}^{(i,j)})$. Applying Lemma 2 then gives that $\forall i, j \in \{1, 2\}, s_1^{(i)} = [0, H(\beta^{(i)}, \hat{\beta}^{(i,j)})]$ is the unique weakly dominant first-period strategy.

This proves that the strategy profiles given by $s^{(i)} = (s_1^{(i)}, s_2^{(i)}; \hat{s}_2^{(i,i)}, \hat{s}_2^{(i,j)})$ constitute the unique (up to sets of measure zero) WDSPPE of the game G_J with heterogenous agents.

■

A.4 Proof of Proposition 4

I present the proof of supermodularity of $X(\cdot)$. The proof of supermodularity of $Y(\cdot)$ is identical.

First, for expositional simplicity, I introduce the following notation:

$$\mathcal{X}(\beta) := \Pi(\text{joint, R} \mid \beta^{(i)} = \beta^{(j)} = \beta, \hat{\beta}^{(i,j)} = \hat{\beta}^{(j,i)} = \hat{\beta}^{(o)})$$

Then note that for any $\beta^{(i)}, \beta^{(j)}$:

$$X(\beta^{(i)}, \beta^{(j)}) = \mathcal{X}(\min\{\beta^{(i)}, \beta^{(j)}\})$$

Take any $\beta^{(i)}, \beta^{(j)}, \beta^{(i')}$, and $\beta^{(j')}$. Without loss of generality, let $\beta^{(i)} \leq \beta^{(j)}$. Note that there are two potential cases: $\beta^{(i')} \leq \beta^{(j')}$ and $\beta^{(i')} > \beta^{(j')}$. I consider each case in turn.

Case 1: $\beta^{(i')} \leq \beta^{(j')}$**.** Here, we have $\beta^{(i)} \leq \beta^{(j)}$ and $\beta^{(i')} \leq \beta^{(j')}$. Without loss of generality, let $\beta^{(i)} \leq \beta^{(i')}$. Then:

$$\min\{\beta^{(i)}, \beta^{(i')}\} = \beta^{(i)} \leq \min\{\beta^{(j)}, \beta^{(j')}\}$$

$$\max\{\beta^{(i)}, \beta^{(i')}\} = \beta^{(i')} \leq \beta^{(j')} \leq \max\{\beta^{(j)}, \beta^{(j')}\}$$

And hence:

$$X(\min\{\beta^{(i)}, \beta^{(i')}\}, \min\{\beta^{(j)}, \beta^{(j')}\}) = \mathcal{X}(\min\{\beta^{(i)}, \beta^{(i')}\}) = \mathcal{X}(\beta^{(i)}) = X(\beta^{(i)}, \beta^{(j)})$$

$$X(\max\{\beta^{(i)}, \beta^{(i')}\}, \max\{\beta^{(j)}, \beta^{(j')}\}) = \mathcal{X}(\max\{\beta^{(i)}, \beta^{(i')}\}) = \mathcal{X}(\beta^{(i')}) = X(\beta^{(i')}, \beta^{(j')})$$

$$\Longrightarrow X(\beta^{(i)}, \beta^{(j)}) + X(\beta^{(i')}, \beta^{(j')}) = X(\min\{\beta^{(i)}, \beta^{(i')}\}, \min\{\beta^{(j)}, \beta^{(j')}\}) +$$

$$+ X(\max\{\beta^{(i)}, \beta^{(i')}\}, \max\{\beta^{(j)}, \beta^{(j')}\})$$

Case 2: $\beta^{(i')} > \beta^{(j')}$**.** Here, $\beta^{(i)} \leq \beta^{(j)}$ and $\beta^{(j')} < \beta^{(i')}$. Without loss of generality, let $\beta^{(i)} \leq \beta^{(j')}$. Then we have:

$$X(\beta^{(i)}, \beta^{(j)}) = \mathcal{X}(\beta^{(i)}) = X(\beta^{(i)}, \min\{\beta^{(j)}, \beta^{(j')}\}) = X(\min\{\beta^{(i)}, \beta^{(i')}\}, \min\{\beta^{(j)}, \beta^{(j')}\})$$

$$X(\beta^{(i')}, \beta^{(j')}) \leq X(\beta^{(i')}, \max\{\beta^{(j)}, \beta^{(j')}\}) = X(\max\{\beta^{(i)}, \beta^{(i')}\}, \max\{\beta^{(j)}, \beta^{(j')}\})$$

$$\implies X(\beta^{(i)}, \beta^{(j)}) + X(\beta^{(i')}, \beta^{(j')}) \leq X(\min\{\beta^{(i)}, \beta^{(i')}\}, \min\{\beta^{(j)}, \beta^{(j')}\}) +$$

$$+ X(\max\{\beta^{(i)}, \beta^{(i')}\}, \max\{\beta^{(j)}, \beta^{(j')}\})$$

This complete the proof of supermodularity of $X(\cdot)$.

■

Appendix B Heterogenous Completion Costs

In this section, I consider two agents with heterogenous costs of effort. Let $c_t^{(i)} \in C_t$ denote agent i's task completion cost in period t, distributed according to $F_t(\cdot)$ (with associated density function $f_t(\cdot)$). Let $f_t(c_t^{(j)}|c_t^{(i)})$ denote the conditional density of $c_t^{(j)}$ given a realization of $c_t^{(i)}$.

For expositional simplicity, while introducing heterogeneity in task completion costs, I consider agents that are homogenous in preferences and beliefs. In particular, assume that Assumption 1 holds.

Let us now characterize the unique WDSPPE of G_J under these conditions. Proceeding with backward induction, consider first the second period. As before, Lemma 1 applies, and each agent i finds it individually optimal to complete the work for any $c_2^{(i)} \in [0, \beta\delta R]$. Note that, while the agents' second-period strategies are unchanged with the introduction of heterogenous completion costs, the likelihood of task completion alters. In particular, jointly assigned work is now completed in the second period only if $c_2^{(1)}$ and $c_2^{(2)}$ *both* fall within the completion region $[0, \beta\delta R]$.

Then in the first period, each agent i expects:

$$\hat{s}_2^{(i,i)} = [0, \hat{\beta}^{(s)}\delta R] \text{ and } \hat{s}_2^{(i,j)} = [0, \hat{\beta}^{(o)}\delta R]$$

Given this, in the first period, each agent i faces the following problem. Observing his cost realization $c_1^{(i)}$, the expected utility from completing the work immediately is $-c_1^{(i)} + \beta\delta^2 R$. His expected utility from postponing is given by:

$$\beta\delta \int_0^{\hat{\beta}^{(o)}\delta R} \int_0^{\hat{\beta}^{(s)}\delta R} [-c_2^{(i)} + \delta R] f_2(c_2^{(i)}) dc_2^{(i)} f_2(c_2^{(j)}|c_2^{(i)}) dc_2^{(j)}$$

Thus, the unique weakly dominant strategy for each agent i in the first period is:

$$s_1^{(i)} = [0, \beta\delta^2 R - \beta\delta \int_0^{\hat{\beta}^{(o)}\delta R} \int_0^{\hat{\beta}^{(s)}\delta R} [-c_2^{(i)} + \delta R] f_2^{(i)}(c_2^{(i)}) f_2(c_2^{(j)}|c_2^{(i)}) dc_2^{(j)} \tag{B.1}$$

The equilibrium of the individual assignment game G_I is still characterized by Proposition 1. Note that, as before, the agents' individual willingness to complete the work in the first period under the joint assignment is higher than under the individual assignment, and increases as beliefs about others, $\hat{\beta}^{(o)}$ worsen. In fact, cost heterogeneity actually further increases each agent's willingness to complete the joint work in the first period relative to the homogenous cost case (compare (B.1) to (3.2)). With heterogenous costs, option value of postponing is lower – since it is less likely that both of the second-period cost realizations will be sufficiently low, – and the workers are more desirous of completing the joint work early on.

However, task completion in the first period now requires both $c_1^{(1)} \in s_1^{(1)}$ and $c_2^{(2)} \in s_2^{(1)}$, which decreases the likelihood of early completion.

Overall, the effects of heterogeneity in task completion costs can be summarized as follows:

- Second-period strategies are unchanged, but likelihood of task completion in the second period declines.

- First-period strategies involve completion for a wider range of individual cost realizations, but the reduced coordination in actions reduces likelihood of successful task completion.

This is similar to the insights obtained in Section 4 considering heterogeneity in preference and belief parameters. While the wedge in beliefs regarding self and others makes the joint assignment method attractive, efficacy of this form of teamwork declines when the agents are sufficiently dissimilar.

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