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Competition among procrastinators

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Abstract

I consider a situation in which workers have present-biased preferences and tend to procrastinate their tasks, but underestimate the degree of self-control problems that they will face in the future. Brocas and Carrillo (J Risk Uncertain 22:141–164, 2001) show that a form of competition always mitigates delay in a setting where agents are perfectly aware of their future self-control problems. However, I show that the introduction of the competition considered in their paper does not necessarily mitigate delay in a setting where agents underestimate the magnitude of their future self-control problems. The intuition is that competition reinforces their belief that they will complete earlier, which undermines their incentive to complete now. This result holds even when there is only one worker who severely underestimates the degree of his or her future self-control problem, suggesting that the mere existence of a single "irrational" agent can undermine the overall performance of organizations. Moreover, the intuition behind my result implies that, to mitigate procrastination, it is important to design schemes in which workers believe that they will not complete early in the future, e.g., reducing competition over time, increasing cost over time, or even enforcing no work day tomorrow.

Keywords Present-biased preferences · Naivete · Competition · Self-control · Time inconsistency

JEL Classification D90 · J22 · D83

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1 Introduction

How does workers' procrastination affect the performance of organizations? Is there any mechanism within an organization that mitigates workers' procrastination? How does the degree of awareness about future self-control problems affect these questions?

I consider a situation in which workers have present-biased preferences and have a tendency to procrastinate their tasks, but underestimate the degree of self-control problems that they will face in the future. In such situations, one might conjecture that their manager wants to introduce some form of competition so that workers finish their tasks earlier. For example, the manager solicits prototypes from its workers within three periods, but the workers may have tendency to procrastinate. Then, the manager may want to introduce competition among its workers to deliver prototypes to the client on time.

Indeed, Brocas and Carrillo (2001)—henceforth, BC—show that a form of competition always mitigates procrastination in a setting where present-biased agents are perfectly aware of their future self-control problems. In contrast, this paper shows that the introduction of the competition considered in BC can exacerbate procrastination in a setting where present-biased agents underestimate the magnitude of their future self-control problems.

I analyze competition among n present-biased workers to see if that can mitigate procrastination. Each worker faces a single task that yields a fixed identical reward v and requires to be performed only once within three periods. However, their manager stops giving the reward once at least one worker completes it. When $k \leq n$ workers undertake the task in the same period, it generates payoff kv and the manager equally splits it, giving reward v to each of the workers. Thus, the competition considered here is innocuous to those who do not procrastinate because each worker is guaranteed the right to perform the task in the first period regardless of what the others do.

The main result of this paper is that the introduction of such competition can delay the completion of their tasks. Moreover, there is a case that the competition delays completion in which only one worker severely underestimates the degree of future self-control problems. The result suggests that the mere existence of a single naive present-biased worker can undermine the overall performance of organizations.

To understand the logic behind the result, note that we often procrastinate because we believe that we will perform the tasks in the future. In other words, if we are certain that we will not perform the tasks in the future, we probably do not procrastinate. Because sophisticated workers are perfectly aware of the magnitude of their future self-control problems, they never procrastinate as a result of holding a false belief that their future-selves will complete earlier in the future. However, among partially naive workers who underestimate the magnitude of their future self-control problems, the introduction of competition has positive and negative effects on earlier completion. The positive effect is that workers' incentive to complete earlier increases to receive a reward before his or her coworkers take it. The negative effect is that workers' incentive to complete earlier decreases since workers more strongly believe that their future-selves will complete earlier in the future. Therefore, the negative effect may outweigh and delay the completion.

There are a number of papers that investigate a single representative time-inconsistent agent's behavior or interactions between time-consistent agents and time-inconsistent agents. These studies include Akerlof (1991), Laibson (1997), O'Donoghue and Rabin (1999a, b, 2001, 2008), Gilpatric (2008), Heidhues and Kőszegi (2010), and Bisin et al. (2015). However, fewer papers analyze interactions among time-inconsistent agents, which includes BC, Battaglini et al. (2005), Chade et al. (2008), and Hsiaw (2013).

My analysis is closest to BC. They consider competition among sophisticated agents with present-biased preferences, who are perfectly aware of their future self-control problems. They find that the competition always mitigates procrastination since with sophisticated agents, the introduction of competition does not have any negative impact on earlier completion. In contrast, this study shows that even when there is only one worker who severely underestimates the degree of future self-control problems, the form of competition considered in BC may exacerbate procrastination.

I next explain preferences and beliefs. Section 3 presents the model for a single-worker case. Section 4 introduces competition among workers. A brief conclusion follows. All proofs are in the Appendix.

2 Present-biased preferences and beliefs

To analyze workers with time-inconsistent preferences who have a tendency to procrastinate, I assume that workers have present-biased preferences or quasi-hyperbolic preferences, which are introduced by Phelps and Pollak (1968). In particular, a worker's total utility at period t is given by

$$U^t\left(u_t, u_{t+1}, \ldots, u_T\right) \equiv u_t + \beta \sum_{s=t+1}^{T} \delta^{s-t} u_s,$$

where u_t represents the instantaneous utility in period t, $\delta \in (0, 1)$ and $\beta \in (0, 1]$. β captures the degree of present bias. A smaller β signifies a larger bias for the present over the future. For $\beta = 1$, workers have the standard time-consistent preferences, exhibiting no present-bias. For $\beta < 1$, workers have a bias for the present.

Following the formulation of partial naivete introduced by O'Donoghue and Rabin (2001), workers may underestimate the magnitude of their present-bias that they will have in the future. Specifically, self-t of a worker, his period-t incarnation, believes that his future selves will choose his behavior based on $\hat{\beta}$, not true value β, with $\beta \leq \hat{\beta} \leq 1$, where $\hat{\beta}$ is the worker's beliefs about the degree of self-control problems that his future selves will face. A worker with $\hat{\beta} = 1$ is called naif, for he is completely unaware of the fact that he will face self-control problems. A worker with $\hat{\beta} = \beta$ is called sophisticate, for he perfectly predicts the degree of his future self-control problems.

3 Benchmark model: a single worker case

In this section, I investigate a single-worker case. The model is essentially identical to O'Donoghue and Rabin (1999a), except that I incorporate partial naivete. Suppose there is a task that requires to be performed only once within three periods $t = 1, 2, 3$. For period $t \in \{1, 2\}$, given that the task has not been performed, he can choose one of $A \equiv \{D, W\}$. When he chooses D in period t, meaning that he "does" his task, it incurs cost $c > 0$ in period t and generates reward $v > 0$ in period $t + 1$. If he chooses W in period $t = 1, 2$, meaning that he "waits" to do his task, the same task is available in period $t + 1$. I assume for notational simplicity that, if the task is available in period 3, he must complete it then, which incurs c in period 3 and generates v in period 4.

I assume that $-c + \beta\delta v \geq 0$ so that the net value of the task is positive in every period and $\delta \in (0, 1)$ so that waiting is costly.

I adopt a solution concept called perception-perfect strategies (PPS) that are considered in O'Donoghue and Rabin (2001). Let $s = (a_1, a_2)$ represent a strategy profile, where $a_t \in A$ is a strategy in period t. Let $\hat{a}_2$ represent self-1's belief about self-2's strategy a_2. Let $U^1\left(a_1, \hat{a}_2, \beta\right)$ be the worker's total utility at period 1 from choosing $a_1 \in A$, given that self-2 follows $\hat{a}_2$. Let $U^2\left(a_2, \beta\right)$ be the worker's total utility at period 2 from choosing $a_2 \in A$. Then, the following is satisfied:

$$
\begin{aligned}
U^1\left(a_1 = D, \hat{a}_2, \beta\right) &= U^2\left(a_2 = D, \beta\right) = -c + \beta\delta v,\ \forall \hat{a}_2 \in A;\\
U^1\left(a_1 = W, \hat{a}_2 = D, \beta\right) &= U^2\left(a_2 = W, \beta\right) = \beta\delta\left\{-c + \delta v\right\};\\
U^1\left(a_1 = W, \hat{a}_2 = W, \beta\right) &= \beta\delta^2\left\{-c + \delta v\right\}.
\end{aligned}
$$

Definition 3.1 Given β, $\hat{\beta}$ and δ, a perception-perfect equilibrium of the single-worker model is a strategy profile $s^{pp} = \left(a_1^{pp}, a_2^{pp}\right)$ and self-1's belief $\hat{a}_2$ such that

1. $U^2\left(\hat{a}_2, \hat{\beta}\right) \geq U^2\left(a_2, \hat{\beta}\right),\ \forall a_2 \in A;$
2. $U^2\left(a_2^{pp}, \beta\right) \geq U^2\left(a_2, \beta\right),\ \forall a_2 \in A;$
3. $U^1\left(a_1^{pp}, \hat{a}_2, \beta\right) \geq U^1\left(a_1, \hat{a}_2, \beta\right),\ \forall a_1 \in A.$

Condition 1 states that self-1 holds a belief $\hat{a}_2$ such that self-2 chooses his action "optimally" according to $\hat{\beta}$, which is not necessarily correct. Conditions 2 and 3 require that in each period t, the worker chooses his action to maximize his period-t total utility, given his belief $\hat{a}_2$. That is, a perception-perfect equilibrium corresponds to a subgame-perfect equilibrium in the game perceived by the worker who believes that his future selves will choose his behavior based on $\hat{\beta}$, not true value β.

For $t = 1, 2$, self-t with β prefers to complete the task in period t rather than period $t + 1$ if and only if

$$
-c + \beta\delta v \geq \beta\delta\left\{-c + \delta v\right\} \text{ or } c \leq \frac{(1-\delta)\,\beta\delta v}{1 - \beta\delta} \equiv L(\beta).
$$

Moreover, self-1 with β prefers to complete the task in period 1 rather than period 3 if and only if

$$-c + \beta\delta v \geq \beta\delta^2 \{-c + \delta v\} \text{ or } c \leq \frac{\left(1-\delta^2\right)\beta\delta v}{1-\beta\delta^2} \equiv H(\beta).$$

Thus, a worker with β satisfying $c \leq L(\beta)$ prefers to complete in the current period; a worker with β satisfying $c \in (L(\beta), H(\beta)]$ prefers to complete one period later; and a worker with β satisfying $c > H(\beta)$ prefers to complete two periods later. Similarly, self-1 with belief $\hat{\beta}$ satisfying $c \leq L\left(\hat{\beta}\right)$ believes that self-2 prefers to complete in $t = 2$, while one satisfying $c > L\left(\hat{\beta}\right)$ believes that self-2 prefers to complete in $t = 3$.

Notice that I assume $\delta < 1$ so that $L(\beta) < H(\beta)$ for any $\beta \in (0, 1)$, in contrast to the literature on present-biased preferences which often assumes $\delta = 1$ for simplicity. However, as I show in this paper, not only β, but also $\delta < 1$ plays an important role to determine the choice by worker(s). When $L(\beta) < c < H(\beta)$, self-1 with β prefers to wait until period 2, but not until period 3. Notice also that both $L(\beta)$ and $H(\beta)$ are increasing in β. Lastly, let $\hat{\beta}^* \in (\beta, 1)$ be such that $L\left(\hat{\beta}^*\right) = H(\beta)$.

Proposition 3.1 *Fix any* $\beta \in (0, 1)$, $\hat{\beta} \in [\beta, 1]$ *and* $\delta \in (0, 1)$. *For* $\hat{\beta} \in \left[\beta, \hat{\beta}^*\right]$,

$$\left(s^{pp}, \hat{a}_2\right) = \begin{cases} ((D, D), D,) & \text{if } c \leq L(\beta); \\ ((W, W), D) & \text{if } c \in \left(L(\beta), L\left(\hat{\beta}\right)\right]; \\ ((D, W), W) & \text{if } c \in \left(L\left(\hat{\beta}\right), H(\beta)\right]; \\ ((W, W), W) & \text{if } c > H(\beta). \end{cases}$$

For $\hat{\beta} \in \left(\hat{\beta}^*, 1\right]$,

$$\left(s^{pp}, \hat{a}_2\right) = \begin{cases} ((D, D), D) & \text{if } c \leq L(\beta); \\ ((W, W), D) & \text{if } c \in \left(L(\beta), L\left(\hat{\beta}\right)\right]; \\ ((W, W), W) & \text{if } c > L\left(\hat{\beta}\right). \end{cases}$$

Note that if the worker were time consistent; that is, $\beta = \hat{\beta} = 1$, his subgame-perfect strategy would be to play D in every period. This proposition says that if the worker is time-inconsistent, but sophisticated, then his perception-perfect strategy s^{pp} is (D, W) when $c \in (L(\beta), H(\beta)]$ and (W, W) when $c > H(\beta)$. Although a sophisticate does not choose D all the time, he chooses W not because he incorrectly foresees his future behavior, but simply because he prefers to complete it later rather than now.

Corollary 3.1 *Consider a worker who is sufficiently close to a sophisticate; i.e.,* $\hat{\beta} \in \left[\beta, \hat{\beta}^*\right]$. *Then, the perception-perfect strategy is not monotone in cost c: if c decreases from region* $\left(L\left(\hat{\beta}\right), H(\beta)\right]$ *to* $\left(L(\beta), L\left(\hat{\beta}\right)\right]$, *his perception-perfect strategy in period* 1 *changes from* D *to* W.

For a worker with $\hat{\beta} \in \left[\beta, \hat{\beta}^*\right]$, when $c \in \left(L\left(\hat{\beta}\right), H(\beta)\right]$, the cost of task is high enough for self-1 to believe that self-2 will choose W, i.e., $\hat{a}_2 = W$. Then, since he prefers to complete the task in period 1 rather than wait until period 3, self-1 completes the task in period 1, i.e., $a_1^{pp} = D$. However, when the cost decreases to $c \in \left(L(\beta), L\left(\hat{\beta}\right)\right]$, self-1 now (incorrectly) believes that self-2 will choose D, i.e., $\hat{a}_2 = D$, which undermines his incentive to undertake the task in period 1, and thus self-1 chooses $a_1^{pp} = W$. This logic will be extended to a multiple-worker case.

When $\hat{\beta} \in \left[\beta, \hat{\beta}^*\right]$, as the degree of naivete gets worse (as $\hat{\beta}$ becomes larger), region $\left(L(\beta), L\left(\hat{\beta}\right)\right]$ expands and region $\left(L\left(\hat{\beta}\right), H(\beta)\right]$ shrinks, which induces to delay. If $\hat{\beta}$ increases to $\hat{\beta} \in \left(\hat{\beta}^*, 1\right]$, self-1 now believes that self-2 will choose D, which lowers his incentive to complete in period 1. Thus, the following corollary obtains.

Corollary 3.2 *For any beliefs $\hat{\beta}'$ and $\hat{\beta}$ with $\hat{\beta}' \geq \hat{\beta}$, if a worker with $\hat{\beta}'$ completes the task in period t, then a worker with $\hat{\beta}$ completes it in period t or earlier. That is, as the worker becomes closer to a sophisticate, he completes his task in the same period or earlier.*

4 Competition among procrastinators

In this section, I introduce the specific form of competition among n workers that is considered in BC to see if that can mitigate procrastination. Each worker faces the same task as in Sect. 3 that requires to be performed only once within three periods $t = 1, 2, 3$. However, their manager stops giving reward v to each worker once at least one worker completes it.[1]

When $k \leq n$ workers undertake the task in the same period, it generates payoff kv and the manager equally splits it, giving reward v to each of the workers. Thus, this competition is innocuous to those who do not procrastinate because everyone is guaranteed the right to perform the task in period 1 regardless of what the others do.

Let β_i and $\hat{\beta}_i$ be worker i's present-bias parameter and belief thereof, respectively. Denote $\beta = (\beta_1, \ldots, \beta_n)$ and $\hat{\beta} = \left(\hat{\beta}_1, \ldots, \hat{\beta}_n\right)$. I assume that $\beta_{\max} \equiv \max\{\beta_1, \ldots, \beta_n\}$ and $\hat{\beta}_{\max} \equiv \max\left\{\hat{\beta}_1, \ldots, \hat{\beta}_n\right\}$ are common knowledge among the workers. I also assume that both the manager and all workers use the identical discount factor $\delta \in (0, 1)$ and $c \leq \beta_i \delta v$, $i = 1, \ldots, n$. Thus, the manager prefers to have the task completed as early as possible.

I introduce a solution concept called perception-perfect (PP) equilibrium, which is an extension of perception-perfect strategies in O'Donoghue and Rabin (2001) to a multiple-agent model. Before defining the solution concept, I introduce several notations similar to those in Sect. 3. Let $s_t = (a_{1t}, \ldots, a_{nt})$ represent a strategy profile of period t, where $a_{it} \in A$ is a strategy of worker i in period $t = 1, 2$. Let

[1] BC consider the case of $t = \infty$ and $\left(\hat{\beta}_1, \ldots, \hat{\beta}_n\right) = (\beta_1, \ldots, \beta_n)$.

$a_{-it} \in A \times \cdots \times A$ denote a profile of period-t strategies for the workers other than i. Abusing notation, let $W_{-i} = (W, \ldots, W)$ represent a profile of actions by the workers other than i in which every opponent chooses W. Let D_{-i} represent a profile of actions by the workers other than i in which at least one opponent chooses D. Let $\hat{a}_{i2}$ be worker i's belief in period 1 about his period-2 strategy. Denote $s = (s_1, s_2)$ and $\hat{s}_2 = \left(\hat{a}_{12}, \ldots, \hat{a}_{n2}\right)$. Let $U_i^1\left(a_{i1,}, a_{-i1}, \hat{s}_2, \beta_i\right)$ be worker i's perceived total utility at period 1 from choosing $a_{i1} \in A$, given that the workers other than i choose a_{-i1} in period 1 and each worker acts consistently with $\hat{s}_2$ in period 2. Let $U_i^2\left(a_{i2,}, a_{-i2}, \beta_i\right)$ be worker i's total utility at period 2 from choosing $a_{i2} \in A$, given that the workers other than i choose a_{-i2} in period 2. Then, the following is satisfied:

$$
\begin{aligned}
U_i^1\left(D, a_{-i1}, \hat{s}_2, \beta_i\right) &= U_i^2\left(D, a_{-i2}, \beta_i\right) = -c + \beta_i \delta v, \ \forall a_{-i1}, \ \forall a_{-i2}, \ \forall \hat{s}_2; \\
U_i^1\left(W, W_{-i}, \left(D, \hat{a}_{-i2}\right), \beta_i\right) &= U_i^2\left(W, W_{-i}, \beta_i\right) = \beta_i \delta \left\{-c + \delta v\right\}, \ \forall \hat{a}_{-i2}; \\
U_i^1\left(W, W_{-i}, \left(W, W_{-i}\right), \beta_i\right) &= \beta_i \delta^2 \left\{-c + \delta v\right\}; \\
U_i^1\left(W, D_{-i}, \hat{s}_2, \beta_i\right) &= U_i^1\left(W, W_{-i}, \left(W, D_{-i}\right), \beta_i\right) \\
&= U_i^2\left(W, D_{-i}, \beta_i\right) = 0, \ \forall \hat{s}_2.
\end{aligned}
$$

Definition 4.1 Given β, $\hat{\beta}$ and δ, a perception-perfect equilibrium of the n-worker model is a strategy profile $s^{PP} = \left\{\left(a_{1t}^{PP}, \ldots, a_{nt}^{PP}\right)\right\}_{t=1}^{2}$ and beliefs $\hat{s}_2 = \left(\hat{a}_{12}, \ldots, \hat{a}_{n2}\right)$ such that:

1. $U_i^2\left(\hat{a}_{i2}, \hat{a}_{-i2}, \hat{\beta}_i\right) \geq U_i^2\left(a_{i2}, \hat{a}_{-i2}, \hat{\beta}_i\right), \ \forall a_{i2} \in A, \ i = 1, \ldots, n.$
2. $U_i^2\left(a_{i2}^{PP}, a_{-i2}^{PP}, \beta_i\right) \geq U_i^2\left(a_{i2}, a_{-i2}^{PP}, \beta_i\right), \ \forall a_{i2} \in A, \ i = 1, \ldots, n;$
3. $U_i^1\left(a_{i1}^{PP}, a_{-i1}^{PP}, \hat{s}_2, \beta_i\right) \geq U_i^1\left(a_{i1}, a_{-i1}^{PP}, \hat{s}_2, \beta_i\right), \ \forall a_{i1} \in A, \ i = 1, \ldots, n.$

Condition 1 states that workers in period 1 hold beliefs $\hat{s}_2$ such that their period-2 actions are best response to each other according to $\hat{\beta}$, which is not necessarily correct. Thus, perception-perfect equilibrium corresponds to subgame-perfect equilibrium in which each subgame is a subgame of the game perceived by the workers who believe that their future selves will choose their behaviors based on $\hat{\beta}$, not true values β.

In perception-perfect equilibria, all workers underestimate the degree of future present-bias of the worker with $\hat{\beta} = \hat{\beta}_{\max}$ to the same degree as he underestimates about his own future present-bias. Thus, all workers correctly anticipate that self-t of worker with $\hat{\beta} = \hat{\beta}_{\max}$ believes that his self-$t+1$ will base his decision on $\hat{\beta}_{\max}$. Thus, workers correctly anticipate others' current behaviors using identically incorrect beliefs about future behaviors of the worker who is thought to face the most severe future self-control problem. However, due to the coordination feature of the game, it is not necessary to impose any further assumption as to how workers estimate the degree of present-bias that others will face in the future.[2]

[2] In general, to analyze multiple partially naive workers, one must specify how each worker forms beliefs about others' beliefs. One can think of many different model specifications. For example, one can assume that in equilibrium, each worker forms correct beliefs about others' current and future behaviors, while forming incorrect belief about his own future behaviors; each worker forms correct beliefs about others' current behaviors but incorrect beliefs about his and others' future behaviors (I thank an anonymous referee

Since this is a coordination game, there exist many equilibria. Furthermore, when a (perceived) subgame has multiple equilibria, it takes the form of a stag hunt game, which has two pure-strategy Nash equilibria: risk-dominant and payoff-dominant strategies. Especially, it is a perception-perfect equilibrium for everyone to choose D in period 1, because, by the assumption $-c + \beta\delta v \geq 0$, everyone prefers to complete in period 1 if he anticipates that at least one worker chooses D in period 1. Thus, competition can mitigate procrastination.

However, choosing D in period 1 may not be plausible because in some case, everyone choosing W is payoff-dominant: everyone can improve by coordinating to W. For example, suppose $c \in \left(L(\beta_{\max}), L\left(\hat{\beta}_{\max}\right)\right]$. Then, everyone believes that all workers prefer to wait until period 2 to complete because everyone in period 1 prefers to delay ($c > L(\beta_i)$ for every i) and everyone in period 1 believes that at least one worker chooses D in period 2 ($c < L\left(\hat{\beta}_{\max}\right)$). Thus, everyone is better off coordinating to W than choosing D in period 1.

This paper focuses on a perception-perfect equilibrium in which workers coordinate to a payoff-dominant strategy in each perceived subgame. That is, whenever there are multiple perception-perfect equilibria, workers coordinate their current actions to a payoff-dominant strategy according to their true present-bias β, given that their future selves will coordinate their actions to a payoff-dominant strategy according to $\hat{\beta}$.

This assumption—as well as the assumption all workers believe that the worker who will face the most severe future self-control problem will choose his future behavior based on $\hat{\beta}_{\max}$—fits well with a setting in which workers communicate and/or interact closely, because workers want to share their work plan in order to coordinate their actions without missing the reward. Since they can guarantee the reward regardless of what the others do by completing the task immediately, they have no incentive to strategically communicate, thus fully revealing their true work plan. In such a situation, voluntary communication among workers can lead to learning the work plan of the worker with $\hat{\beta}_{\max}$ and coordinating to the payoff-dominant strategy.

Indeed, Miller et al. (2002) and Miller and Moser (2004) find that communication among workers promotes coordination to a payoff-dominant strategy in both the stag hunt and prisoners' dilemma games. Social interaction and cultural learning also promote it (see Bolton et al. 2016; Golman and Page 2010).

Proposition 4.1 *For all $\left(\beta, \hat{\beta}, \delta\right)$, the following beliefs $\hat{s} = \left(\hat{a}_{12}, \ldots, \hat{a}_{n2}\right)$ and strategy profile $s^{PP} = \left\{\left(a_{1t}^{PP}, \ldots, a_{nt}^{PP}\right)\right\}_{t=1}^{2}$ are a perception-perfect equilibrium:*

- $\hat{s} = \begin{cases} (D, \ldots, D) & \text{if } c \leq L\left(\hat{\beta}_{\max}\right); \\ (W, \ldots, W) & \text{if } c > L\left(\hat{\beta}_{\max}\right). \end{cases}$
- $\left(a_{12}^{PP}, \ldots, a_{n2}^{PP}\right) = \begin{cases} (D, \ldots, D) & \text{if } c \leq L(\beta_{\max}); \\ (W, \ldots, W) & \text{if } c > L(\beta_{\max}). \end{cases}$

Footnote 2 continued
for this argument). Moreover, if each worker incorrectly believe others' future or current behaviors, we also have to specify how wrong it is—whether each worker is wrong about others' behaviors to a greater or lesser degree, or the same degree as when he is wrong about his own future behaviors.

- $\left(a_{11}^{PP}, \ldots, a_{n1}^{PP}\right) = \begin{cases} (D, \ldots, D) & \textit{if } c \le L(\beta_{\max}); \\ (W, \ldots, W) & \textit{if } c \in (L(\beta_{\max}), H(\beta_{\max})] \textit{ and } c \le L\left(\hat{\beta}_{\max}\right); \\ (D, \ldots, D) & \textit{if } c \in (L(\beta_{\max}), H(\beta_{\max})] \textit{ and } c > L\left(\hat{\beta}_{\max}\right); \\ (W, \ldots, W) & \textit{if } c > H(\beta_{\max}). \end{cases}$

Moreover, in the above perception-perfect equilibrium, in each perceived subgame, everyone chooses a payoff-dominant perception-perfect equilibrium strategy whenever available; that is, the following is satisfied for any perception-perfect equilibrium beliefs $\hat{s}' = (\hat{a}'_{12}, \ldots, \hat{a}'_{n2})$ *and strategy profile* $s^{PP\prime} = \left\{(a_{1t}^{PP\prime}, \ldots, a_{nt}^{PP\prime})\right\}_{t=1}^{2}$*:*

1. $U_i^2\left(\hat{a}_{i2}, \hat{a}_{-i2}, \hat{\beta}_i\right) \ge U_i^2\left(\hat{a}'_{i2}, \hat{a}'_{-i2}, \hat{\beta}_i\right), \ \forall\, i = 1, \ldots, n;$
2. $U_i^2\left(a_{i2}^{PP}, a_{-i2}^{PP}, \beta_i\right) \ge U_i^2\left(a_{i2}^{PP\prime}, a_{-i2}^{PP\prime}, \beta_i\right), \ \forall\, i = 1, \ldots, n;$
3. $U_i^1\left(a_{i1}^{PP}, a_{-i1}^{PP}, \hat{s}_2, \beta_i\right) \ge U_i^1\left(a_{i1}^{PP\prime}, a_{-i1}^{PP\prime}, \hat{s}'_2, \beta_i\right), \ \forall\, i = 1, \ldots, n.$

The proposition shows that competition can exacerbate procrastination. Notice that $\hat{\beta}_i < \hat{\beta}^*$ if and only if $L(\hat{\beta}_i) < H(\beta_i)$. Thus, when $\hat{\beta}_i < \hat{\beta}^*$, he is so sophisticated that it is possible to have $L(\beta_i) \le L(\hat{\beta}_i) < c < H(\beta_i)$; that is, self-1 prefers to delay by exactly one period (i.e., $L(\beta_i) < c < H(\beta_i)$) but anticipates that self-2 will prefer to delay too (i.e., $L(\hat{\beta}_i) < c$). Then, without competition, worker i would choose D in period 1 because he believes that he will choose W in period 2 and he prefers not to wait until period 3 to complete the task. On the other hand, consider the competition among workers whose $\left(\beta, \hat{\beta}, \delta\right)$ satisfies $c \in \left(L(\beta_{\max}), L\left(\hat{\beta}_{\max}\right)\right]$. Then, workers believe that the worker with $\hat{\beta} = \hat{\beta}_{\max}$ will choose D in period 2 regardless of what the others do, which makes D a best response to each other in period 2. Moreover, since $L(\beta_{\max}) < c$, everyone prefers to wait until period 2 to complete the task. Thus, coordinating to W in period 1 is the perception-perfect equilibrium.

Further, as stated in the following corollary, competition can delay completion even when there is only one worker who severely underestimates the degree of future self-control problems.

Corollary 4.1 *Suppose* $\beta_i = \beta$ *for every* $i = 1, \ldots, n$*;* $\hat{\beta}_i \in \left[\beta, \hat{\beta}^*\right]$ *such that* $L(\beta) < L\left(\hat{\beta}_i\right) < c \le H(\beta)$ *for every* $i = 1, \ldots, n-1$*; and* $L(\beta) < c < L\left(\hat{\beta}_n\right)$*. Then, among workers* $\{1, \ldots, n-1\}$*, with or without competition, every worker chooses* D *in period* 1*. However, with competition among workers* $\{1, \ldots, n\}$*, every worker chooses* W *in period* 1 *in the perception-perfect equilibrium described in Proposition* 4.1.

Other than worker n, each of $(n-1)$ workers is sufficiently close to a sophisticate. Moreover, since $L(\beta) < L\left(\hat{\beta}_i\right) < c \le H(\beta)$ for every $i = 1, \ldots, n-1$, with or without competition, everyone chooses D in period 1 since they expect to choose W in period 2. However, with competition among n workers including worker n, who is naive enough that $L(\beta_n) < c < L\left(\hat{\beta}_n\right)$, they believe—possibly through voluntary communication—that they will complete in period 2, inducing them to coordinate to W in period 1. In this sense, the competition can undermine workers' incentive to complete earlier since with competition, workers more strongly believe that their future-selves will complete earlier. As in Corollary 3.1, workers tend to procrastinate when they believe that their future selves will complete earlier. This logic holds even when we add only one worker who is incorrectly believed to be a "hard worker" tomorrow.

Moreover, as in Corollary 3.1, perception-perfect equilibrium strategies are not monotone in cost c.

Corollary 4.2 *Suppose every worker is sufficiently close to a sophisticate, satisfying* $\beta_{\max} \le \hat{\beta}_{\max} \le \hat{\beta}^*$. *If cost* c *decreases from region* $\left(L\left(\hat{\beta}_{\max}\right), H(\beta_{\max})\right]$ *to* $\left(L(\beta_{\max}), L\left(\hat{\beta}_{\max}\right)\right]$, *the period-*1 *perception-perfect equilibrium strategy described in Proposition 4.1 changes from* D *to* W *for every worker.*

The logic behind the corollary is the same as the single-worker case. When $\hat{\beta}_{\max} \in \left[\beta_{\max}, \hat{\beta}^*\right]$, with $c \in \left(L\left(\hat{\beta}_{\max}\right), H(\beta_{\max})\right]$, the cost is high enough for self-1 to believe that they will choose W in period 2. Then, since they prefer to complete in period 1 rather than period 3, they complete in period 1. However, when the cost decreases to $c \in \left(L(\beta_{\max}), L\left(\hat{\beta}_{\max}\right)\right]$, self-1 now believes that they will choose D in period 2, which makes W a best response to each other in period 1.

To reinforce the intuition behind the above two corollaries, consider competition among the same $(n-1)$ workers as Corollary 4.1, but in period 2 they face an additional competitor who immediately completes for sure. Due to competition with this "hard worker" in period 2, these $(n-1)$ workers now believe that they will complete in period 2 for sure, undermining their incentive to complete in period 1. Therefore, they can agree to coordinate (possibly through voluntary communication) not to complete in period 1, which results in procrastination. This negative effect of competition can be socially significant since this logic holds for even large n.

Extension

This study assumes that workers coordinate to a payoff-dominant strategy W whenever available in each perceived subgame, although everyone choosing a risk-dominant strategy D is also a Nash equilibrium in each perceived subgame. In what follows, I show that coordinating to a payoff-dominant strategy W is the unique equilibrium in weakly undominated strategies if we consider the following extension to a continuous-time model. Assume that periods $t = 1, 2, 3$ correspond, respectively, to $[0, 1)$, $[1, 2)$, $[2, 3]$. The only differences from the main model are each worker can choose D at any point in time within each period $t = 1, 2, 3$, and their choices are observable. Assume that everyone prefers to complete in period 2 rather than period 1 so that both $(D, \ldots, D)$ and $(W, \ldots, W)$ are equilibria in the main model. Then, at any point in time within $[0, 1)$, choosing D before someone chooses D is weakly dominated by choosing D only after someone chooses D. Thus, everyone choosing D in period 1 cannot be an equilibrium in weakly undominated strategies.

5 Conclusion

Counterintuitively, I show that with partially naive workers, the introduction of competition may delay the completion of their tasks. This result suggests that not only present-bias but also the degree of naivete plays an important role in determining organizational performance. Moreover, the result holds even when there is only one worker who severely underestimates the degree of his future self-control problems. This result suggests that the mere existence of a single naive present-biased worker can be an important factor that determines the performance of even large organizations. Moreover, it suggests that paternalistic policies ought to be carefully designed and implemented.

The key logic behind these results is that workers' incentive to complete earlier decreases if they strongly believe that their future-selves will complete earlier. Thus, to combat procrastination, one needs to design schemes in which workers believe that they will not complete early in the future; e.g., reducing competition over time, increasing cost over time (see O'Donoghue and Rabin 2008), or even enforcing no work day tomorrow.

I considered a specific form of competition considered in BC in which all workers can receive reward when they complete the task simultaneously. Another extreme form of competition is to provide reward to only one winner when multiple workers complete first. With this competition, procrastination will be mitigated in the sense that at least one worker completes in the first period. However, one can imagine that this form of competition would reduce incentives of many workers to complete the task as common in winner-take-all contests, which is not ideal in certain settings.

Appendix

Proof of Proposition 3.1

Let me first check the optimality of $\hat{a}_2$. $U^2\left(a_2 = D, \hat{\beta}\right) = -c + \hat{\beta}\delta v \geq \hat{\beta}\delta\{-c + \delta v\} = U^2\left(a_2 = W, \hat{\beta}\right)$ if and only if $c \leq L\left(\hat{\beta}\right)$, yielding $\hat{a}_2 = D$ if $c \leq L\left(\hat{\beta}\right)$ and $\hat{a}_2 = W$ if $c > L\left(\hat{\beta}\right)$. The same argument yields the optimality of a_2^{pp}; i.e., $a_2^{pp} = D$ if $c \leq L(\beta)$ and $a_2^{pp} = W$ if $c > L(\beta)$.

To consider a_1^{pp}, first suppose $c \leq L\left(\hat{\beta}\right)$. Then, $\hat{a}_2 = D$. $U^1\left(a_1 = D, \hat{a}_2 = D, \beta\right) = -c + \beta\delta v \geq \beta\delta\{-c + \delta v\} = U^1\left(a_1 = W, \hat{a}_2 = D, \beta\right)$ if and only if $c \leq L(\beta)$. Therefore, $a_1^{pp} = D$ if $c \leq L(\beta)$ and $a_1^{pp} = W$ if $c > L(\beta)$. Similarly, suppose $c > L\left(\hat{\beta}\right)$. Then, $\hat{a}_2 = W$. $U^1\left(a_1 = D, \hat{a}_2 = W, \beta\right) = -c + \beta\delta v \geq \beta\delta^2\{-c + \delta v\} = U^1\left(a_1 = W, \hat{a}_2 = W, \beta\right)$ if and only if $c \leq H(\beta)$. Therefore, $a_1^{pp} = D$ if $c \leq H(\beta)$ and $a_1^{pp} = W$ if $c > H(\beta)$.

Note that $L\left(\hat{\beta}\right) \leq H(\beta)$ for $\hat{\beta} \in \left[\beta, \hat{\beta}^*\right]$, while $L\left(\hat{\beta}\right) > H(\beta)$ for $\hat{\beta} \in \left(\hat{\beta}^*, 1\right]$. Combining these results completes the proof. □

Proof of Proposition 4.1

Let me first prove that beliefs $\hat{s}_2$ are best response to each other according to $\hat{\beta}$. Suppose $c \leq L\left(\hat{\beta}_{\max}\right)$. Then, self-1 workers believe that self-2 with $\hat{\beta} = \hat{\beta}_{\max}$ prefers to complete in period 2, yielding $\hat{s}_2 = (D, \ldots, D)$. Suppose $c > L\left(\hat{\beta}_{\max}\right)$. Then, self-1 workers believe that self-2 of every worker prefers to choose W in period 2, supporting $\hat{s}_2 = (W, \ldots, W)$ as payoff-dominant equilibrium beliefs.

Similarly, let me show that the period-2 strategy profile $\left(a_{12}^{PP}, \ldots, a_{n2}^{PP}\right)$ is a best response to each other according to β. Suppose $c \leq L(\beta_{\max})$. Then, self-2 with $\beta = \beta_{\max}$ prefers to complete in period 2, yielding $\left(a_{12}^{PP}, \ldots, a_{n2}^{PP}\right) = (D, \ldots, D)$. Suppose $c > L(\beta_{\max})$. Then, self-2 of every worker prefers to choose W in period 2. Thus, $\left(a_{12}^{PP}, \ldots, a_{n2}^{PP}\right) = (W, \ldots, W)$ is the payoff-dominant equilibrium strategy profile.

Now let me show that the period-1 strategy profile $\left(a_{11}^{PP}, \ldots, a_{n1}^{PP}\right)$ is a best response to each other according to β, given that their period-2 selves choose $\hat{s}_2$. (Case 1) Suppose $c \leq L(\beta_{\max})$. Then, self-1 with $\beta = \beta_{\max}$ prefers to complete in period 1, yielding $\left(a_{11}^{PP}, \ldots, a_{n1}^{PP}\right) = (D, \ldots, D)$. (Case 2) Suppose $c \in (L(\beta_{\max}), H(\beta_{\max})]$ and $c \leq L\left(\hat{\beta}_{\max}\right)$. Then, $\hat{s}_2 = (D, \ldots, D)$, and self-1 of every worker prefers to receive the reward in period 2 rather than period 1. Thus, $\left(a_{11}^{PP}, \ldots, a_{n1}^{PP}\right) = (W, \ldots, W)$ is the payoff-dominant equilibrium strategy profile. (Case 3) Suppose $c \in (L(\beta_{\max}), H(\beta_{\max})]$ and $c > L\left(\hat{\beta}_{\max}\right)$. Then, $\hat{s}_2 = (W, \ldots, W)$, but self-1 with $\beta = \beta_{\max}$ does not want to wait until period 3. Thus, self-1 of worker with $\beta = \beta_{\max}$ prefers to choose D in period 1, yielding $\left(a_{11}^{PP}, \ldots, a_{n1}^{PP}\right) = (D, \ldots, D)$. (Case 4) Suppose $c > H(\beta_{\max})$. Then, self-1 of every worker prefers to receive the reward in period 2 or 3 rather than period 1. Thus, $\left(a_{11}^{PP}, \ldots, a_{n1}^{PP}\right) = (W, \ldots, W)$ is the payoff-dominant equilibrium strategy profile. Combining the above results completes the proof. □

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