Self Control in the Face of Multiple Projects

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Abstract

We study how people with present bias make choices when they face multiple, multi-stage projects. Naive people (naifs), who are unaware of their self-control problems, may start a project, but never finish it. They may multitask; that is, start a new project before finishing an old project. They may also start a project with a lower net present value (NPV) before they start one with a higher NPV. These behaviors are suboptimal from a long-run perspective. Sophisticated people (sophisticates), who are aware of their self-control problems, do not start a project but not finish it. However, like naifs, they may multitask and not prioritize projects on the basis of NPV. Multitasking is more likely when the projects all have low start-up costs and the projects with the lowest start-up costs have high costs to finish. People are more likely to choose a suboptimal project sequence if the high NPV projects have high start-up costs. If allowed to choose the cost structure endogenously, both naifs and sophisticates prioritize projects by NPV but choose a cost structure that is more likely to lead them to multitask.

What can we do about these anomalies? We offer two remedies. First, adding projects to project portfolios (i.e., increasing load) increases the absolute value of completing the current project stage for naifs, and hence alleviates procrastination, even when they do not actually work on the added projects. Increasing load also alters the relative values of completing different project stages. Therefore, for both naifs and sophisticates, it can reduce the possibility of multitasking and suboptimal sequence if the added projects are carefully chosen.

Second, increasing people's awareness about their present bias (i.e., turning naifs into sophisticates) can also alleviate these anomalies. When people face a given project portfolio, it is good to be sophisticated. If allowed to select projects at a cost to form their project portfolios, naifs include more projects in their portfolio than sophisticates, but they may select projects that

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they do not start or finish. Naifs may also complete more projects or complete projects with higher net present values than sophisticates complete. Thus, it may be good to be naive from a long-run perspective.

Keywords: Project management; Multitasking; Sequencing; Procrastination; Present-biased preferences; Self control

1 Introduction

At work and in daily life, people often face competing demands for their time and attention from multiple projects or tasks. These projects typically require costly effort to complete over a period of time but yield only future benefits. Casual observation and empirical evidence suggest that people are inefficient in scheduling multiple projects (i.e., when to do which project), and their inefficiency is reflected in three anomalies. The first is procrastination, which is well documented in project management literature and is sometimes known as student syndrome (Larson and Gray 2021). The second is multitasking, whereby people juggle projects or tasks. Multitasking is common among knowledge workers like software engineers (Perlow 1999), information consultants (González and Mark 2005), physicians (KC 2014), and judges (Bray et al. 2016), and it often hampers productivity (Hammond 2016). The third is not prioritizing important projects, which we refer to as suboptimal project sequencing (Boyse 2018). For example, doctors may prioritize easy tasks, which hampers productivity in the long run (Ibanez at al. 2018, KC et al. 2020). What causes these anomalies?

In this paper, we seek to provide an explanation based on people's present bias. We study a model in which people are faced with two projects. Both projects have two stages: a starting stage and a finishing stage. Both stages require costly effort to complete but result in a reward stream only after completion. Multitasking is defined as starting a new project before finishing an old project. Suboptimal project sequencing happens when people do not prioritize projects by their net present value (NPV). In this environment, rational people, who discount future rewards and costs exponentially and whose objective is to maximize their total discounted utility, start and finish the project with a higher NPV and then start and finish the project with a lower NPV. People with present bias, however, behave differently.

First, people with present bias may procrastinate. In particular, naifs, people who have present bias but are unaware of it, may start a project, but never finish it. Sophisticates, people who have present bias and are fully aware of it, always finish a project that they have started. These results have been shown in the literature when there is only one project (O'Donoghue and Rabin 1999, 2008). We show that in the context of multiple projects, they continue to hold true. Second, people with present bias may multitask by starting a new project before they finish an old one instead of completing the projects sequentially. This is inefficient because one of the projects could be completed sooner and reward received sooner if they completed the projects sequentially. Furthermore, when naifs multitask, at least one project is started but not finished. Multitasking is more likely to occur when projects all have low start-up costs but the projects with the lowest start-up costs have high finishing costs. Third, whereas rational people always prioritize projects on the basis of NPV, people with present-biased preferences may choose to work on low start-up cost projects first. A suboptimal project sequence is more likely to occur when the projects with high NPVs have high start-up costs. Whether and how people with present-biased preferences multitask or choose a suboptimal project sequence depends on the cost structure of the projects. When people can choose the cost structure endogenously, the suboptimal project sequence problem goes away. However, they choose a cost structure that is more likely to lead them to multitask.

If present bias is the cause for these anomalies, what can be done about it? We show that adding projects to a project portfolio (or increasing load) alleviates procrastination for naifs, even if they don't actually work on the added projects. Adding projects to a project portfolio may also prevent both naifs and sophisticates from multitasking and choosing a suboptimal sequence if the added projects are carefully chosen. In our framework, both the absolute value of completing a project stage and the relative values of competing different project stages depend on how people plan to schedule the remaining project stages in the future. Adding projects increases the absolute value of completing every project stage, and hence it alleviates procrastination for naifs. Adding a carefully chosen new project can increase the relative value of completing the "correct" stage more than that of completing the "wrong" stage. Therefore, it can guide people to avoid multitasking and choose the optimal project sequence.

Sophistication, or increasing the people's awareness of their self-control problem, can also alleviate all the anomalies. This, however, does not mean that it is always good to be sophisticated. When people with present bias face a given project portfolio, it is good to be sophisticated. It is good because sophistication leads to more completed projects, less multitasking, and more efficient sequencing. When they can select projects at a cost to create their project portfolios, relative to rational people, both naifs and sophisticates include too few projects in their portfolios. But naifs always include more projects in their portfolio than sophisticates do because they overestimate the values of the projects they have yet to work on. Naifs fail to anticipate that there might be projects that they select but never start and projects that they start but never finish. More interestingly, they also fail to anticipate that they may multitask or may not follow the optimal project sequence.

In contrast, sophisticates are fully aware of all these issues, so they are more selective in choosing projects. Although sophisticates always complete all of the projects they select but naifs may not, naifs may actually complete more projects than sophisticates, and they may also complete projects with higher NPVs than sophisticates do. Therefore, in this context, sophistication does not always pay. O'Donohue and Rabin (1999) show that when costs are immediate and rewards arrive in the future, sophistication alleviate procrastination, which is beneficial. We show that besides procrastination, sophistication also reduces the possibility of multitasking and suboptimal sequencing, but sophistication may not be beneficial when projects have to be chosen endogenously at a cost.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. In Section 3, we describe the model, show how rational agents behave as a benchmark, and show that present bias can lead to procrastination, multitasking and suboptimal projet sequence. We describe the detailed behavior of the naifs and sophisticates in Sections 4 and 5, respectively. We endogenize the project cost structure in Section 6. In Section 7, we offer two prescriptions that may alter behavior. One is increasing work load by adding projects to portfolio and the other is increasing people's awareness of their self-control problems. Finally, Section 8 concludes the paper. Throughout the paper, we use "increasing," "decreasing," "more," and "less" in their weak sense to mean "nondecreasing," "nonincreasing," "no less than," and "no more than," respectively.

2 Literature Review

Understanding how individual workers manage multiple projects or tasks is central to the operations management literature on worker productivity (Bray et al. 2016, Gurvich et al. 2020). KC (2014) examines the productivity implications of multitasking by physicians. Although switching tasks may involve a setup cost, they show that a moderate amount of multitasking may be beneficial because it allows physicians to better utilize their idle time. Duan et al. (2020) show that for emergency department physicians, switching between patients of different types reduces efficiency by increasing the time they spend on each patient, patient waiting time and the department's congestion level. Ibanez at al. (2018) study the task sequencing of radiologists who need to process a batch of diagnostic images. They find that doctors frequently deviate from the prescribed sequence, and this deviation generally reduces productivity. KC et al. (2020) document the short and long-term productivity impact of emergency room doctors prioritizing easier tasks. The literature focuses on the effects of multitasking and sequencing on performance. These effects can be positive and hence the choices are rational, or negative and hence the choices are irrational. In contrast, we seek to understand whether and why a common behavioral bias—present-biased preference—causes multitasking and suboptimal project sequencing.

Present-biased preference has been studied extensively in the behavioral economics literature on self-control problems (Frederick et al. 2002, Laibson 1997, O'Donoghue and Rabin 1999). For experimental evidence that suggests that people do indeed have such a preference, see Ainslie (1991), Loewenstein and Prelec (1992), and Loewenstein and Thaler (1989). Present-biased preference can be used to explain various behaviors such as procrastination (O'Donoghue and Rabin 1999), savings-consumption decisions (Angeletos et al. 2001), and job search decisions (DellaVigna and Paserman 2005). This study builds on that of O'Donoghue and Rabin (2008), who examine procrastination in the context of a single project with two stages. We extend their model to multiple projects and focus on behavioral anomalies that only happen in the presence of multiple projects. We contribute to this strand of literature by showing that multitasking and suboptimal project sequencing, which are both well documented and have important productivity implications, can also be explained by present-biased preferences.

Our paper is related to the literature that examines how to overcome self-control problems caused by present-biased preferences. One stream of research focuses on the role of external and internal commitment devices used by people who are aware of their self-control problems (Brocas et al. 2004). Common external commitment devices include illiquid assets in savings decisions (Laibson 1997), binding contracts in retirement decisions (Diamond and Köszegi 2003), and promises towards other parties in project management (Carrillo and Dewatripont 2008). Setting goals such as self-imposed deadlines is an important internal commitment device. In the context of a single project, several papers examine why goals can be effective in mitigating self-control problems assuming that goals serve as reference points for performance (Jain 2009, Koch and Nafziger 2011, Hsiaw 2013). When there are multiple projects, Koch and Nafziger (2016) and Hsiaw (2018) develop theories to explain why people sometimes evaluate goals in a broadly bracketed mental account and sometimes under narrow bracketing. The former paper focuses on the trade-off between risk pooling and weakened incentives to stick to goals under broad bracketing, whereas the latter studies the trade-off between risk pooling and time discounting for multi-stage sequential projects.

Compared with the above research, our work investigates how benevolent third-parties seek to achieve better outcomes for present-biased people. Along this line of research, O'Donoghue and Rabin (2006) demonstrate the value of temporal incentives such as deadlines and prospective choices in alleviating procrastination. Gruber and Köszegi (2001) explore the idea of using sin taxes to magnify the monetary cost of consumption in order to combat addiction. Our paper adds to this stream of literature by showing that increasing load or awareness of self-control problems may eliminate inefficiencies in scheduling multiple projects.

Our work also belongs to the emerging body of literature that marries operations management and present bias. Plambeck and Wang (2013) show that charging for subscriptions is optimal for a service provider whose customers have present-biased preferences. Wu et al. (2014) study optimal contract design and team composition for achieving project goals when workers are present-biased. Li et al. (2017) study the classical optimal stopping problem when the decision maker has present bias and discuss its implications in project management and health care. Gao et al. (2021) study the dynamic pricing problem of a monopolist selling to strategic consumers with present-biased preferences. Liao and Chen (2021) study the optimal design of conditional long-term cash transfer programs to prevent noncommunicable diseases for present-biased people. Shi et al. (2023) propose an incentive scheme to mitigate the the effect of present bias in project execution. They demonstrate that this scheme enhances on-time completion rates and decreases expected project delays compared to other benchmark incentives. Hall and Liu (2023) incorporate present bias into a scheduling system that involves making decisions about project timing and sequencing. They develop efficient algorithms to optimize revenue for both naifs and sophisticates. Most of these papers focus on prescriptive analysis for a central planner in the face of present-biased agents. Our paper contributes to this literature by providing a positive analysis that explores how present bias causes anomalies in scheduling multi-stage projects, along with a normative analysis that suggests remedies for addressing these anomalies.

3 The Model and Benchmark

We assume that time is discrete and there are an infinite number of periods. There are two projects that the agents can work on. Following O'Donoghue and Rabin (2008), we assume that each project consists of two stages, which we refer to as "starting" and "finishing" the project. In each period, the agents can complete the current stage or do nothing. In addition, the agents can work on only one project in each period. For project i, starting the project incurs immediate cost c_i and finishing the project incurs immediate cost k_i. Upon completion of project i at period τ, the agents receive constant reward v_i each period from $\tau + 1$ onward. Under the standard exponential discounting model with discount factor δ ($0 < \delta < 1$), the net present value (NPV) of project i, denoted by J_i, is equal to $-c_i + \delta(-k_i + \frac{\delta}{1-\delta}v_i)$. Without loss of generality, we assume that the parameters satisfy $J_1 > J_2 > 0$. For rational people (i.e., people with exponential discounting preferences) who maximize their total discounted utility, it is easy to show that they start and finish each project if and only if its NPV is positive.

We define *multitasking*[1] as starting a new project before finishing an old project. We say agents adopt a *suboptimal sequence* if they do not prioritize projects by their NPVs. Suppose that project i has been started in the first period. Starting project j and then finishing project i instead of finishing project i and then starting project j result in a utility loss of $(1-\delta)(-k_i + \frac{\delta}{1-\delta} v_i) + (1-\delta)c_j$. Here the first term is the loss from receiving the net benefit of finishing project i one period later, and the second term is the loss from paying the start-up cost of project j one period earlier. As such, rational people do not multitask. We can show that rational people rank projects by their NPVs and then start and finish them sequentially. We summarize their behavior in the following lemma as a benchmark.

Lemma 1 *Rational people start and finish project 1 and then start and finish project 2.*

A present-biased agent's inter-temporal preferences in period t can be represented by

$$U_t = u_t + \beta \sum_{i=t+1}^{\infty} \delta^{i-t} u_i,$$

where u_i is the instantaneous utility in period i, the parameter δ $(0 < \delta < 1)$ represents the long-run time-consistent discounting and the parameter β $(0 < \beta \leq 1)$ measures short-term impatience (Laibson 1997). There are two types of agents: naifs and sophisticates. Both naifs and sophisticates have $\beta < 1$. Naifs are unaware of their self-control problems and believe they will behave like rational people in the future. Sophisticates foresee their self-control problems and correctly anticipate their future behavior. When $\beta = 1$, the above preferences are the same as those of the rational people. To be consistent with the literature in present-biased preferences, we call rational people *time-consistent agents* (TCs).

Under present-biased preferences, we adopt the *perception-perfect strategy* as the solution concept, which requires that in all situations, an agent chooses optimally given her current preferences and her perceptions of her future behavior. More specifically, strategy s is a map of the history of actions $h_{t-1} = \{a_1, ..., a_{t-1}\}$ to action a_t for any t. Here, $h_0 = \emptyset$. Let $V_t(h_{t-1}, s, \beta, a)$ denote an agent's total utility from taking action a in period t and following strategy s starting from period

[1]In O'Donoghue and Rabin (1999), multitasking is defined as performing the same activity multiple times. Multitasking is also sometimes defined as performing multiple tasks at the same time (talking while driving or watching YouTube while eating lunch).

$t+1$ conditional on history h_{t-1}. In generic terms, $V_t(h_{t-1}, s, \beta, a)$ is given by

$$V_t(h_{t-1}, s, \beta, a) = u_t(a) + \beta \sum_{i=t+1}^{\infty} \delta^{i-t} u_i^s,$$

where $u_t(a)$ is period-t's instantaneous utility under action a, and u_i^s is period i's instantaneous utility under strategy s.

For all t and all possible history h_{t-1}, strategy s^{TC} is a perception-perfect strategy for TCs if $s^{TC}(h_{t-1}) = \arg\max_a V_t(h_{t-1}, s^{TC}, 1, a)$; strategy s^N is a perception-perfect strategy for naifs if $s^N(h_{t-1}) = \arg\max_a V_t(h_{t-1}, s^{TC}, \beta, a)$; strategy s^S is a perception-perfect strategy for sophisticates if $s^S(h_{t-1}) = \arg\max_a V_t(h_{t-1}, s^S, \beta, a)$. Given a perception-perfect strategy s where $s \in \{s^N, s^S\}$, the *long-run utility* of present-biased agents is measured by $\sum_{i=1}^{\infty} \delta^i u_i^s$, which is the total utility of the strategy from TCs' perspective (O'Donoghue and Rabin 1999).

We summarize the behavioral anomalies in Theorem 1 and defer a detailed discussion of naifs' and sophisticates' behavior to Sections 4 and 5.

Theorem 1 *Under the present bias model, both naifs and sophisticates may not start a project with a positive NPV, may multitask, or may adopt a suboptimal sequence. In addition, naifs may start a project, plan to finish it, but never actually do.*

Under present bias, there are three anomalies: multitasking, suboptimal sequencing, and procrastination (i.e., starting a project without finishing it). In what follows, we provide detailed analysis about how present-biased people behave when facing multiple, multi-stage projects and offer remedies for the anomalies.

4 Naifs

To understand how naifs behave, let's begin by considering the three choices available in the first period. The first choice is to do nothing. As naifs believe that they will behave like TCs in the future, they plan to work on the two projects starting in period 2: first project 1 and then project 2. Doing so gives them a utility equal to

$$\beta(\delta J_1 + \delta^3 J_2). \tag{1}$$

The second choice is to start project 1 in the first period. This choice generates a utility equal to

$$-c_1 + \beta\big(\delta(-k_1 + \frac{\delta}{1-\delta} v_1) + \delta^2 J_2\big). \tag{2}$$

The third choice is to start project 2 in the first period. As naifs believe that they will behave like TCs in the future, we next consider the choices TCs make in the second period. For TCs, once project 2 is started in the first period, they can finish project 2 in the second period and then start and finish project 1 in the following two periods, which gives them a utility equal to $(-k_2+\frac{\delta}{1-\delta}v_2)+\delta J_1$. Alternatively, they can start and finish project 1 in the second and third periods before finishing project 2 in the fourth period, receiving a utility equal to $J_1+\delta^2(-k_2+\frac{\delta}{1-\delta}v_2)$. Finally, they can start project 1 in the second period, finish project 2 in the third period and finish project 1 in the fourth period, generating a utility equal to $-c_1+\delta(-k_2+\frac{\delta}{1-\delta}v_2)+\delta^2(-k_1+\frac{\delta}{1-\delta}v_1)$. The third option is always dominated by the first option because multitasking is suboptimal for TCs, as shown in Section 3. Therefore, in period 2, the maximal discounted utility for TCs in the second period, conditional on project 2 already being started, is given by

$$z_2 = \begin{cases} (-k_2+\frac{\delta}{1-\delta}v_2)+\delta J_1 & \text{if} \quad -k_2+\frac{\delta}{1-\delta}v_2 \geq \frac{1}{1+\delta}J_1; \\ J_1+\delta^2(-k_2+\frac{\delta}{1-\delta}v_2) & \text{if} \quad -k_2+\frac{\delta}{1-\delta}v_2 < \frac{1}{1+\delta}J_1. \end{cases}$$

Hence for naifs, starting project 2 in the first period generates a utility

$$-c_2+\beta\delta z_2. \tag{3}$$

Comparing (1), (2), and (3), we can obtain naifs' choice in the first period. Naifs do not start projects for two reasons. First, the projects are not worthwhile to start (i.e., both (2) and (3) are negative). Second, naifs *procrastinate*: the projects are worthwhile to start but naifs plan to start them in the next period and never actually start them (i.e., both (2) and (3) are positive but smaller than (1)). Similarly, the projects require costly effort to finish and the reward only arrives in the future. Therefore, naifs may not finish a project they have started for the same reasons.

To lay bare the driving forces behind multitasking, we consider a special case in which $v_1 = v_2 = v$ and $\delta \to 1$. When $\delta \to 1$, both projects are worthwhile. Notice that naifs prefer finishing a project τ periods later to finishing it now if

$$-k+\beta\frac{\delta}{1-\delta}v \leq \beta\delta^\tau(-k+\frac{\delta}{1-\delta}v);$$

and they prefer to starting a project τ periods later to starting it now if

$$-c+\beta\delta(-k+\frac{\delta}{1-\delta}v) \leq \beta\delta^\tau(-c+\delta(-k+\frac{\delta}{1-\delta}v)).$$

As $\delta \to 1$, these two conditions are equivalent to $(1-\beta)k \geq \tau\beta v$ and $(1-\beta)c \geq \tau\beta v$, respectively. Here, $\tau\beta v$ is the reward loss caused by the delay of τ periods in receiving the reward[2], and $(1-\beta)k$

[2]Agents receive an infinite stream of reward v per period after the project is finished. When $\delta \to 1$, the total reward they receive is reduced by v if they delay finishing the project by one period.

or $(1-\beta)c$ is the cost savings from procrastination. The following proposition provides the condition under which naifs multitask.

Proposition 1 *Suppose that* $v_1 = v_2 = v$. *When* $\delta \to 1$, *naifs multitask if and only if (a)* $\max\{c_1, c_2\} < \frac{2\beta v}{1-\beta}$ *and (b)* $c_1 < c_2 < k_1 - \frac{\beta v}{1-\beta}$ *or* $c_2 < c_1 < k_2 - \frac{\beta v}{1-\beta}$.

The condition in Proposition 1 is necessary and sufficient for naifs to multitask. When naifs multitask, they start both projects before finishing either. When condition (a) holds, naifs start one project in the first period instead of procrastinating. For naifs, procrastination delays the reward for *each* project by one period, which is not preferred if the cost savings from delaying is no larger than $2\beta v$.

Condition (b) includes two cases. If $c_1 < c_2 < k_1 - \frac{\beta v}{1-\beta}$, naifs start project 1 before project 2. If $c_2 < c_1 < k_2 - \frac{\beta}{1-\beta v}$, naifs start project 2 before project 1. Suppose that project i is started in the first period. Starting project j instead of finishing project i means that naifs delay receiving the reward from project i and delay incurring cost k_i by one period but paying cost c_j now rather than in the future. It is optimal to do so if and only if the net utility $-\beta v + (1-\beta)k_i - (1-\beta)c_j$ is positive, or equivalently, $k_i > c_j + \frac{\beta v}{1-\beta}$.

Naifs' choice in the first period is determined only by the relative magnitudes of c_1 and c_2. Because naifs wrongly believe that they will follow TCs' optimal behavior in the future, if they start project 1, they believe they will finish it and then start and finish project 2 in the future without any delay. Whereas if they start project 2, when $\delta \to 1$, they believe they will finish project 2 and then start and finish project 1 in the future without any delay. In either case, they believe they will start collecting the reward for one project in period 3 and for the other project in period 5. As such, naifs always begin with the project with a lower start-up cost in the first period.

Condition (b) also implies that when naifs multitask, there is at least one project i with $k_i > \frac{\beta v}{1-\beta}$. This condition means that if project i is the only project remaining to be finished, then naifs will keep procrastinating, and it will never be finished. Consider two cases. If $k_i > \frac{\beta v}{1-\beta}$ holds for both $i = 1, 2$, then obviously, one of the two projects has to be the last and only one remaining to be finished, and it will never be finished. Now, suppose that $k_i > \frac{\beta v}{1-\beta}$, but $k_j \leq \frac{\beta v}{1-\beta}$ for $j \neq i$. In this case, after starting the projects in periods 1 and 2, respectively, if naifs choose a project to finish in period 3, it has to be project j because it has a lower cost to finish than project i. After project j is finished in period 3, then project i is the only remaining project to be finished, and hence, it will never be finished. The same logic applies when there are more than two projects in the portfolio. In other words, when there is multitasking, there is at least one project that naifs start but never finish.

The proposition below characterizes the condition under which naifs do not prioritize projects by NPV. To disentangle suboptimal sequencing from multitasking, we focus on the case where both projects are completed.

Proposition 2 *Suppose that $v_1 = v_2 = v$. When $\delta \to 1$, naifs complete both projects and complete project 2 before project 1 if and only if $c_2 < c_1$, $k_2 < c_1 + \frac{\beta v}{1-\beta}$ and $\max\{c_1, k_1\} < \frac{\beta v}{1-\beta}$.*

In Proposition 2, the condition $\max\{c_1, k_1\} < \frac{\beta v}{1-\beta}$ is to ensure that naifs start and then finish project 1 in the third and fourth periods, respectively. For naifs not to multitask in the second period, the cost savings from starting project 1 instead of finishing project 2 must be no higher than the revenue lost from delaying the reward for project 2 by one period, i.e., $(1-\beta)(k_2-c_1) < \beta v$. Finally, $c_2 < c_1$ is necessary for naifs to start project 2 in the first period.

When naifs face only one project i, O'Donoghue and Rabin (2008) show that they complete the project if and only if $\max\{c_i, k_i\} < \beta v/(1-\beta)$. When they face two projects simultaneously, however, only a weaker condition for k_2 is necessary for naifs to complete project 2. After starting project 2, planning to complete project 1 afterward gives naifs a stronger incentive to finish project 2. This issue is further explored in Section 7.

Proposition 2 clearly shows that if naifs complete both projects when the two projects are presented independently (i.e., $\max\{c_i, k_i\} < \beta v/(1-\beta)$ for $i = 1, 2$), then they will also complete both projects when they are presented simultaneously, and the project with a lower start-up cost will be worked on first.

5 Sophisticates

As sophisticates are aware of their future self-control problems and correctly predict their future behavior, the current self interacts strategically with the future self. This intrapersonal game may have multiple equilibria regarding when to complete a stage (O'Donoghue and Rabin 2008). For example, suppose that project i is the only project available and the first stage of the project was completed in period τ. For the second stage, we assume that

$$-k_i + \beta \frac{\delta}{1-\delta} v_i < \beta\delta(-k_i + \frac{\delta}{1-\delta} v_i)$$

and

$$-k_i + \beta \frac{\delta}{1-\delta} v_i \geq \beta\delta^2(-k_i + \frac{\delta}{1-\delta} v_i).$$

The conditions mean that for sophisticates, finishing the project now is not as good as finishing it a period later but better than finishing it two periods (or longer) later. As such, there are two perception-perfect strategies for finishing the project. Recall that a strategy is a map of the history of actions $h_{t-1} = \{a_1, ..., a_{t-1}\}$ to action a_t for *any* t. Given that the project hasn't been finished in period t, the first perception-perfect strategy is to finish it if and only if $t = \tau + 1$, $\tau + 3$, $\tau + 5$, $\cdots$, and the second is to finish the project if and only if $t = \tau + 2$, $\tau + 4$, $\tau + 6$, $\cdots$.

To understand why the two strategies are perception-perfect for sophisticates, let us take the second strategy as an example and verify that sophisticates' behavior are indeed consistent with the strategy. In period $\tau + 1$, the utility of finishing the project is $-k_i + \beta \frac{\delta}{1-\delta} v_i$. The utility of not finishing the project depends on what sophisticates believe they will do in the future. Because they believe they will finish the project in period $\tau + 2$, the utility of not finishing the project is $\beta\delta(-k_i + \frac{\delta}{1-\delta} v_i)$. Thus, consistent with the strategy, sophisticates do not finish the project in period $\tau + 1$. In period $\tau + 2$, the utility of finishing the project is still $-k_i + \beta \frac{\delta}{1-\delta} v_i$. However, the utility of not finishing the project now is $\beta\delta^2(-k_i + \frac{\delta}{1-\delta} v_i)$, because sophisticates believe they will finish it in period $\tau + 4$. Consequently, sophisticates finish the project in period $\tau + 2$. We can similarly verify that sophisticates indeed follow the strategy for any period $t \geq \tau + 3$.

The above analysis shows that sophisticates actually finish the project in either period $\tau + 1$ or $\tau + 2$, depending on the perception-perfect strategy they choose. The example illustrates that multiple equilibria arise from sophisticates' tolerance of delay. In general, as long as the project is worthwhile to finish (i.e., $-k_i + \beta \frac{\delta}{1-\delta} v_i > 0$), sophisticates will finish it despite that they may procrastinate for a few periods.

Regardless of the number of equilibria, sophisticates may not start a project with a positive NPV, may multitask or adopt a suboptimal sequence. Whereas naifs choose not to start a project with a positive NPV either because it is unworthy or becasue of procrastination, the only reason for sophisticates not to start a project with a positive NPV is because it is unworthy to start $(-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta} v_i) < 0)$ or finish $(-k_i + \frac{\beta\delta}{1-\delta} v_i < 0)$. Unlike naifs, sophisticates do not start a project and leave it unfinished because if they know they will not finish the project, they will not start it in the first place.

To better understand why sophisticates multitask, we again consider the special case in which $v_1 = v_2 = v$ and $\delta \to 1$. In addition, when there are multiple equilibria regarding when to complete a stage, we focus on the equilibrium that leads to its immediate completion. Such an equilibrium gives sophisticates the highest utility from a long-run perspective. More specifically, because both projects have positive NPVs and when δ is sufficiently close to 1, $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta} v_i) > 0$, there always exists an integer $\kappa_i \geq 1$ such that

$$\kappa_i = \min\{d \geq 1 : -c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) \geq \beta\delta^d(-c_i + \delta(-k_i + \frac{\delta}{1-\delta}v_i))\}.$$

This means that in period t, sophisticates can choose a perception-perfect strategy in which they start project i in period t, $t+\kappa_i$, $t+2\kappa_i$, $\cdots$. Under this strategy, sophisticates start project i in period t irrespective of the value of κ_i. The same logic applies to any stage of the projects, and so when $\delta \to 1$, sophisticates always pick a project to work on instead of doing nothing.

Let $I(x)$ denote the indicator function with $I(x) = 1$ for $x \geq 0$ and $I(x) = 0$ otherwise. The following proposition identifies the sufficient and necessary conditions for sophisticates.

Proposition 3 *Suppose that $v_1 = v_2 = v$. When $\delta \to 1$, sophisticates always complete both projects. They multitask if and only if $c_1 < c_2 < k_1 - \frac{\beta v}{1-\beta}$ or $c_2 + \frac{\beta v}{1-\beta} I(c_2 + \frac{\beta v}{1-\beta} - k_1) < c_1 < k_2 - \frac{\beta v}{1-\beta}$.*

When δ approaches 1, both $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i)$ and $-k_i + \frac{\beta\delta}{1-\delta}v_i$ are positive for $i = 1, 2$, so for sophisticates, both projects are worthwhile, and they believe that they will complete them in the future. Therefore, sophisticates start and finish both projects.

According to Proposition 3, sophisticates multitask and start project 1 before project 2 if $c_1 < c_2 < k_1 - \frac{\beta v}{1-\beta}$; they multitask and start project 2 before project 1 if $c_2 + \frac{\beta v}{1-\beta} I(c_2 + \frac{\beta v}{1-\beta} - k_1) < c_1 < k_2 - \frac{\beta v}{1-\beta}$. Similar to naifs, sophisticates start new project j instead of finishing old project i if and only if $k_i > c_j + \frac{\beta v}{1-\beta}$. However, there are two differences in the sets of conditions that lead naifs and sophisticates to multitask. First, condition (a) in Proposition 1 is not necessary for sophisticates to multitask. As explained earlier, when $\delta \to 1$, sophisticates work on a project instead of procrastinating, so an upper bound on costs is not necessary to induce them to work.

Second, for sophisticates to start project 2 instead of project 1 in the first period, the costs must satisfy $c_2 + \frac{\beta v}{1-\beta} I(c_2 + \frac{\beta v}{1-\beta} - k_1) < c_1$, which is stronger than the corresponding condition for naifs, i.e., $c_2 < c_1$. As sophisticates always follow their plan in the future, starting project 2 in the first period and planning on completing both projects with multitasking implies that $k_2 > c_1 + \frac{\beta v}{1-\beta}$. Consider the following two cases. In the first case, suppose that $k_1 < c_2 + \frac{\beta v}{1-\beta}$ holds. If sophisticates consider starting project 1 in the first period, they will plan on completing both projects sequentially without multitasking. Switching from starting with project 2 to starting with project 1 means that sophisticates can obtain the reward for one of the projects one period earlier, and the net benefit from doing so is equal to $(1-\beta)(c_2 - c_1) + \beta v$. Therefore, in the first period, starting project 2 is better than starting project 1 if and only if $(1-\beta)(c_2 - c_1) + \beta v < 0$, or equivalently, $c_1 > c_2 + \frac{\beta v}{1-\beta}$. In the second case, suppose that $k_1 \geq c_2 + \frac{\beta v}{1-\beta}$ holds. If sophisticates start project 1 in the first period, they must plan on subsequently completing both projects by multitasking. Therefore, whether they start project 1 or project 2 makes no difference to the timing of receiving the reward. In this case, sophisticates prefer starting project 2 to starting project 1 if and only if $c_1 > c_2$.

For sophisticates to start project 1 instead of project 2 in the first period, the costs only need to satisfy $c_1 < c_2$, which is the same as that for naifs. Starting project 1 in the first period and planning on completing both projects by multitasking in the future implies that $k_1 > c_2 + \frac{\beta v}{1-\beta}$. As project 1 has a higher NPV than project 2, we have $k_2 > c_1 + k_1 - c_2$. Therefore, $k_2 > c_1 + \frac{\beta v}{1-\beta}$. If sophisticates start project 2 in the first period, they must also plan on completing both projects by multitasking. Therefore, no matter which project they start first, sophisticates receive the same total reward. In this case, sophisticates prefer starting with project 1 to starting with project 2 if and only if $c_1 < c_2$.

We next show the conditions under which sophisticates do not prioritize projects by NPV. Similar to Proposition 2, we focus on the case where both projects are completed sequentially.

Proposition 4 *Suppose that $v_1 = v_2 = v$. When $\delta \to 1$, sophisticates complete project 2 before project 1 if and only if $c_2 < c_1$ and $k_2 < c_1 + \frac{\beta v}{1-\beta}$.*

The rationale behind Proposition 4 is as follows. Suppose that sophisticates start project 2 in the first period and plan on completing both projects without multitasking, we must have $k_2 < c_1 + \frac{\beta v}{1-\beta}$. Because project 1 has a higher NPV than project 2, we have $k_1 < c_2 + k_2 - c_1$. Consequently, we have $k_1 < c_2 + \frac{\beta v}{1-\beta}$. This implies that if sophisticates start project 1 in the first period, they must plan on completing both projects without multitasking. In this case, sophisticates receive the same total reward irrespective of their choice in the first period. Therefore, sophisticates prefer to start project 2 in the first period if and only if $c_2 < c_1$.

We can compare the conditions in Propositions 2 and 4. The upper bound on costs, i.e., $\max\{c_1, k_1\} < \beta v/(1-\beta)$, in Proposition 2 is needed to induce naifs to work on project 1, but this condition is not necessary for sophisticates. Therefore, naifs and sophisticates are equally likely to get the sequence wrong if naifs complete both projects. In other words, if naifs complete project 2 before project 1, so do sophisticates. If sophisticates complete project 2 before project 1, naifs either do not complete both projects or also complete project 2 before project 1.

For people with present-biased preferences, the project sequence depends critically on the start-up costs. A special case of our model is when both projects' finishing costs are zero, and in that case, the easier project (i.e., the project with a lower total cost) will be started first. There is strong empirical evidence for this. For example, Ibanez et al. (2018) show that radiologists frequently deviate from the prescribed sequence when processing a batch of diagnostic images, and they tend to prioritize tasks that they expect to complete faster. In a follow-on study, KC et al. (2020) show a similar phenomenon, which they call task completion propensity, among emergency room doctors when they select patients from the waiting area.

Figure 1 illustrates the behavior of naifs and sophisticates for the special case in which $v_1 = v_2$ and $\delta \to 1$. To draw the figure, we assume that the total cost of each project is fixed, i.e., $c_i + k_i = K_i$ for $i = 1, 2$. We further assume that $K_1 - \frac{\beta v}{1-\beta} < \frac{\beta v}{1-\beta} < K_2 - \frac{\beta v}{1-\beta} < \frac{2\beta v}{1-\beta}$. In both Figure 1(a) and Figure 1(b), agents complete project 2 before project 1 in region S; they multitask and start project i before the other project in region M_i. For naifs, they start and finish only project i in region F_i; and they start and finish project 1, and then start project 2 but do not finish it in region F_1'. For sophisticates, they complete project 1 before project 2 in region O. The figure suggests that sophisticates are less likely to multitask or adopt a suboptimal sequence than naifs.

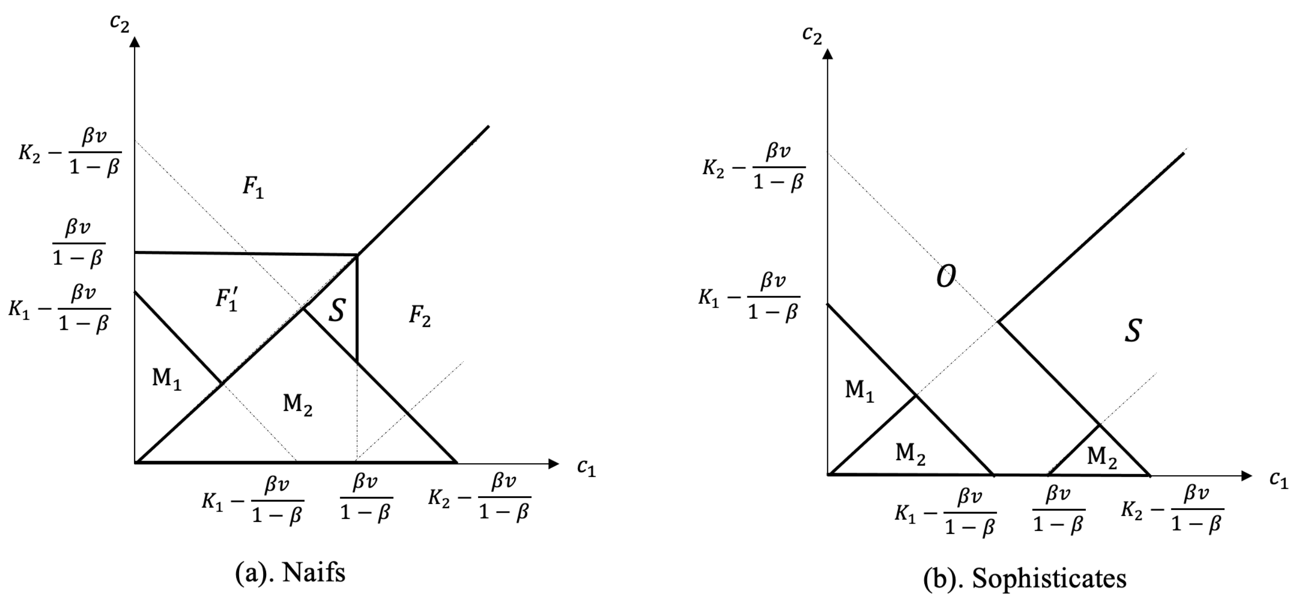

Figure 1: The behavior of people with present bias

6 Endogenous Cost Structure

The previous analysis assumes that the cost structures of the projects are exogenously given. In reality, agents can sometimes determine how the costs are allocated over the course of a project. For example, a project may require a total of 12 hours of effort. The agent can freely decide the number of hours to work on the project each day, except that she cannot work for more than

8 hours on a given day. O'Donoghue and Rabin (2008) show that for a single project with two stages, when the cost structure is endogenous, agents prefer to defer as much of the cost as possible to the second stage. Therefore, endogenizing the cost structure makes naifs more likely to start a project, and simultaneously makes them less likely to finish it; endogenizing the cost structure makes sophisticates more likely to start and finish a project because they choose the cost structure while accounting for incentives in the finishing stage. The impact of an endogenous cost structure on the number of stages completed is similar for multiple projects. That is, endogenizing costs make present-biased agents more likely to start projects, but also make naifs less likely to finish projects that they have started. We next focus on investigating how endogenizing costs affects multitasking and the sequencing of projects, both of which are behavioral anomalies that only happen when there are multiple projects[3].

Let $\mathbf{P}(A_i, \bar{a}) = \{(c_i, k_i) | c_i + k_i = A_i, c_i \leq \bar{a}, k_i \leq \bar{a}\}$ denote the set of feasible choices of cost structure for project i. Here, A_i is the total cost that must be incurred to complete project i, and $\bar{a}$ is the maximum cost that can be incurred in any period. We also assume that $\bar{a} \leq A_i \leq 2\bar{a}$ so that each project requires two stages of work. To gain insight into what drives multitasking and to obtain a direct comparison between exogenous and endogenous cost structures, we again assume that $v_1 = v_2 = v$ and let $\delta \to 1$. Given $c_i \leq \bar{a}$, $k_i \leq \bar{a}$ and $c_i + k_i \geq \bar{a}$, we are comparing behavior under exogenous cost structures (c_1, k_1) and (c_2, k_2) with behavior under endogenous cost structures $\mathbf{P}(c_1 + k_1, \bar{a})$ and $\mathbf{P}(c_2 + k_2, \bar{a})$.

Proposition 5 *Suppose that for $i = 1, 2$, $v_i = v$, $c_i \leq \bar{a}$, $k_i \leq \bar{a}$, $c_i + k_i \geq \bar{a}$ and $\delta \to 1$.*

(i) Both naifs and sophisticates start project 1 before they start project 2 when costs are endogenous.

(ii) If present-biased agents multitask under exogenous cost structures (c_1, k_1) and (c_2, k_2), they also multitask under endogenous cost structures $\mathbf{P}(c_1 + k_1, \bar{a})$ and $\mathbf{P}(c_2 + k_2, \bar{a})$, irrespective of whether they are naifs or sophisticates.

Proposition 5 suggests that endogenizing costs may help present-biased agents get project sequencing right, but may exacerbate their multitasking problem. The key reason for this is that agents prefer to defer as much of the cost as possible to the second stage because of present bias. As the two projects have the same reward, the project with a higher NPV must have a lower total

[3]Similar to O'Donoghue and Rabin (2008), here we assume that project success (i.e., the reward, number of stages required, and total effort) does not depend on the cost structure. Choo (2014), however, shows that there is a U-shaped relationship between the amount of time spent in the problem definition stage and a project's duration.

cost. Thus, agents can allocate a lower start-up cost for the higher NPV project than to the lower NPV project. In other words, present-biased agents prioritize projects by NPV when project costs are endogenous.

When costs are exogenous, present-biased agents multitask primarily because the cost to finish an old project is higher than the cost to start a new project. As endogenizing costs induces present-biased agents to defer more of the cost to the finishing stage, the multitasking problem can only be aggravated.

7 Remedies for the Anomalies

In earlier sections, agents are exposed to a project portfolio with a given set of projects and agents are either naive or sophisticated. We have shown that present-biased preferences can cause multitasking and suboptimal sequencing. What can we do about these anomalies? In this section, we offer two prescriptions. The first is about adding new projects to the portfolio (or increasing load) and the second is about increasing agents' awareness about their self-control problems.

7.1 Adding Projects to Project Portfolios

The impact of increased workload on performance is an important topic in operations management (KC and Terwiesch 2009, KC et al. 2020). In our context, because TCs make decisions solely on the basis of NPVs, their behavior toward existing projects is unaffected by the addition of a new project. However, increasing load may change the relative magnitude of present and future payoffs for present-biased agents, thus changing their behavior. Theorem 2 describes how adding a project to the project portfolio can affect agents' behavior.

Theorem 2

(i) Adding a project to the portfolio makes naifs complete more stages of existing projects, but it does not affect sophisticates' decisions about whether to start and finish existing projects.

(ii) For both naifs and sophisticates, adding a project to the portfolio may prevent them from multitasking and choosing a suboptimal sequence.

Theorem 2(i) indicates that increasing load alleviates naifs' procrastination. When a new project is added to the portfolio, naifs plan to start and finish the new project in the future as what TCs do. Hence, the absolute value of starting or finishing an existing project (or the cost of procrastinating) is higher when the work load increases. When the new project has a high NPV and a high start-up cost, it can motivate naifs to complete all existing projects despite that they never actually work on the new project. Naifs' behavior violates *independence of irrelevant alternatives*, eliminating an option from the choice set that is not chosen should not change the agent's choice from the remaining options, a property that TCs never violate (see, e.g., O'Donoghue and Rabin 2001). Unlike naifs, sophisticates correctly predict that they will complete a project if and only if it is worthwhile independently. Hence, increasing load does not change the number of existing projects completed by sophisticates.

Increasing load may also change the relative value of starting or finishing different projects, thereby eliminating multitasking and suboptimal sequencing, as suggested by Theorem 2(ii). Consider the following example in which present-biased agents adopt a suboptimal sequence and start project 2 first. In the first period, if naifs start project 1, they expect that they will finish project 1 and then start and finish project 2 in the future. If naifs start project 2, they expect that they will finish project 2 and then start and finish project 1 provided that the reward v_2 is relatively high. Suboptimal sequencing suggests that c_2 is low relative to c_1. Suppose that we introduce a new project 3 whose NPV satisfies $J_1 > J_3 > J_2$. Now if project 1 is started first, naifs believe they will finish project 1 and then complete project 3 and project 2 in turn; whereas if project 2 is started first, naifs believe that they will finish project 2 and then complete project 1 and project 3 in turn. Because project 3 is completed sooner in the former case than in the latter case, it increases the value of starting project 1 more than that of starting project 2. Consequently, if c_2 is not too low relative to c_1, the new project may induce naifs to follow the optimal sequence and start project 1 first. This line of reasoning in the example also holds for sophisticates as long as the new project makes them actually follow the plans by naifs.

In summary, when a new project is added to the project portfolio, its impact on the value of completing an stage of an existing project depends on how agents plan to schedule the new project in the future. A carefully chosen new project may increase the value of completing the correct stage more than that of completing the wrong stage. Hence, as long as the immediate cost of working on the wrong stage is not too low relative to that of the correct stage, increasing load can eliminate the anomalies in project scheduling and make present-biased agents behave like TCs.

7.2 Awareness of Self-control Problems

In our framework, sophisticates are *fully aware* of their future self-control problems, and naifs are *completely unaware* of their future self-control problems. In practice, people are likely in between the two extremes: they are partially naive and underestimate their future self-control problems (O'Donoghue and Rabin 2001). Several recent studies show that exposure to similar tasks and learning can increase agents' level of sophistication (Ali 2011, Bisin and Hyndman 2020). Does increased awareness of self-control problems always benefit agents? To answer the question, we next compare the payoffs of naifs and sophisticates.

Theorem 3

(i) If a project is completed by naifs, then it is also completed by sophisticates; if naifs start both projects without multitasking, then sophisticates do not multitask; if naifs start project 1 before project 2, so do sophisticates.

(ii) Sophisticates obtain a higher long-run utility than naifs.

Theorem 3(i) includes three findings. First, sophisticates complete more projects than naifs complete. As explained earlier, sophisticates do not start a project either because they believe it is not worthwhile or because they do not expect to finish it. If a project is not worthwhile, naifs prefer to delay starting it; if a project is not expected to be finished by sophisticates, naifs prefer to delay finishing it. In either case, naifs do not complete a project that sophisticates never start. Second, sophisticates are less likely to multitask than naifs. Third, sophisticates are more likely to prioritize projects based on NPVs than naifs.

Theorem 3(ii) extends the findings in O'Donoghue and Rabin (1999) to multiple, multi-stage projects: when costs are immediate and rewards arrive in the future, sophistication pays. In our context, it pays because it leads to more completed projects, less multitasking and more efficient project sequences. For example, suppose that naifs start project 2, then start project 1 and finish project 1 but leave project 2 unfinished. Consider the following three possible choices that sophisticates make. First, sophisticates behave the same as naifs except that they finish project 2 in the end. In this case, sophisticates have a higher long-run utility because they complete more projects. Second, sophisticates complete project 2 first and then project 1 sequentially. In this case, sophisticates have a higher long-run utility because they complete more projects as well as avoid multitasking. Third, sophisticates complete project 1 and project 2 sequentially. In this case, sophisticates have a higher long-run utility because they complete more projects, avoid multitasking and adopt a more efficient sequence.

Theorem 3 holds under an implicit assumption: both naifs and sophisticates are exposed to the same project portfolio with a given set of projects. In many situations, people must decide in advance how many and which projects to work on. For example, knowledge workers usually exert effort to evaluate proposals for candidate projects when determining which ones should be included in the portfolio.

To model project choice, we introduce period 0 in which agents select the projects they will work on. We further assume that including project i in the project portfolio requires costly effort e_i in period 0. We again assume that all projects have positive NPVs. In the following, we show how naifs and sophisticates behave differently.

Theorem 4 *Suppose that project portfolios are endogenously determined by agents.*

(i) If a project is selected by sophisticates, then it is also selected by naifs.

(ii) Naifs may complete more projects than sophisticates.

(iii) Naifs and sophisticates may complete different projects, and the project completed by naifs may have a higher NPV than the one completed by sophisticates.

When the projects are endogenously determined, naifs are not aware that they may not complete all of the projects they select, that they may not follow the optimal sequence, and that they may not complete the projects sequentially. However, sophisticates are fully aware of these self-control problems. Therefore, the projects are more valuable to naifs than to sophisticates, and naifs always include more projects in their portfolio than sophisticates, as shown in Theorem 4(i).

In stark contrast to Theorem 3(ii), Theorem 4(ii) and (iii) suggest that sophistication may not be good if agents are allowed to select projects to form their portfolio. Sophistication does not always pay because naifs may either complete more projects or complete a more profitable project than sophisticates.

To understand why naifs may complete more projects than sophisticates, consider the following example. Suppose that the parameters satisfy $(c_1, k_1, v_1) = (4.5, 5, 2)$, $(c_2, k_2, v_2) = (1.6, 7, 1.6)$, $\delta = 0.9$, $\beta = 0.87$, and $(e_1, e_2) = (4.8, 3)$. Under these parameters, sophisticates correctly predict that if they include both projects in their portfolio, they will complete project 2 before they complete project 1. However, a two-period delay in completing project 1 reduces its value, and hence, it is no longer worth including project 1 in the portfolio because $-e_1 + \beta\delta^3 J_1 = -0.234 < 0$. Therefore, sophisticates only plan to work on project 2 and indeed complete project 2. Naifs wrongly believe that they will complete project 1 before completing project 2, so they plan to work on both projects but actually complete project 2 before project 1. Despite the wrong sequence, naifs complete both projects. From a long-run perspective, naifs' utility is $-e_1 - e_2 + \delta(J_2 + \delta^2 J_1) = 2.003$, which is higher than sophisticates' utility $-e_2 + \delta J_2 = 1.554$.

In summary, it makes sense to include project 1 in the portfolio if and only if the right sequence is followed. Sophisticates correctly anticipate that they will not follow the right sequence, and hence, they do not include it in their portfolios. Naifs, however, plan to follow the right sequence and hence they include it in their portfolios. Once it is included, cost e_1 becomes sunk and naifs may finish it, although they follow a different sequence than they initially planned.

Sophisticates may also select a project with a low NPV rather than a project with a high NPV because they correctly anticipate that selecting the high NPV project may lead to multitasking. Consider the following example: $(c_1, k_1, v_1) = (4.5, 6, 3)$, $(c_2, k_2, v_2) = (0.01, 11, 2)$, $\delta = 0.86$, $\beta = 0.825$, and $(e_1, e_2) = (3.625, 0.01)$. Under these parameters, sophisticates correctly anticipate that if they include both projects in their portfolio, they will multitask, i.e., start project 2, start and finish project 1, and finally, finish project 2. Multitasking reduces the values of the projects, and including both projects is not as good as only including project 2. Therefore, sophisticates select only project 2 and complete it. Naifs, however, select both projects because they believe they will complete project 1 and project 2 sequentially, which is not what they actually do. They will multitask i.e., start project 2, start and finish project 1, and leave project 2 unfinished. Thus, despite incurring the cost of selecting and starting project 2 and not accruing any benefit, their long-run utility is $-e_1 - e_2 + \delta(-c_2 + \delta J_1) = 0.9335$, which is still higher than sophisticates' long-run utility $-e_2 + \delta J_2 = 0.9323$.

Overall, the presence of period 0, at which time projects need to be selected at a cost, creates an opportunity for another type of inefficiency. Both naifs and sophisticates are too conservative in including projects in their portfolio, but sophisticates are more so than naifs. Although sophistication alleviates procrastination and reduces the possibility of multitasking and choosing a suboptimal sequence, it may make agents more likely to reject projects with a positive NPV. Therefore, sophistication may not always pay.

8 Discussion and Conclusion

When people face multiple, long-term projects, they may procrastinate, multitask or choose suboptimal project sequence, which are well documented in the literature and have negative productivity implications. We show in this study that these anomalies can be explained by present-biased preferences. We offer two remedies for the anomalies. One is to add projects to the portfolio and the other is to raise the people's awareness of their self-control problems. Both remedies alleviate procrastination and may also reduce the possibility of multitasking and suboptimal sequence, but there are situations where increased awareness of present bias may not be good from a long-term perspective. Although multitasking and suboptimal project sequence often happen together with procrastination, the drivers behind them are not the same. Whether one multitasks or how one chooses the project sequence depends on the relative values of choosing different project stages to work, and the relative values are different for present-biased people from those for rational people. Therefore, present-biased people may multitask and choose suboptimal project sequence while rational people do not. Procrastination, however, is caused by a low absolute value of competing a project stage (i.e., low motivation to get things done right away). Therefore, adding a common deadline to the project portfolio, which changes the absolute values but not the relative values, may alleviate procrastination, but would not alleviate the other two anomalies.

Although both multitasking and suboptimal project sequencing are well documented, the existing literature focuses on its "rational" causes and their productivity implications. Our aim, however, is to explain these phenomena using the well-established present-biased preference framework. Future research could incorporate the rational causes into our framework. For example, one could incorporate uncertainty, in which case even TCs may multitask (Ross 1983). When people can allocate costs across different stages of a project's life cycle, the total cost required, the total time required, and the project's performance may depend on the allocation, as shown in Choo (2014). It would be interesting to investigate how the choices made by present-biased agents deviate from the optimal allocation. Finally, the possibility of learning across projects could be considered. In this case, the present-biased agents may not take full advantage of the benefit of starting more challenging and more educational projects first (KC et al. 2020).

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Appendix

Proof of Lemma 1: Because each project i has a positive NPV, i.e., $-c_i + \delta(-k_i + \frac{\delta}{1-\delta}v_i) > 0$, the net utility of completing the project $-k_i + \frac{\delta}{1-\delta}v_i$ is also positive. As such, if rational people start a project, they will always finish it. Since we assume that projects have positive NPVs, rational people will complete both projects.

Suppose that project i has been started in the first period. Starting project j and then finishing project i instead of finishing project i and then starting project j result in a utility loss of $(1-\delta)(-k_i + \frac{\delta}{1-\delta}v_i) + (1-\delta)c_j$. Here the first term is the loss from receiving the net benefit of finishing project i one period later, and the second term is the loss from paying the start-up cost of project j one period earlier. As such, rational people do not multitask.

The above analysis shows that rational people must complete the two projects sequentially. Since $J_1 + \delta^2 J_2 > J_2 + \delta^2 J_1$, rational people complete project 1 and then complete project 2.

Proof of Theorem 1: We analyze naifs' behavior first. There are three cases.

Case I. Naifs do nothing in the first period if (1) > (2) and (1) > (3). The first condition is equivalent to

$$c_1 > \frac{\beta\delta(1-\delta)}{1-\beta\delta}\left((-k_1 + \frac{\delta}{1-\delta}v_1) + \delta J_2\right). \tag{4}$$

The second condition is equivalent to

$$c_2 > \frac{\beta\delta}{1-\beta\delta^3}\left(z_2 - \delta^3(-k_2 + \frac{\delta}{1-\delta}v_2) - J_1\right). \tag{5}$$

Note that z_2 is independent of c_2. Therefore, when conditions (4) and (5) hold, the immediate costs of starting both projects are relatively high, so naifs do nothing in the first period, although they plan to complete both projects starting from the next period. As the costs and benefits do not vary over time, naifs never start any project in this case.

Case II. Naifs start project 1 in the first period if (2) > (1) and (2) > (3). The first condition is equivalent to

$$c_1 < \frac{\beta\delta(1-\delta)}{1-\beta\delta}\left((-k_1 + \frac{\delta}{1-\delta}v_1) + \delta J_2\right),$$

which is the same as

$$c_2 < -\frac{1-\beta\delta}{\beta\delta^2(1-\delta)}c_1 + \frac{1}{\delta}(-k_1 + \frac{\delta}{1-\delta}v_1) + \delta(-k_2 + \frac{\delta}{1-\delta}v_2). \tag{6}$$

The second condition is equivalent to

$$c_2 > \frac{1}{1-\beta\delta^2}\left(c_1 - \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1) - \beta\delta^3(-k_2 + \frac{\delta}{1-\delta}v_2) + \beta\delta z_2\right). \tag{7}$$

We can write the second period utilities for naifs' three options, do nothing, finish project 1, or start project 2, respectively as follows:

$$\beta\delta\Big((-k_1 + \frac{\delta}{1-\delta}v_1) + \delta J_2\Big), \tag{8}$$

$$-k_1 + \beta\Big(\frac{\delta}{1-\delta}v_1 + \delta J_2\Big), \tag{9}$$

and

$$-c_2 + \beta\delta K, \tag{10}$$

where

$$K = \max\Big\{[-k_2 + \frac{\delta}{1-\delta}v_2] + \delta[-k_1 + \frac{\delta}{1-\delta}v_1], [-k_1 + \frac{\delta}{1-\delta}v_1] + \delta[-k_2 + \frac{\delta}{1-\delta}v_2]\Big\}.$$

If conditions (6), (7), (8) > (9), and (8) > (10) hold, then naifs only start project 1, but do not finish it.

If conditions (6), (7), (10) > (9), and (10) > (8) hold, then naifs multitask. Note that the third condition is equivalent to

$$c_2 \leq \frac{1}{1-\beta\delta}\Big(k_1 + \beta\delta K - \beta\frac{\delta}{1-\delta}v_1 - \beta\delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)\Big), \tag{11}$$

and the fourth condition is equivalent to

$$c_2 \leq \frac{1}{1-\beta\delta^2}\Big(\beta\delta K - \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1) - \beta\delta^3(-k_2 + \frac{\delta}{1-\delta}v_2)\Big). \tag{12}$$

Case III. Naifs start project 2 in the first period if (3) > (1) and (3) > (2). The first condition is equivalent to

$$c_2 < \frac{\beta\delta}{1-\beta\delta^3}\Big(z_2 - \delta^3(-k_2 + \frac{\delta}{1-\delta}v_2) - J_1\Big). \tag{13}$$

The second condition is equivalent to

$$c_2 < \frac{1}{1-\beta\delta^2}\Big(c_1 - \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1) - \beta\delta^3(-k_2 + \frac{\delta}{1-\delta}v_2) + \beta\delta z_2\Big). \tag{14}$$

We can write the second period utilities of naifs' three options, do nothing, finish project 2, or start project 1, respectively as follows:

$$\beta\delta z_2, \tag{15}$$

$$-k_2 + \beta\bigg(\frac{\delta}{1-\delta}v_2 + \delta J_1\bigg), \tag{16}$$

and

$$-c_1 + \beta\delta K. \tag{17}$$

If conditions (13), (14), (15) > (16), and (15) > (17) hold, then naifs only start project 2, but never finish it.

If conditions (13), (14), (17) > (16), and (17) > (15) hold, then naifs multitask. Note that the third condition is equivalent to

$$(1-\beta\delta)c_1 \le k_2 - \frac{\beta\delta}{1-\delta}v_2 + \beta\delta K - \beta\delta^2(-k_1 + \frac{\delta}{1-\delta}v_1), \tag{18}$$

and the fourth condition is equivalent to

$$c_1 \le \beta\delta(K - z_2). \tag{19}$$

We now analyze sophisticates' behavior. According to the discussion in Section 5, there are multiple equilibria regarding when to complete a stage, that is, sophisticates may procrastinate but always complete a worthwhile stage (eventually). We next show that sophisticates may multitask, adopt a suboptimal sequence or not start a positive NPV project even when sophisticates always pick the perception-perfect strategy that leads to immediate completion of a worthwhile stage.

Because sophisticates correctly predict their future behavior, they do not start a project they know they will not finish. Thus, if $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) < 0$ or $-k_i + \frac{\beta\delta}{1-\delta}v_i < 0$, sophisticates do not start project i even the project has positive NPV.

Now suppose that $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) > 0$ and $-k_i + \frac{\beta\delta}{1-\delta}v_i > 0$ for $i = 1, 2$. Sophisticates must complete the two projects. Similar to the preceding analysis of naifs' behavior, we can write down all of the conditions that lead to a particular project sequencing for sophisticates and then carefully checking whether the conditions can hold simultaneously. For example, let us look at the conditions that lead sophisticates to start project 2, then start and finish project 1, and finally finish project 2.

Given that both projects have been started in the first two periods, sophisticates would finish project 1 before project 2 if and only if

$$-k_1 + \beta(\frac{\delta}{1-\delta}v_1 + \delta(-k_2 + \frac{\delta}{1-\delta}v_2)) > -k_2 + \beta(\frac{\delta}{1-\delta}v_2 + \delta(-k_1 + \frac{\delta}{1-\delta}v_1)). \tag{20}$$

Given that project 2 is started in period 1, sophisticates would prefer starting project 1 to finishing project 2 in period 2 if and only if

$$-c_1 + \beta(\delta(-k_1 + \frac{\delta}{1-\delta}v_1) + \delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)) > -k_2 + \beta(\frac{\delta}{1-\delta}v_2 + \delta J_1). \tag{21}$$

Note that on the LFS of (21), sophisticates correctly predict that if they start project 1 in period 2, they will finish project 1 and then finish project 2 when (20) holds.

In the first period, suppose that sophisticates start project 1. They may expect to finish project 1 and then start and finish project 2, with a utility $u_1 = -k_1 + \frac{\delta}{1-\delta}v_1 + \delta J_2$; or they may expect to start project 2, then finish project 1 and finally finish project 2, with a utility $u_2 = -c_2 + \delta(-k_1 + \frac{\delta}{1-\delta}v_1) + \delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)$. As a result, sophisticates would prefer starting project 2 to starting project 1 if and only if

$$-c_2 + \beta\delta(-c_1 + \delta(-k_1 + \frac{\delta}{1-\delta}v_1) + \delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)) > -c_1 + \beta\delta \max\{u_1, u_2\}. \tag{22}$$

Again on the LFS of (22), sophisticates correctly predict that if they start project 2 in period 1, they will start project 1 and then finish project 1 and finally finish project 2 when (20) and (21) hold. To conclude, when the three conditions (20), (21) and (22) hold simultaneously, sophisticates start project 2, then start and finish project 1, and finally finish project 2. ■

Proof of Proposition 1: Naifs multitask if and only if they start the two projects in the first two periods. In the first period, naifs prefer starting project 1 to delaying it if $c_1 < \frac{\beta}{1-\beta}2v$, and they prefer starting project 1 to starting project 2 if $c_1 < c_2$. Therefore, naifs start project 1 in the first period if $c_1 < \min\{\frac{\beta}{1-\beta}2v, c_2\}$.

In the second period, naifs prefer starting project 2 to delaying it if $c_2 < \frac{\beta}{1-\beta}2v$, and they prefer starting project 2 to finishing project 1 if $c_2 < k_1$. Therefore, naifs start project 2 in the second period if $c_2 < \min\{\frac{\beta}{1-\beta}2v, k_1 - \frac{\beta}{1-\beta}v\}$.

To conclude, naifs start project 1 in the first period and then start project 2 in the second period if and only if $\max\{c_1, c_2\} < \frac{\beta}{1-\beta}2v$ and $c_1 < c_2 < k_1 - \frac{\beta}{1-\beta}v$. Similarly, naifs start project 1 in the first period and then start project 2 in the second period if and only if $\max\{c_1, c_2\} < \frac{\beta}{1-\beta}2v$ and $c_2 < c_1 < k_2 - \frac{\beta}{1-\beta}v$.

Proof of Proposition 2: In the first period, naifs prefer starting project 2 if and only if $c_2 < \min\{\frac{\beta}{1-\beta}2v, c_1\}$. In the second period, naifs prefer finishing project 2 if and only if $k_2 < \min\{\frac{\beta}{1-\beta}2v, c_1 + \frac{\beta}{1-\beta}v\}$. In the third period, naifs prefer starting project 1 if and only if $c_1 < \frac{\beta}{1-\beta}v$. In the fourth period, naifs finish project 1 if and only if $k_1 < \frac{\beta}{1-\beta}v$. To summarize, the conditions are $c_2 < c_1 < \frac{\beta}{1-\beta}v$, $k_2 < c_1 + \frac{\beta}{1-\beta}v$, and $k_1 < \frac{\beta}{1-\beta}v$. ■

Proof of Proposition 3: When δ approaches 1, both $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i)$ and $-k_i + \frac{\beta\delta}{1-\delta}v_i$ are positive, so sophisticates complete each project eventually.

To characterize the sufficient and necessary conditions for sophisticates to multitask, we can write down all of the conditions that lead sophisticates to multitask and then summarize them. In the following, we derive the conditions under which sophisticates start project 1, then start project 2, finish project 1, and finally, finish project 2. Suppose that both project 1 and project 2 have been started, for sophisticates to finish project 1 before project 2, only requires

$$-k_1 + \beta(\frac{\delta}{1-\delta}v + \delta(-k_2 + \frac{\delta}{1-\delta}v)) \geq -k_2 + \beta(\frac{\delta}{1-\delta}v + \delta(-k_1 + \frac{\delta}{1-\delta}v)).$$

When $\delta \to 1$, the above condition is equivalent to $k_1 \leq k_2$.

Suppose that project 1 is started, for sophisticates to start project 2 rather than finish project 1, only requires

$$-c_2 + \beta\delta(-k_1 + \frac{\delta}{1-\delta}v + \delta(-k_2 + \frac{\delta}{1-\delta}v)) \geq -k_1 + \beta\delta(\frac{1}{1-\delta}v - c_2 + \delta(-k_2 + \frac{\delta}{1-\delta}v))).$$

When $\delta \to 1$, the above condition is equivalent to $k_1 \geq c_2 + \frac{\beta v}{1-\beta}$. As project 1 has a higher NPV than project 2, we have $c_1 + k_1 < c_2 + k_2$. This implies that $k_2 - c_1 > k_1 - c_2 > \frac{\beta v}{1-\beta}$, and hence, if sophisticates start project 2 in the first period, they must also plan on completing both projects by multitasking. Thus, to ensure that project 1 is started before project 2, we need

$$-c_1+\beta\delta(-c_2+\delta(-k_1+\frac{\delta}{1-\delta}v)+\delta^2(-k_2+\frac{\delta}{1-\delta}v)) \geq -c_2+\beta\delta(-c_1+\delta(-k_1+\frac{\delta}{1-\delta}v)+\delta^2(-k_2+\frac{\delta}{1-\delta}v)))$$

When $\delta \to 1$, the above condition is equivalent to $c_2 \geq c_1$. We can similarly analyze other cases and summarize the conditions that lead to multitasking. ■

Proof of Proposition 4: This proof is similar to that of Proposition 3. If sophisticates start project 2 in the first period and plan to complete both projects without multitasking, from Proposition 3, we must have $k_2 < c_1 + \frac{\beta v}{1-\beta}$. As project 1 has a higher NPV than project 2, $k_1 - c_2 < k_2 - c_1 < \frac{\beta v}{1-\beta}$. Again following Proposition 3, the inequality $k_1 - c_2 < \frac{\beta v}{1-\beta}$ implies that if sophisticates start project 1 in the first period, they must also plan on completing both projects without multitasking. Therefore, starting project 1 or project 2 makes no difference to the timing of receiving the rewards. Sophisticates prefer to start project 2 in the first period if and only if $c_2 < c_1$. ■

Proof of Proposition 5: Because of the discounting associated with present bias, agents defer as much of the cost as possible to the second stage. This implies that agents choose the following optimal cost structure: $(c_i^*, k_i^*) = (c_i + k_i - \bar{a}, \bar{a})$ for $i = 1, 2$. As project 1 has a higher NPV than project 2, we have $c_1 + k_1 < c_2 + k_2$. Thus, $c_1^* < c_2^*$. According to Proposition 1, naifs multitask if and only if $c_2 + k_2 - \bar{a} < \min\{\frac{2\beta v}{1-\beta}, \bar{a} - \frac{\beta v}{1-\beta}\}$. When (a) $\max\{c_1, c_2\} < \frac{2\beta v}{1-\beta}$ and (b) $c_1 < c_2 < k_1 - \frac{\beta v}{1-\beta}$ or $c_2 < c_1 < k_2 - \frac{\beta v}{1-\beta}$ hold, we always have $c_2 + k_2 - \bar{a} < \min\{\frac{2\beta v}{1-\beta}, \bar{a} - \frac{\beta v}{1-\beta}\}$. Therefore, if naifs multitask under exogenous cost structures (c_1, k_1) and (c_2, k_2), they also multitask under endogenous cost structures $\mathbf{P}(c_1 + k_1, \bar{a})$ and $\mathbf{P}(c_2 + k_2, \bar{a})$.

Based on Proposition 3, sophisticates multitask if and only if $c_2 + k_2 - \bar{a} < \bar{a} - \frac{\beta v}{1-\beta}$. It is not hard to show that when $c_1 < c_2 < k_1 - \frac{\beta v}{1-\beta}$ or $c_2 + \frac{\beta v}{1-\beta} I(c_2 + \frac{\beta v}{1-\beta} - k_1) < c_1 < k_2 - \frac{\beta v}{1-\beta}$ hold, we always have $c_2 + k_2 - \bar{a} < \bar{a} - \frac{\beta v}{1-\beta}$. Therefore, if sophisticates multitask under exogenous cost structures (c_1, k_1) and (c_2, k_2), they also multitask under endogenous cost structures $\mathbf{P}(c_1 + k_1, \bar{a})$ and $\mathbf{P}(c_2 + k_2, \bar{a})$. ■

Proof of Theorem 2: (i) We shall prove this part for the case when only project 1 is in the portfolio. The proof for the general case is similar. We first look at sophisticates. Suppose that sophisticates complete project 1 when it is the only project available. Then it is obvious that sophisticates still complete project 1 if they are exposed to both projects. Therefore, we focus on the case in which sophisticates do not complete project 1 when it is the only project available. Consider two subcases.

Subcase I. Suppose that $-c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta} v_1) \leq 0$. If $-c_2 + \beta\delta(-k_2 + \frac{\delta}{1-\delta} v_2) \leq 0$, sophisticates expect that they will never start project 2, so adding project 2 has no effect on project 1. If $-c_2 + \beta\delta(-k_2 + \frac{\delta}{1-\delta} v_2) > 0$, suppose that sophisticates expect that they will complete project 2 in the future, then they will start project 1 if $-c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta} v_1 + \delta J_2) > 0$. However,

$$-c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta} v_1 + \delta J_2) < \beta\delta J_2,$$

thus starting project 1 is not as good as only completing project 2 in the future. Therefore, adding project 2 does not induce sophisticates to start working on project 1.

Subcase II. Suppose that $-c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta} v_1) > 0$, but sophisticates never start the project because they do not expect to finish it, i.e, $-k_1 + \frac{\beta\delta}{1-\delta} v_1 < 0$. The same logic as in *Subcase I* applies, especially when $-c_2 + \beta\delta(-k_2 + \frac{\delta}{1-\delta} v_2) > 0$: finishing project 1 is not as good as only completing project 2 in the future. Therefore, project 2 has no effect on project 1.

We now look at naifs. For naifs, adding project 2 to their portfolio increases the value of starting project 1 from $-c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta} v_1)$ to $-c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta} v_1 + \delta J_2)$, so project 1 is more likely to be worthwhile. Although the value of not starting project 1 also increases from $\beta\delta J_1$ to $\beta\delta(J_1 + \delta^2 J_2)$, naifs are less likely to procrastinate since $\beta\delta^2 J_2 > \beta\delta^3 J_2$. Therefore, naifs are more likely to start a project when a new project is added to their portfolio. Similarly, for a project that naifs start but do not finish, they are more likely to finish it if a new project is added to their portfolio.

(ii) The general idea of the proof is to construct a new project to de-bias agents. We shall prove the result for naifs. The proof is similar for sophisticates. To simplify the analysis and focus on the major insights, we assume that $\delta \to 1$. In this case, all projects are worthwhile. Since multitasking and suboptimal sequencing are all about relative values of starting or finishing different project stages, we could artificially assign a terminal period T of receiving rewards without affecting cost comparisons between working on different stages. We use the case where where naifs start project 2 and then start project 1 as an example. In the first period, the utility of starting project 1 is

$$-c_1 + \beta(-k_1 + (T-2)v_1 - c_2 - k_2 + (T-4)v_2).$$

Suppose that $v_1 < 2v_2$, the utility of starting project 2 is

$$-c_2 + \beta(-k_2 + (T-2)v_2 - c_1 - k_1 + (T-4)v_1).$$

The utility of doing nothing is

$$\beta(-c_1 - k_1 + (T-3)v_1 - c_2 - k_2 + (T-5)v_2).$$

Thus, for naifs to start project 2 in period 1, we need

$$c_2 < \min\{c_1 + \frac{2\beta(v_2 - v_1)}{1-\beta}, \frac{\beta(3v_2 - v_1)}{1-\beta}\}. \tag{23}$$

In the second period, the utility of finishing project 2 is

$$-k_2 + \beta((T-1)v_2 - c_1 - k_1 + (T-3)v_1).$$

The utility of starting project 1 is

$$-c_1 + \beta(-k_1 + (T-2)v_1 - k_2 + (T-3)v_2),$$

and the utility of doing nothing is

$$\beta(-k_2 + (T-2)v_2 - c_1 - k_1 + (T-4)v_1).$$

Accordingly, for naifs to start project 1 in period 2, we need

$$c_1 < \min\{k_2 + \frac{\beta(v_1 - 2v_2)}{1-\beta}, \frac{\beta}{1-\beta}(v_1 + v_2)\}. \tag{24}$$

To summarize, when (23) and (24) hold, naifs multitask and follow a suboptimal sequence.

We now investigate whether adding a project 3 can de-bias naifs. In the first period, we need to induce naifs to starting project 1 instead of starting project 2. Obviously, naifs would still start project 2 first if they expect to complete project 3 after the other two projects. As such, we must have $J_1 > J_3 > J_2$. This condition is equivalent to $v_1 > v_3 > v_2$ as $\delta \to 1$. We further assume that c_3 is sufficiently large so that naifs never start project 3. Then the utility of starting project 1 is

$$-c_1 + \beta(-k_1 + (T-2)v_1 - c_3 - k_3 + (T-4)v_3 - c_2 - k_2 + (T-6)v_2).$$

The utility of starting project 2 is

$$-c_2 + \beta(-k_2 + (T-2)v_2 - c_1 - k_1 + (T-4)v_1 - c_3 - k_3 + (T-6)v_3).$$

The utility of doing nothing is

$$\beta(-c_1 - k_1 + (T-3)v_1 - c_3 - k_3 + (T-5)v_3 - c_2 - k_2 + (T-7)v_2).$$

For naifs to start project 1, we need $c_2 > c_1 + \frac{\beta(4v_2 - 2v_1 - 2v_3)}{1-\beta}$ and $c_1 < \frac{\beta(v_1+v_2+v_3)}{1-\beta}$. Since $v_1 > v_3 > v_2$, it is easy to show that we need $c_2 > c_1 + \frac{4\beta(v_2-v_1)}{1-\beta}$ to guarantee that there is a feasible v_3. In other words, to correct suboptimal sequencing, c_2 cannot be too low relative to c_1.

Now in the second period, we need to induce naifs to finishing project 1 instead of starting project 2. The utility of finishing project 1 is

$$-k_1 + \beta((T-1)v_1 - c_3 - k_3 + (T-3)v_3 - c_2 - k_2 + (T-5)v_2)$$

The utility of starting project 2 is

$$-c_2 + \beta(-k_1 + (T-2)v_1 - k_2 + (T-3)v_2 - c_3 - k_3 + (T-5)v_3)$$

The utility of doing nothing is

$$\beta(-k_1 + (T-2)v_1 - c_3 - k_3 + (T-4)v_3 - c_2 - k_2 + (T-6)v_2).$$

Thus, for naifs to finish project 1, we need $k_1 < c_2 + \frac{\beta(v_1+2v_3-2v_2)}{1-\beta}$ and $k_1 < \frac{\beta(v_1+v_2+v_3)}{1-\beta}$. To ensure a feasible v_3, we need $k_1 < c_2 + \frac{\beta(3v_1-2v_2)}{1-\beta}$ and $k_1 < \frac{\beta(2v_1+v_2)}{1-\beta}$. Thus, to correct multitasking, k_1 can not be too high relative to c_2. ■

Proof of Theorem 3: (i) The proofs include three parts. In part one, we prove that if project i is not completed by sophisticates, it is not completed by naifs either. Recall that sophisticates do not complete project i either because it is not worthwhile ($-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) < 0$) or because they do not expect to finish it ($-k_i + \frac{\beta\delta}{1-\delta}v_i < 0$). Suppose that $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) < 0$. Consider the following two cases.

Case I. Suppose that project i has a higher NPV than project j, i.e., $J_i \geq J_j$. In this case, if naifs prefer starting project i to delaying it, we have

$$-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i + \delta J_j) > \beta\delta(J_i + \delta^2 J_j),$$

which is equivalent to

$$\beta\delta^2(1-\delta)J_j > \beta\delta J_i + c_i - \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i).$$

Because $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) < 0$, the inequality above implies that $\beta\delta^2(1-\delta)J_j > \beta\delta J_i$, and consequently, $J_j > J_i$. This is a contradiction, and thus naifs prefer to delay starting project i.

Case II. Suppose that $J_i < J_j$. In this case, if naifs prefer starting project i to delaying it, we have

$$-c_i + \beta\delta \max\{-k_i + \frac{\delta}{1-\delta}v_i + \delta J_j, J_j + \delta^2(-k_i + \frac{\delta}{1-\delta}v_i)\} > \beta\delta(J_j + \delta^2 J_i). \tag{25}$$

When $-k_i + \frac{\delta}{1-\delta}v_i \leq \frac{1}{1+\delta}J_j$, inequality (25) is

$$-c_i + \beta\delta(J_j + \delta^2(-k_i + \frac{\delta}{1-\delta}v_i)) > \beta\delta(J_j + \delta^2 J_i),$$

which is equivalent to

$$-c_i + \beta\delta^3(-k_i + \frac{\delta}{1-\delta}v_i) > \beta\delta^3 J_i.$$

However, the above inequality cannot hold because $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) < 0$.

When $-k_i + \frac{\delta}{1-\delta}v_i > \frac{1}{1+\delta}J_j$, inequality (25) is

$$-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i + \delta J_j) > \beta\delta(J_j + \delta^2 J_i),$$

which is equivalent to

$$-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) > \beta\delta(1-\delta)J_j + \beta\delta^3 J_i.$$

The above inequality does not hold because the LFS is negative while the RHS is positive. Therefore, if $-c_i + \beta\delta(-k_i + \frac{\delta}{1-\delta}v_i) < 0$, naifs prefer to delay starting project i.

Similarly, we can prove that if $-k_i + \frac{\beta\delta}{1-\delta}v_i < 0$, naifs prefer to delay finishing project i. Together, we show that if sophisticates do not complete a project, naifs do not complete it either.

In part two, we prove that when naifs start both projects but do not multitask, then sophisticates do not multitask. We only prove the statement assuming that both projects are completed, and other cases can be proved similarly. We first prove that if naifs complete project 1 and then complete project 2, sophisticates also complete project 1 and then complete project 2. Suppose that project 1 is started in the first period. Naifs finish project 1 in the second period requires that

$$-k_1 + \beta(\frac{\delta}{1-\delta}v_1 + \delta J_2) \geq -c_2 + \beta\delta K, \tag{26}$$

where

$$K = \max\Big\{ -k_2 + \frac{\delta}{1-\delta}v_2 + \delta(-k_1 + \frac{\delta}{1-\delta}v_1), -k_1 + \frac{\delta}{1-\delta}v_1 + \delta(-k_2 + \frac{\delta}{1-\delta}v_2)\Big\}.$$

Inequality (26) implies that sophisticates also finish project 1 in the second period because sophisticates correctly predict their future behavior, and if they start project 2, their future utility must be lower than K. In the first period, naifs prefer starting project 1 to starting project 2 requires that

$$-c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1 + \delta J_2) > -c_2 + \beta\delta z_2$$

where

$$z_2 = \max\{-k_2 + \frac{\delta}{1-\delta}v_2 + \delta J_1, J_1 + \delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)\}.$$

Again sophisticates correctly predict that if they start project 2 right now, their future utility must be lower than z_2. Therefore, sophisticates also start project 1 in the first period.

We now prove that if naifs complete project 2 before project 1, sophisticates also complete project 2 before project 1. Consider the following two cases.

Case 1. Suppose that sophisticates start project 2 in the first period. Naifs prefer finishing project 2 to starting project 1 if and only if

$$-k_2 + \beta(\frac{\delta}{1-\delta}v_2 + \delta J_1) \geq -c_1 + \beta\delta K.$$

Following the same reasoning as in previous cases, sophisticates should also finish project 2 in the second period. In this case, sophisticates obtain the same long-run utility as naifs.

Case 2. Suppose that sophisticates start project 1 in the first period. Note that in the first period, naifs prefer starting project 2 to starting project 1. Thus,

$$-c_2 + \beta\delta z_2 > -c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1 + \delta J_2). \tag{27}$$

Subcase (a). If $-k_2 + \frac{\delta}{1-\delta}v_2 + \delta J_1 \geq J_1 + \delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)$, then $z_2 = -k_2 + \frac{\delta}{1-\delta}v_2 + \delta J_1$. In this case, sophisticates would not start project 1 in the first period. This is because sophisticates correctly predict that if they start project 1 in the first period, their future utility must be smaller than that of TCs. Inequality (27) then implies that sophisticates would rather start project 2 in the first period.

Subcase (b). If $-k_2 + \frac{\delta}{1-\delta}v_2 + \delta J_1 < J_1 + \delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)$, then $z_2 = J_1 + \delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)$. Naifs start project 2 in the first period because they wrongly believe that they will start project 1, finish project 1, and finally, finish project 2. However, naifs in fact will finish project 2, and start and finish project 1. Sophisticates correctly predict that if they start project 2 first, they will follow what naifs actually do. If $-c_2 + \beta\delta(-k_2 + \frac{\delta}{1-\delta}v_2 + \delta J_1) > -c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1 + \delta J_2)$, then sophisticates would not start project 1 in the first period. Therefore, we only consider scenarios in which the following inequalities hold:

$$-c_2 + \beta\delta(-k_2 + \frac{\delta}{1-\delta}v_2 + \delta J_1) < -c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1 + \delta J_2) \tag{28}$$

and

$$-c_2 + \beta\delta(J_1 + \delta^2(-k_2 + \frac{\delta}{1-\delta}v_2)) > -c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1 + \delta J_2). \tag{29}$$

Inequality (28) is equivalent to

$$c_1 < c_2 + \frac{\beta\delta(1-\delta^2)(-k_1 + \frac{\delta}{1-\delta}v_1 - (-k_2 + \frac{\delta}{1-\delta}v_2))}{1-\beta\delta^2}. \tag{30}$$

Meanwhile, inequality (29) is equivalent to

$$c_1 > \frac{\beta\delta(1-\delta)(-k_1 + \frac{\delta}{1-\delta}v_1) + (1-\beta\delta^2)c_2}{1-\beta\delta}. \tag{31}$$

However, we can easily verify that inequalities (30) and (31) contradict each other.

In summary, we can rule out Case 2 in which sophisticates start project 1 in the first period.

In part three, we prove that if naifs start project 1 before project 2, so do sophisticates. We omit the proof as it follows from the same reasoning as in the previous part.

(ii) According to part two of (i), if naifs complete both projects, sophisticates complete the two projects in the same sequence. As such, sophisticates obtain the same long-run utility as naifs.

Suppose that naifs start and finish only project 1, following the same reasoning of part two in (i), if sophisticates complete both projects, they must complete project 1 before project 2 without multitasking. Thus, sophisticates obtain a higher long-run utility than naifs. Similarly, if naifs start and finish only project 2, we can also show that sophisticates either only complete project 2 or complete project 2 before project 1, and therefore, they obtain a higher long-run utility than naifs.

Suppose that naifs complete project 2 or project 1 with multitasking, we can also follow the same reasoning of part two in (i) to verify that sophisticates always obtain a higher long-run utility than naifs. As an example, consider the following case. Naifs start project 2 and then start and finish project 1. Sophisticates obviously obtain a higher long-run utility than naifs if they start project 2, then start and finish project 1, and finally finish project 2. Sophisticates may also start and finish project 2, and then start and finish project 1. We show next that in this case, sophisticates also obtain a higher long-run utility than naifs. Because naifs finish project 1 in period 3, we know that if sophisticates multitask, they must finish project 1 and then project 2 in periods 3 and 4. For sophisticates to finish project 2 in period 2, we must have

$$-k_2 + \beta(\frac{\delta}{1-\delta}v_2 + \delta J_1) > -c_1 + \beta\delta(-k_1 + \frac{\delta}{1-\delta}v_1 + \delta(-k_2 + \frac{\delta}{1-\delta}v_2)).$$

For naifs to start project 1 in period 2, we must have

$$-k_2 + \beta(\frac{\delta}{1-\delta}v_2 + \delta J_1) < -c_1 + \beta\delta(-k_2 + \frac{\delta}{1-\delta}v_2 + \delta(-k_1 + \frac{\delta}{1-\delta}v_1)).$$

The two inequalities above are equivalent to

$$(1-\beta)k_2 < (1-\beta)c_1 + \beta(1-\delta^2)(-k_2 + \frac{\delta}{1-\delta}v_2) - \beta(1-\delta)J_1$$

and

$$(1-\beta)k_2 > (1-\beta\delta)c_1 + \beta(1-\delta)(-k_2 + \frac{\delta}{1-\delta}v_2),$$

respectively. This implies that

$$\begin{aligned} J_1 &< -c_1 + \delta(-k_2 + \frac{\delta}{1-\delta}v_2) \\ &\leq (1+\delta)(-k_2 + \frac{\delta}{1-\delta}v_2). \end{aligned}$$

Therefore, sophisticates' long-run utility $-c_2 + \delta(-k_2 + \frac{\delta}{1-\delta}v_2) + \delta^2 J_1$ is greater than $-c_2 + \delta J_1 + \delta^3(-k_2 + \frac{\delta}{1-\delta}v_2)$, which in turn is greater than naifs long-run utility $-c_2 + \delta J_1$. ■

Proof of Theorem 4: (i) Naifs' utility in period 0 is given by $\max\{0, -e_1+\beta\delta J_1, -e_2+\beta\delta J_2, -e_1-e_2+\beta\delta(J_1+\delta^2 J_2)\}$. Because sophisticates correctly predict their future behavior, their future utility from project i is either J_i or 0. This means that whenever sophisticates include project i in their portfolio, naifs must also include project i in their portfolio.

To prove(ii) and (iii), we only need to find examples for which the statements hold. The examples are provided in the discussion after the theorem. ■