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http://www.coll.mpg.de

Doing it when others do: a strategic model of procrastination*

Claudia Cerrone†

Abstract

This paper develops a strategic model of procrastination in which present-biased agents prefer to do an onerous task in the company of someone else. This turns their decision of when to do the task into a *procrastination game* – a dynamic coordination game between present-biased players. The model characterises the conditions under which interaction mitigates or exacerbates procrastination. Surprisingly, a procrastinator matched with a worse procrastinator may do her task *earlier* than she otherwise would: she wants to avoid the increased temptation that her peer's company would generate. Procrastinators can thus use bad company as a commitment device to mitigate their self-control problem. Principals can reduce procrastination by matching procrastinators with each other, but the efficient matching may not be stable.

JEL classification: C72, C73, D03, D91.

"Fellowship in woe doth woe assuage,
as palmers' chat makes short their pilgrimage."
— Shakespeare

1. Introduction

Suppose you have been teaching a class long enough to know which of your students tend to procrastinate, and how strong their proclivity is. They are aware of their tendency to procrastinate, yet unable to avoid it, and you are concerned that this may undermine their performance in the final exam. As the exam is critical for their career, they want to overcome procrastination. This paper shows that it may be optimal to match average procrastinators with the worst.

In this article, I develop a strategic model of time-inconsistent procrastination. The key and novel feature of the model is that people – who have a time-inconsistent preference for immediate gratification, known as present-bias, and are faced with an onerous task – prefer to do the task

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†Max Planck Institute for Research on Collective Goods, Bonn. E-mail: cerrone@coll.mpg.de

when someone else does.[1] This simple assumption turns the decision of when to do the task into a game – a dynamic coordination game between present-biased players. The players have potentially heterogeneous present-bias and are "sophisticated", i.e. aware of their present-bias.[2] The task must be performed by a final period, gets increasingly costly over time, and is less costly if performed when the other player does.

I characterise the conditions under which interaction mitigates or exacerbates procrastination relative to the case in which people act in isolation, and thus show how principals can reduce procrastination by matching people with each other in the appropriate way, thereby improving people's welfare and reducing inefficient delay.

Example (Avoidance of bad company)**.** Two students, Alice and Bob, are given three possible dates – three subsequent Tuesdays – to take a compulsory maths test. The cost of taking the test – the effort exerted – is experienced immediately and increases over the three dates. In fact, as the deadline approaches, taking the test gets increasingly stressful, because the students get increasingly busy with other assessments and because they face the risk of experiencing some unexpected event that may prevent them from working. Let the costs of taking the test over the three dates be $\mathbf{c} \equiv (c_1, c_2, c_3) = (2, 3.5, 10)$. From an *ex ante* perspective, it would be optimal for Alice and Bob to take the test on the first Tuesday. However, when the time comes, due to their present-bias they give added weight to the immediate disutility from working and thus may delay. Alice overvalues the present more than Bob. They are both aware of this setup.

On the third Tuesday the test must be taken, if it has not been taken yet. On each of the first two Tuesdays, $t \in \{1, 2\}$, each student decides whether to take the test immediately, thus experiencing c_t, or delay the test to a later date $\tau > t$, thus experiencing $\beta_i c_\tau$, where for $i \in \{A, B\}$ $\beta_i \in (0, 1)$ denotes their present-bias factor.[3] Let their present-bias factors respectively be $\beta_A = 0.1$ and $\beta_B = 0.5$. Then in isolation Alice would take the test on the last Tuesday and Bob on the second one. We can regard Alice as a *severe* procrastinator and Bob as a *moderate* one.

Being friends, Alice and Bob prefer to take the test on the same Tuesday, as taking the test when the other does will be less unpleasant. Let the reduction in the cost of taking the test generated by the company of the other be 40%. Moreover, being friends, they know each other's tendency to procrastinate. What happens when they interact with each other? How will they affect each other's behaviour? The (unique) equilibrium of the "procrastination game" is for

[1] The assumption is supported by empirical evidence. Banarjee et al. (2007) find that women's probability of getting breast cancer screening increases with the frequency of screenings among their co-workers and neighbours. As the women in this sample were employees of a health organisation and thus likely to be informed about the benefits of screening, their behaviour does not seem to be due to learning. Rao et al. (2012) show that students become more likely to get vaccinated against the flu when their friends do, and the excess clustering of friends at inoculation clinics suggests that students coordinate their vaccination decisions.

[2] I will also explore how naïvete – the unawareness of the present-bias – affects the main results of the model under sophistication.

[3] This is a special case of present-biased or $\beta\delta$ preferences where $\delta = 1$.

Alice to take the test on the last Tuesday and for Bob to take it on the *first*. Why? Alice's present-bias is too strong for her to take the test earlier than on the last date. Bob knows that, by himself, he would take the test on the second week and resist the temptation to delay further (the cost of taking the test in the second week, 3.5, is smaller than the discounted cost of delaying, 5). However, in the presence of Alice taking the test on the second week is no longer realistic, as her company will make delaying additionally tempting (the cost of taking the test in the second week is now bigger than the discounted cost of delaying with Alice, i.e. 5(1-0.4) = 3). Hence he takes the test on the first Tuesday, earlier than he otherwise would, to avoid the increased temptation that Alice's company would generate on the second Tuesday. □

This example illustrates one of the possible ways in which people's procrastination behaviour can be influenced by the procrastination of others, and provides the intuition behind one of the most interesting results of the model. A "hardcore" procrastinator like Alice, who overvalues the present to such an extent that not even good company can help her, can provide a positive externality: she can help a peer with self-control problems to procrastinate less. The bad company of a peer who has a worse self-control problem than one's own is thus desirable, as it can be used as a commitment device to mitigate one's own self-control problem.

More in general, the model shows that, given three periods to do the task, the interaction between two "heterogeneous procrastinators" – two people who, like Alice and Bob, would both procrastinate in isolation but to a different extent – will weakly reduce procrastination. Either they will behave as in isolation, or one will do the task earlier, or both of them will.

The equilibrium in which delay is reduced for one player, which I call "avoidance of bad company", is described in the above example. In the equilibrium in which delay is reduced for both players, which I call "mutual reduction of procrastination", Alice's bias is smaller than in the example above. While she would not do the task in the first period if by herself, she would in the presence of Bob, as his company would make delaying less tempting in the first period. Thus, Alice and Bob will coordinate to do the task in the first period, earlier than each of them would in isolation. Each of them uses the company of the other as a commitment device – albeit in different ways – to mitigate their own self-control problem.

When two "homogeneous procrastinators" – two people who procrastinate to the same extent in isolation – interact, behaving as they would in isolation will always be an equilibrium, but there *may* also be additional equilibria where they coordinate on an earlier date.

In some cases interaction can be harmful. For example, someone who would do the task immediately in isolation might be induced by a procrastinator like Bob to delay the task to second period.

Finally, the matching that minimises overall procrastination, may not be stable. Thus, principals may want to decree the matching rather than giving people freedom of choice.

The above results imply that (i) principals *can* help people procrastinate less by pairing them up, (ii) who is matched with whom matters, (iii) the best matching may need to be enforced.[4]

These results are policy relevant. Procrastination is a pervasive and costly phenomenon. Postponing activities such as starting a diet, exercising, having medical checkups, saving for retirement, or searching for a job, leads to costs both for the individual and for society. In light of that, the UK government has implemented incentive schemes to encourage people to undertake such activities earlier. Two examples, both implemented by the UK National Health Service (NHS), are the smoking cessation scheme *Quit4U*, which offered people in Scotland cash for each week without smoking, and the vouchers offered to overweight and obese patients to attend 12 meetings of the weight loss programme *Weight Watchers*. Similarly, firms offer their employees incentives to reduce inefficient delay in the workplace. These incentives are generally individual-based and do not account for the influence that people may have on each other. My model shows how peer influences can be exploited to make policy interventions aimed at reducing procrastination cheaper and more effective. Incentives can be targeted to some and also have an impact on others, which reduces their per-unit cost. In the absence of incentives, people can be encouraged to undertake onerous tasks earlier by simply being matched with someone else.

The model is solved by backward induction. When both players are sophisticated, my solution concept is equivalent to a Subgame Perfect Nash Equilibrium. Being a coordination game, the model often has multiple equilibria. Equilibrium selection in games with time-inconsistent players is an unexplored and compelling area. One of the contributions of this paper is to propose a method to compute risk-dominance in dynamic games with simultaneous move and time-inconsistent, sophisticated players. The basic intuition is that, under time-inconsistent preferences, in any stage of the game the players will play the risk-dominant equilibrium from the perspective of *that* stage.

This paper relates to three strands of the literature. First, it contributes to the literature on time-inconsistent procrastination. O'Donoghue & Rabin (1999) show that a present-biased, sophisticated individual will procrastinate an onerous activity less than a present-biased, naïve one.[5] My model extends theirs to a strategic setting by arguing that a present-biased individual may prefer to do an onerous activity with others.

Second, this paper relates to the game-theoretical literature on self-control. Brocas & Carrillo (2001) show that competing on a task can mitigate present-biased people's tendency to procrastinate, whereas cooperating on a task can exacerbate procrastination. My paper complements their work by showing how present-biased people can influence each other's procrastination even when they work on independent tasks. Battaglini et al. (2005) explore how observing each other's

[4] The results that peers *can* mitigate self-control problems is consistent with experimental evidence on self-control in the workplace. Kaur et al. (2010) find that social arrangements in the workplace can mitigate self-control problems, and there is a strong peer effect in the workers' demand for commitment.

[5] Akerlof (1991) does not frame his analysis of procrastination in terms of time-inconsistent preferences (procrastination occurs because the cost of doing a task is more salient when it is immediate than when it is delayed), but his model is equivalent to a model of present-biased preferences.

behaviour affects time-inconsistent people's ability to overcome self-control problems, in an environment where people have incomplete information about their ability to resist temptation and can learn from observing others as characteristics are correlated. My paper explores an alternative mechanism through which people affect each other's capability to overcome self-control problems. Takeoka & Ui (2014) explore strategic interaction between players with self-control problems modelled as temptation preferences as in Gul & Pesendorfer (2001). My paper complements their work by exploring strategic interaction between players with self-control problems modelled as time-inconsistent preferences.

Finally, this paper contributes to the literature incorporating time-inconsistent preferences into game theory. A number of papers introduce time-inconsistent preferences into extensive form games (Sarafidis (2006), Akin (2007)). I introduce time-inconsistent preferences into an extensive game with simultaneous moves, and propose a possible equilibrium selection criterion.

This paper is structured as follows. Section 2 develops a strategic model of procrastination under sophistication. Section 3 characterises and discusses the equilibrium outcomes of the model, focusing on the interaction between two players with different tendencies to procrastinate. Section 4 discusses equilibrium selection under time-inconsistency. Section 5 explores matching in a population of procrastinators. Section 6 extends the model to the case in which at least one player is naïve. Section 7 concludes and discusses avenues for future research.

2. The procrastination game

I extend the individual model of procrastination by O'Donoghue & Rabin (1999) (henceforth, ODR 1999) to a strategic setting.

2.1. Model

Let $\mathcal{G}$ denote a dynamic game which I call "procrastination game". The game has three periods, but in the third period there is no decision to be taken. The subgame of $\mathcal{G}$ in any node $t \in \{1, 2\}$ is denoted by $\mathcal{G}^t$. Let $\{A, B\}$ denote the set of players and let $a_{i,t} \in \{0, 1\}$ denote the action that each player i plays in each period t, where $\{0, 1\}$ is the action set. Each player must perform an individual task. In each period, she must choose either to do the task immediately ($a_{i,t} = 1$) or to wait ($a_{i,t} = 0$). If she waits, she will face the same decision in the following period. If she waits until the third period, she must do the task then.

Time-inconsistency Each player i has quasi-hyperbolic, time-inconsistent preferences.[6] For $t \leqslant 3$, let u_t denote an individual's utility in t. Her intertemporal utility at time $t = 1$, U_i^1, is,

$$U_i^1(u_1, u_2, u_3) \equiv u_1 + \beta\delta u_2 + \beta\delta^2 u_3, \text{ where } 1 \geq \beta > 0, \delta \leq 1. \tag{1}$$

δ represents time-consistent impatience and β captures a time-inconsistent preference for immediate gratification. If $\beta = 1$, (1) is equivalent to exponential discounting and the player is time-consistent. If $\beta < 1$, (1) describes quasi-hyperbolic discounting and the player is present-biased. Following the literature, I consider the individual in each period as a separate "self" who chooses her current behaviour to maximise her current preferences, whereas her future selves will choose her future behaviour. A time-inconsistent individual's decision problem can then be modelled as a sequential game between her selves at different points in time. She is "sophisticated" if she is able to fully predict her future (mis)behaviour. I assume that both players are sophisticated. The alternative assumption that she is "naïve", i.e. she mistakenly thinks that she will behave as a time-consistent individual in the future, will be discussed in Section 6.

As this paper is concerned with procrastination arising from time-inconsistency, I assume that $\beta < 1$. Second, for concreteness I assume that $\delta = 1$.[7]

Task The task requires only one period of effort and is completed once begun. It has immediate costs and delayed benefits, normalised to zero. Let $\mathbf{c} \equiv (c_1, c_2, c_3)$ denote the cost schedule, where $c_t \geq 0$ for each $t \leq 3$.

Assumption 1. In any procrastination game $\mathcal{G}$, $c_3 > c_2 > c_1$.

Assumption 1 allows for focusing on situations in which delaying is not optimal from an *ex ante* perspective and arises from time-inconsistency. Moreover, many onerous tasks get increasingly costly over time. For example, working on a problem set feels more and more stressful as the deadline approaches. The later a fine is paid, the higher the charge will be due to late payment penalties.

[6] Evidence shows that, when considering two future periods, people give stronger relative weight to the earlier period as it gets closer, which implies that the discount factor increases with the time horizon or, in other words, people are hyperbolic discounters. Changing the delay might then change peoples preferences over two options and lead to time-inconsistency (Thaler (1981)). This motivated the introduction of a quasi-hyperbolic model of discounting (Phelps & Pollak (1968)). This simplification of hyperbolic discounting assumes a declining discount rate between the current period and the next one, but a constant discount rate thereafter.

[7] This assumption is without loss of generality. Note that $\delta = 1$ implies that, under two periods, (1) would be equivalent to exponential discounting. This is the reason why a three-period case is the simplest case to be considered.

Preferences Letting τ_i denote the period in which player i completes the task, her intertemporal utility in t from doing the task in $\tau_i \geq t$ is given by

$$U_i^t(\tau_i, \tau_{-i}) \equiv \begin{cases} -c_{\tau_i} & \text{if } \tau_i = t \neq \tau_{-i} \\ -c_{\tau_i}(1-\kappa) & \text{if } \tau_i = t = \tau_{-i} \\ -\beta_i c_{\tau_i} & \text{if } \tau_{-i} \neq \tau_i > t \\ -\beta_i c_{\tau_i}(1-\kappa) & \text{if } \tau_i = \tau_{-i} > t \end{cases} \tag{2}$$

In each period t, if player i decides to do the task immediately ($\tau_i = t$), she will suffer that period's cost, c_τ. If she decides to wait ($\tau_i > t$), she will face the same decision in the following period. Her decision will depend not only on her degree of present-bias, β_i, but also on her opponent's completion date, τ_{-i}. In fact, whenever she does the task in the same period as her peer (i.e. $\tau_{-i} = \tau_i$), that period's cost will be reduced by κc_{τ_i}.

Assumption 2 ensures that the cost reduction generated by company is positive, but not as large as to invert the cost structure and make the cost of doing the task no longer increasing over time. That is, $c_t \leq c_{t+1}(1-\kappa)$. The intuition is the following. The players are assumed to value each other's company, but up to a point – the extent to which they value company will not be as large as to make delaying optimal from an *ex ante* perspective. If the preference for coordination is unboundedly strong, any coordinated outcome is an equilibrium. The analysis of equilibria in games with smaller preference for company requires more subtlety.

Assumption 2. In any procrastination game $\mathcal{G}$, $\kappa \in \left(0, 1 - \max\{\frac{c_1}{c_2}, \frac{c_2}{c_3}\}\right]$.

The players' preferences are common knowledge, hence the procrastination game is a game of complete information. It describes situations in which two people know each other's tendency to procrastinate, as it is the case for close social ties like spouses, siblings and close friends.

Benchmark case: autarky as the absence of benefit from company If the players are assumed *not* to value company, i.e. $\kappa = 0$, their preferences become

$$U_i^t(\tau_i, \tau_{-i}) \equiv \begin{cases} -c_{\tau_i}, & \text{if } \tau_i = t; \\ -\beta_i c_{\tau_i}, & \text{if } \tau_i > t. \end{cases} \tag{3}$$

Their decision problem becomes equivalent to that of an individual who acts in isolation, as in ODR 1999. Thus, their individual model of procrastination is obtained as a special case of my model and will be used as a benchmark model throughout this paper.

2.2. Strategy and solution concept

For $i \in \{A, B\}$, let $\mathcal{S}_i$ denote the strategy set and $U_i : \mathcal{S}_A \times \mathcal{S}_B \to \mathbb{R}$ the payoff function. A *strategy* is given by $\mathbf{s}_i \equiv (a_{i,1}, a_{i,2}(a_{-i,1})) = (a_{i,1}, (0), a_{i,2}(1))) \in \mathcal{S}_i$, where, for $t \in \{1, 2\}$, $a_{i,t}$ specifies whether player $i \in \{A, B\}$ does the task in t or waits, given she has not yet done it.

The strategy $\mathbf{s}_i$ specifies doing it in period t if $a_{i,t} = 1$, and waiting if $a_{i,t} = 0$. In addition to specifying when player i will actually do the task, a strategy also specifies what she "would" do in periods after she has already done it. A player's strategy in $t = 2$, $a_{i,2}$, will depend on whether the opponent has done the task in $t = 1$. Note that the definition of strategy in a procrastination game embeds ODR's definition of strategy. In fact, when $\kappa = 0$ a player's optimal behaviour in $t = 2$ does not depend on her opponent's in $t = 1$, i.e. $a_{i,2}(a_{-i,1} = 0) = a_{i,2}(a_{-i,1} = 1)$. Thus, for ease of notation, when $\kappa = 0$ a strategy can be written as $\mathbf{s}_i \equiv (a_{i,1}, a_{i,2}) = \tilde{\mathbf{s}}_i$.

In each period t, each self-t player i plays an action $a_{i,t} \in \{0, 1\}$ to maximize (2), where $a_{i,t} = 1$ if $\tau_i = t$ and $a_{i,t} = 0$ if $\tau_i > t$.

ODR's solution concept under sophistication, called *perception-perfect strategy* for sophisticates, requires that the individual chooses optimally given her current preferences and her knowledge of her future behaviour. A sophisticate does the task today if and only if given her current preferences doing it now is preferred to waiting for her future selves to do it. Since the sophisticate's decision problem can be modelled as a sequential game with perfect information and a finite number of periods, it can be solved via backward induction.

In a procrastination game, a perception-perfect strategy for sophisticates requires that, at each subgame, each player chooses optimally given her current preferences, her knowledge of her future behaviour *and* her knowledge of her opponent's behaviour given her own.

In any dynamic game between present-biased agents, it is necessary to specify whether each player can correctly predict her opponent's future behaviour. I define a player "peer-sophisticated" if in equilibrium her beliefs about her opponent's strategies are correct, and assume that in a procrastination game every player is peer-sophisticated.

Assumption 3. In any procrastination game $\mathcal{G}$, every player $i \in \{A, B\}$ is *peer-sophisticated*.

When both players are sophisticated and peer-sophisticated, a pair of strategies $(\mathbf{s}_A, \mathbf{s}_B) \equiv ((a_{A,1}, a_{A,2}(a_{B,1})), (a_{B,1}, a_{B,2}(a_{A,1})))$ is an equilibrium of the game $\mathcal{G}$ if, in every node, each player $i \in \{A, B\}$ plays a perception-perfect strategy for sophisticates given her opponent's behaviour.[8] I shall call the solution concept thus defined "Perception-Perfect Equilibrium" for sophisticates (hereafter PPE). Since both players are sophisticated and peer-sophisticated, backward induction can be used as a solution concept. A PPE is equivalent to a Subgame Perfect Nash Equilibrium.

Definition 1 (PPE)**.** Given a procrastination game $\mathcal{G}$, a pair of strategies $(\mathbf{s}_A, \mathbf{s}_B)$ is a Perception-Perfect Equilibrium for sophisticates if, for $i \in \{A, B\}$, $\mathbf{s}_i \equiv (a_{i,1}, a_{i,2}(a_{-i,1}))$ satisfies, for all $t \in \{1, 2\}$, $a_{i,t} = 1$ if and only if $U_i^t(t_i, \tau_{-i}) \geq U_i^t(\tau_i', \tau_{-i})$, where $\tau_i' \equiv \min_{\tau_i > t}\{\tau_i | a_{\tau_i} = 1\}$ and τ_{-i} is the completion date induced by $\mathbf{s}_{-i}$.

[8] A perception-perfect strategy maps into the timing of completion, i.e. $\tau_i \equiv \min_t\{t | a_{i,t} = 1\}$.

3. Equilibria

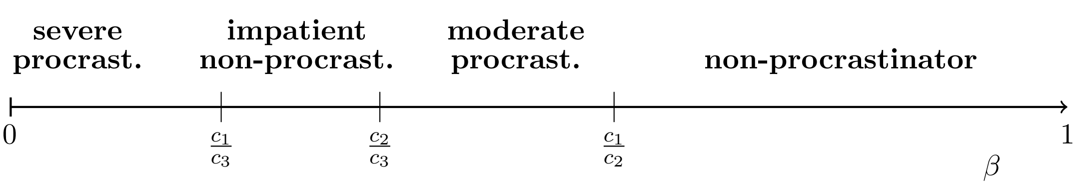
In this section, I will characterise the equilibrium outcomes of the procrastination game when A (she) and B (he) are both sophisticated and have potentially heterogenous present-bias factors. Since time is discrete and multiple values of a player's present-bias factor can map into the same strategy, a player's "type" will be given by the behaviour that her present-bias factor would lead to, were she acting in isolation, i.e. her would-be autarky behaviour.[9] As discussed above, when $\kappa = 0$ the definition of strategy in a procrastination game becomes equivalent to the definition of strategy in isolation.

There are four sophisticated types. Two of them procrastinate, albeit to a different extent. The other two perform the task in the first period. One of them does so because her bias is extremely small, while the other one to prevent herself from procrastinating until the last period.

Definition 2 (Types under sophistication)**.** A sophisticated player's type is given by the strategy she would choose in isolation. Then, for $i \in \{A, B\}$, player i's type is (i) "severe procrastinator" if $\tilde{\mathbf{s}}_i = (0,0)$, i.e. if $\beta_i < \frac{c_1}{c_3}$; (ii) "moderate procrastinator" if $\tilde{\mathbf{s}}_i = (0,1)$, i.e. if $\frac{c_1}{c_2} > \beta_i \geq \frac{c_2}{c_3}$; (iii) "non-procrastinator" if $\tilde{\mathbf{s}}_i = (1,1)$, i.e. if $\beta_i \geq \frac{c_1}{c_2}$; (iv) "impatient non-procrastinator" if $\tilde{\mathbf{s}}_i = (1,0)$, i.e. if $\frac{c_2}{c_3} > \beta_i \geq \frac{c_1}{c_3}$.[10]

It should be noted that, in order to allow for "moderate procrastinators" to exist, henceforth it will be assumed that $\frac{c_2}{c_3} < \frac{c_1}{c_2}$. In fact, was the latter not assumed, it would not be possible to explore the interaction between two different types of procrastinators – which, as discussed below, is the most interesting case and the one this paper will be focusing on.

The figure below illustrates the types under sophistication for $\mathbf{c} = (2, 3.5, 10)$, the same parameter values as in the opening example.



In what follows, I will characterise the equilibria of the game in the case of two players of the same type and in the case of two players of different types.

3.1. Heterogeneous types: two different procrastinators

Suppose that A and B belong to two different types. Since each of them can be of four possible types, there are six possible combinations of players. Since there are only two types of

[9] Each player has complete information on the opponent's type.

[10] A sophisticate's completion date does not vary monotonically with her β. A relatively more present-biased person can decide to do the task earlier than a less present-biased one as she knows that, if she waited, she would not resist the temptation to delay. The less present-biased person knows that she can afford to wait.

procrastinators, there is only one possible combination of two different types of procrastinators. In what follows, I will focus on the latter case, the interaction between a moderate procrastinator and a severe procrastinator, as it shows surprising, yet intuitive, new ways in which people can influence each other's procrastination behaviour.

Proposition 1. *The interaction between two different types of procrastinators weakly reduces procrastination: either they behave as in isolation, or one of them does the task earlier than in isolation, or both do.*

The two cases in which procrastination is reduced illustrate two novel and surprising peer effects, which I label "avoidance of bad company" and "mutual reduction of procrastination".

Proposition 2 (Avoidance of bad company)**.** *Suppose that A is a severe procrastinator and B is a moderate procrastinator. If* $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ *and* $\beta_B < \min\{\frac{c_2}{c_3(1-\kappa)}, \frac{c_1}{c_2}\}$*, the unique equilibrium of the procrastination game* $\mathcal{G}$ *will be* $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(1,(0,1)))$.

Proposition 3 (Mutual reduction of procrastination)**.** *Suppose that A is a severe procrastinator and B is a moderate procrastinator. If* $\beta_A \geqslant \frac{c_1(1-\kappa)}{c_3}$ *and* $\beta_B < \min\{\frac{c_2}{c_3(1-\kappa)}, \frac{c_1}{c_2}\}$*, then the unique equilibrium of the procrastination game* $\mathcal{G}$ *will be* $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,1)))$.

Proof. See Appendix A.

Avoidance of bad company If the present-bias of the severe procrastinator, A, is large enough, she will leave the undone until the third period (when she is obliged to do it), as she would do in isolation. She is simply too present-biased to benefit from B's company: regardless of B's behaviour, she chooses to delay in both periods. What happens to B when he interacts with such a "hardcore" procrastinator? *If his present-bias is sufficiently high* ($\beta_B < \frac{c_2}{c_3(1-\kappa)}$), he will bring the task forward to the first period. The intuition is the following. Being sophisticated, B knows that if he leaves the task until the second period, he will not resist the temptation to delay one additional period to enjoy A's company. In fact, while if he is by himself he is sufficiently patient to resist the temptation to delay, in the presence of A delaying becomes increasingly tempting. As a consequence, he decides to do the task earlier than he otherwise would, so as to avoid the increased temptation that A's company would generate.

Note that, if A deviated from her optimal behaviour and did the task in the first period, then B would do the task in the second period, i.e. $a_{B,2}(a_{A,1} = 1) = 1$. In fact, in this case B would know that, having A already done the task, he would not be exposed to additional temptation in the second period and would therefore resist the temptation to delay further.

Also note that B would do the task in the second period also if his present-bias was smaller than what it is assumed above (i.e. if $\beta_B \geqslant \frac{c_2}{c_3(1-\kappa)}$). In fact, in this case he would know that he could afford to wait until the second period, as he would be sufficiently patient to resist the temptation to delay further. The latter implies that this implies that B's completion date varies non-monotonically with his degree of present-bias: B will end up doing the task *earlier* if he is more present-biased than if he is less present-biased, as the awareness of this larger present-bias will induce him to try and save himself from temptation.

It is interesting to notice that the result that bad company can be desirable is obtained also in Battaglini et al. (2005), although in their paper this happens for a very different reason. They show that, in a model where observing others affects people's self-control behaviour, the ex-ante ideal peer is someone with a slightly worse self-control problem than one's own, as "if such a peer can do it, then we can too". Instead, my model shows that the company of someone with a worse self-control problem can be used as a commitment device: avoiding peer-enhanced temptation can lead one to mitigate her own self-control problem. Thus, my model provides a second channel through which bad company can be beneficial under self-control problems.

Mutual reduction of procrastination Suppose that B is a moderate procrastinator as above, and A is still a severe procrastinator but her bias is now smaller than in the previous case. Then, the unique equilibrium of the game will be for A and B to coordinate to do the task in the first period, earlier than each of them would in isolation. The intuition is the following. Unlike in the previous case, A is now sufficiently patient that, while she would not do the task in the first period by herself, she would in the presence of B, as his company makes doing the task in the first period less costly, and thus delaying less tempting. A prefers doing the task in the first period with B than in the third period without him. Therefore, A and B use each other's company as a commitment device to mitigate their own self-control problem. A's company induces B to do the task one period earlier than he would in isolation, and B's company induces A to do the task two periods earlier than in isolation.

Similarly as above, note that, if A deviated from her optimal behaviour and did not do the task in the first period, then B would no longer do the task in the second period, i.e. $a_{B,2}(a_{A,1} = 0) = 0$, as he would delay until the third period with A.

Also note that if B's present-bias was smaller than assumed above (i.e. if $\beta_B \geqslant \frac{c_2}{c_3(1-\kappa)}$), then there will also be an additional equilibrium in which A and B behave as in isolation.

It can be concluded that a moderate procrastinator and a severe procrastinator are weakly better off interacting with each other than acting in isolation: their interaction will not lead any of them to delay further, but can lead one or both to delay less.[11] In the next subsection, I explore what happens when each of them interacts with someone of the same type.

3.2. Homogeneous types

Suppose that A and B belong to the same type. Since each of them can belong to four possible types, there are four possible combinations of players of the same type. Proposition 4 states

[11] The results of the model under three periods extend to the case of more than three periods.

that, like the interaction between different procrastinators, also the interaction between two procrastinators of the same type, i.e. two severe procrastinators or two moderate procrastinators, weakly reduces procrastination. However, unlike in the case of two different procrastinators, behaving as in isolation will always be an equilibrium, whereas doing the task earlier *may* be an equilibrium, and when it is, it will not be unique.

Proposition 4. *The interaction between two procrastinators of the same type weakly reduces procrastination: behaving as in isolation will always be an equilibrium, and there may also be additional equilibria in which they coordinate on an earlier date.*

Proposition 5. *The interaction between two non-procrastinators of the same type weakly exacerbates procrastination: behaving as in isolation will always be an equilibrium, and there may also be additional equilibria in which they coordinate on a later date.*

Proof. See Appendix A.

For two *non-procrastinators* of the same type, as for two procrastinators of the same type, behaving as in isolation will always be optimal and there may be also additional equilibria. However, two non-procrastinators may also coordinate on a later date. Hence, interaction can be harmful. Corollary 1 states that, in any procrastination game between players of the same type, behaving as in autarky will always be an equilibrium. Thus, if there is a unique equilibrium, it will be to behave as in isolation. The intuition is the following. If a given choice is optimal in isolation, it will still be so in the presence of a peer who shares the same preferences and whose company will make such choice even more appealing.

Corollary 1. *In any procrastination game $\mathcal{G}$ where A and B belong to the same type and there is a unique PPE, then the PPE will be the same as the isolation equilibrium.*

Section 4 will discuss equilibrium selection in a procrastination game with homogeneous types and multiple equilibria, and, more generally, in dynamic games with simultaneous moves and time-inconsistent, sophisticated players.

3.3. Other cases

I have focused the subsection on heterogeneous types on the interaction between two different procrastinators, as it is the most interesting case. In what follows, I discuss the main insights that can be learnt from the other five cases of interaction between heterogeneous types.

Proposition 6. *The interaction between a non-procrastinator/impatient non-procrastinator and a severe procrastinator weakly reduces procrastination: either they behave as in isolation or they coordinate on doing the task in the first period.*

Proposition 7. *The interaction between a non-procrastinator/impatient non-procrastinator and a moderate procrastinator may exacerbate procrastination: either they behave as in isolation, or they coordinate on doing the task in the first period, or they coordinate on doing the task in the second one.*

Proposition 8. *The interaction between a non-procrastinator and an impatient non-procrastinator weakly exacerbates procrastination: either they behave as in isolation or they coordinate on delaying until the second period.*

Proof. See Appendix A.

Propositions 7 and 8 show that in some cases interaction may be harmful. A non-procrastinator may be induced by a moderate procrastinator to delay. Two different non-procrastinators may coordinate on delaying. Then, pairing people up does not always help. Whether the company of a peer is beneficial, and how beneficial it is, will crucially depend on *how* people are matched.

Example. Consider a procrastination game where $\mathbf{c} = (2, 3.5, 10)$ and $\kappa = 0.4$. The equilibrium regions are illustrated by Figure 1. Each axis measures a player's present-bias factor, which determines her four possible types. Hence, starting from the origin, each axis displays severe procrastinator (SP), impatient non-procrastinator (INP), moderate procrastinator (MP) and non-procrastinator (NP). The black straight lines delimit the four types' regions. The five differently shaded areas in the graph display the following equilibria – from the lightest to the darkest area. (i) Equilibria in which both players behave as in isolation (denoted in the legend as "both as in isolation"). (ii) Multiple equilibria: one player behaves as in isolation and the other does the task either earlier or later, depending on which equilibrium is played (denoted as "multiplicity"). (iii) Equilibria in which one player does the task earlier than in isolation (denoted as "one player better off). (iv) Equilibria in which both players do the task earlier than in isolation (denoted as "both players better off"). (v) Equilibria in which one player does the task later than in isolation (denoted as "one player worse off"). In the four areas on the secondary diagonal, i.e. the areas corresponding to the interaction between players of the same type, the equilibrium selection method proposed above has been used. Hence, behaving as in isolation is either the unique equilibrium or the dynamically risk-dominant one. □

4. Equilibrium selection under time-inconsistency

Equilibrium selection in dynamic games with simultaneous moves and time (in)consistent players is an unexplored and compelling area. In what follows, I will argue that in such games the two main equilibrium selection criteria, Pareto-dominance and risk-dominance, may be in conflict.

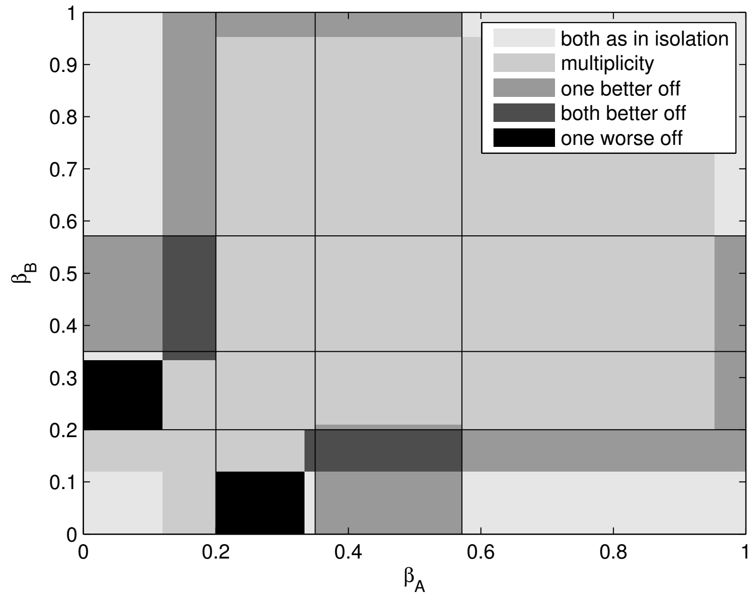


Figure 1: Equilibrium regions for $\mathbf{c} = (2, 3.5, 10)$ and $\kappa = 0.4$.

Since costs increase over time and the benefit of company is assumed to be not as large as to make costs non-increasing, the Pareto-dominant outcome – evaluated from ex-ante perspective – will always be to do the task on the earliest completion date. It is reasonable to expect that, under time-inconsistent preferences, the players will not select the outcome that their *ex ante*, unbiased self would choose.

In a 2×2 simultaneous-move game, a pure-strategy NE is (pairwise) risk-dominant if it has the highest Nash product, i.e. the highest product of the deviation losses. In other words, if the players have less incentive to deviate from it than from the other NE. In a dynamic game with simultaneous moves and time-consistent players, risk-dominance can be computed in the strategic form of the game, using an *ex ante* perspective. Alternatively, risk-dominance can be computed "subgame by subgame", i.e. in every subgame of the dynamic game. These two ways to compute risk-dominance will be equivalent under time-consistency. When players have time-inconsistent preferences instead, these two methods may not yield the same results, as the players will be "different selves" in each subgame, and thus may not behave as their ex-ante selves would. In light of this, I argue that under time-inconsistent preferences it is reasonable to expect the players to play, in every subgame, the risk-dominant equilibrium *from the perspective of that particular subgame*. Since in each subgame the players play a 2×2 simultaneous move game, I can use the standard definition of risk-dominance in Harsanyi & Selten (1988) and adapt it to my environment. The 2×2 game in the second period is well-defined: the players choose whether doing the task immediately or in the third period. In contrast, the actions of the 2×2 game in the first node depend on what the players will play in the following one. As both players are sophisticated, in the first period they can correctly predict which equilibrium will be played in the second period. Thus, in the first stage risk-dominance can be calculated given that the risk-dominant NE will be played in the second stage. A formal definition follows.

Definition 3 (Dynamic risk-dominance).
In a procrastination game $\mathcal{G}$ between two players of the same type, A and B, a pair of strategies $(\mathbf{s}_A, \mathbf{s}_B) = ((a_{A,1}, a_{A,2}(a_{B,1})), (a_{B,1}, a_{B,2}(a_{A,1})))$ are "dynamically risk-dominant" if (i) $(a_{A,2}(a_{B,1}), a_{B,2}(a_{A,1}))$ is the risk-dominant NE of $\mathcal{G}^2$, (ii) $(a_{A,1}, a_{B,1})$ is the risk-dominant NE of $\mathcal{G}^1$.

For players of the same type, dynamic risk dominance yields a general result: behaving as in isolation will always be the risk-dominant equilibrium – if not the unique one.

Proposition 9. *In a procrastination game $\mathcal{G}$ between two players of the same type, the equilibrium in which the players behave as they would in isolation will be "dynamically risk-dominant".*

Proof. See Appendix A.

Proposition 9 implies that, even if the interaction between two players of the same type can lead to coordination on an earlier date (see Section 3.2), such welfare-improving outcomes are not likely to be chosen. Thus, company – whether potentially beneficial or potentially harmful – is not likely to have an effect. This suggests that pairing up two different procrastinators is more likely to be beneficial than pairing up two procrastinators of the same type.

This result also implies that in a procrastination game, Pareto-dominance and risk-dominance might be in conflict. A classic example of a coordination game in which Pareto-dominance and risk-dominance are in conflict is the Stag Hunt.[12]

For players of different types, dynamic risk dominance does not yield a general result. Which equilibrium is risk-dominant will crucially depend on the costs and the degree of present-bias.[13]

5. Matching procrastinators

The equilibria of the procrastination game derived in Section 3 show that interaction *can* mitigate procrastination behaviour and that whether it does will crucially depend on the players' types. In particular, the interaction between two procrastinators of different types is weakly beneficial, whereas the interaction between two procrastinators of the same type, although potentially beneficial, is expected not to have an effect. Thus, a principal who knows the agents'

[12] Each hunter must choose whether to hunt a stag or a hare without knowing her opponent's choice. Hunting a stag requires the cooperation of the opponent. Hunting a hare does not, but a hare is worth less than a stag. Coordinating on stag hunting is the Pareto-dominant NE; coordinating on hare hunting is the risk-dominant NE. The conflict arises because there is a safer alternative to the Pareto-dominant equilibrium, i.e. an alternative that does not require cooperation.

[13] The derivation of the dynamically risk-dominant equilibrium in each case in which the game yields multiple equilibria and the players are of different types is available upon request.

tendencies to procrastinate can induce them to delay less by simply matching them with each other *in the appropriate way*, thereby improving their welfare and reducing inefficient delay. It is then a natural and important step to explore whether the efficient matching – the matching that minimises overall procrastination – is stable. If it is, then principals should allow agents to match freely. If it is not, they should sort types.

Consider a procrastination game between two different procrastinators, a severe procrastinator A and a moderate one B, where $\beta_A < \frac{c_1(1-\kappa)}{c_3}$, i.e. A is an "extreme" type of severe procrastinator. In equilibrium, a moderate procrastinator will do the task earlier if he interacts with an extreme procrastinator (Proposition 1), and will act as in isolation if he interacts with another moderate type (Propositions 4 and 9).[14] An extreme procrastinator will always do the task in the last period. This implies that, in a population of extreme procrastinators (type A) and moderate procrastinators (type B), procrastination will be lower if each person is paired with someone of the opposite type (negative assortative matching), rather than with someone of the same type (positive assortative matching). In what follows, I explore whether the efficient matching, i.e. the matching that minimises overall procrastination, is stable.

Population Consider a finite set of individuals $\Omega = \{1, 2, ..., n\}$ and two even sets Ω_A and Ω_B of agents of type A and B. Let $\Omega = \Omega_A \cup \Omega_B$.

Definition 4 (Matching)**.** A matching μ is a one to one mapping from Ω onto itself such that for all $i, j \in \Omega$, if $\mu(i) = j$, then $\mu(j) = i$, where $\mu(i)$ denotes the partner of individual i under the matching.

If $\mu(i) = i$, then agent i is single under μ.[15]

Definition 5 (Positively assortative matching)**.** A matching μ is *positively assortative* when, if $i \in \Omega_x$, then $\mu(i) \in \Omega_x$, for $x \in \{A, B\}$ and $\mu(i) \neq i$ for all $i \in \Omega_x$.

Definition 6 (Negatively assortative matching)**.** If $n_x \leq n_{-x}$, a matching μ is *negatively assortative* when, if $i \in \Omega_x$, then $\mu(i) \in \Omega_{-x}$ for all $i \in \Omega_x$ and for $x \in \{A, B\}$.

As individuals of the same type are indistinguishable, individuals only care about which type they are matched to.

Definition 7 (Stable matching)**.** A matching μ is stable if (i) each player strictly prefers her partner to being single, and (ii) for no pair $\{i, j\} \in \Omega$ it is the case that i strictly prefers j to $\mu(i)$ and j strictly prefers i to $\mu(j)$.

Proposition 10. *In a population Ω of extreme and moderate procrastinators, a matching μ is stable if and only if it is positively assortative.*

[14] In this section, it is assumed that $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1}{c_2}$, but all the results hold also if $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1}{c_2}$.

[15] This is a version of what is known as the roommate problem (Gale & Shapley (1962)).

Proof. See Appendix A.

A matching between a moderate procrastinator and an extreme procrastinator, despite being the matching that minimises overall procrastination, will not be stable. This is due to the fact that two extreme procrastinators will strictly prefer being with each other than being each with someone of the other type. In fact, when two extreme procrastinators are matched with each other will do the task in the last period together, thereby facing a cost $c_3(1-\kappa)$, whereas when each is matched with someone of the other type they will do the task in the last period by themselves (as their partner will do the task earlier), thereby facing a cost $c_3 > c_3(1-\kappa)$.

This result implies that if a principal is able to observe the agents' types, he will prefer to sort types rather than allow for free matching. If he cannot observe the types, he will prefer to match the agents randomly than to let them freely match.

Consider again a procrastination game between a severe procrastinator A and a moderate one B, but now assume that $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$, so that A is no longer an extreme type of severe procrastinator. In equilibrium, A and B will coordinate on doing the task earlier than each of them would in isolation (Proposition 1).

Now consider a population of moderate types B and severe, non-extreme types A. Overall procrastination will be lower if A and B types are matched with each other than with their own types. Now a negatively assortative matching is efficient and stable, as it leads each type to do the task in the first period and benefit from company. No pair would break this matching to be single or match someone of the same type, as the latter would lead them to do the task later than in the first period.

Proposition 11. *In a population Ω of severe (non-extreme) procrastinators and moderate procrastinators, a matching μ is stable if and only if it is negatively assortative.*

Proof. See Appendix A.

6. Naïvete

In this section, I will relax the assumption that both players are sophisticated and allow for one of them to be naïve. In what follows, I will first describe strategy and solution concept under naïvete and then explore whether and how the main results under sophistication change when one of the players is naïve.[16]

[16]The full characterisation of the equilibria when one or both players are naïve is available upon request.

6.1. Strategy and solution concept

ODR's solution concept under naïvete, called perception-perfect strategy for naifs, requires that the individual chooses optimally given her current preferences and her potentially incorrect perception of her future behaviour. A naif does the task today if and only if it is the optimal period of *all the remaining periods* given her current preferences. In my setting, this definition can be simplified. As there are only three periods and the task must be done in the third one, if not previously done, the only period in which a naif may fail to predict her future behaviour is the first one. Since costs increase over time, in the first period a naif will compare doing the task immediately versus doing it *in the following period*. This is the only condition. As in this section both sophistication and naïvete are considered, the superscript s will be used to denote the former and the superscript n to denote the latter.

Definition 8. A perception-perfect strategy for *naifs* is a strategy $\tilde{\mathbf{s}}^n \equiv (\tilde{a}_1^n, \tilde{a}_2^n)$ that satisfies for all $t \in \{1, 2\}$ $\tilde{a}_t^n = 1$ if and only if $U^t(t) \geq U^t(t+1)$.

In a procrastination game, a perception-perfect strategy for naifs requires that, at each subgame, each player chooses optimally given her current preferences, her potentially incorrect beliefs about her future behaviour and her knowledge of her opponent"s behaviour.

When one player, say A, is sophisticated, and the other one, B, is naïve, and both are peer-sophisticated, a pair of strategies $(\mathbf{s}_A^s, \mathbf{s}_B^n) \equiv ((a_{A,1}^s, a_{A,2}^s(a_{B,1}^n)), (a_{B,1}^n, a_{B,2}^n(a_{A,1}^s)))$ is an equilibrium if, in every node, A plays a perception-perfect strategy for sophisticates (O'Donoghue & Rabin (1999)) given B's behaviour and B plays a perception-perfect strategy for naifs given A's behaviour. I shall call the solution concept thus defined "Perception-Perfect Naïve Equilibrium" (hereafter PPNE).

Definition 9 (PPNE)**.** Given a procrastination game $\mathcal{G}$, a pair of strategies $(\mathbf{s}_A^s, \mathbf{s}_B^n)$ is a Perception-Perfect Naïve Equilibrium if $\mathbf{s}_A^s \equiv (a_{A,1}^s, a_{A,2}^s(a_{B,1}^n))$ satisfies for all $t \in \{1, 2\}$ $a_{A,t}^s = 1$ iff $U_A^t(t_A, \tau_B) \geq U_A^t(\tau_A', \tau_B)$ and $\mathbf{s}_B^n \equiv (a_{B,1}^n, a_{B,2}^n(a_{A,1}^s))$ satisfies for all $t \in \{1, 2\}$ $a_{B,t}^n = 1$ iff $U_B^t(t, \tau_A) \geq U_B^t(t+1, \tau_A)$, where $\tau_A' \equiv \min_{\tau_A > t}\{\tau_A | a_{\tau_A} = 1\}$.

Unlike a PPE, a PPNE is not equivalent to a Subgame Perfect Nash Equilibrium. However, it can still be derived by backward induction, or, more precisely, a "naïve backward induction": each naïve player will backward induct under the (potentially incorrect) belief that, if she does not do the task today, she will do it tomorrow. Since the game is finite and players best respond, an equilibrium will always exist.

Solving a procrastination game requires the adoption of different solution concepts, depending on the players' awareness of their self-control problems. PPNE are a superset of self-confirming equilibria. In a self-confirming equilibrium, people may hold incorrect beliefs about nodes that are off the equilibrium path (Fudenberg & Levine (1993)). In contrast, in a PPNE people may hold incorrect – optimistic – beliefs about nodes that are *on* the equilibrium path. As self-confirming equilibria are a superset of Nash equilibria, PPNE are also a superset of Nash equilibria.

As mentioned above, I maintain the assumption that every player is peer-sophisticated. This implies that a naif can correctly predict her opponent's future behaviour but not her own. This might seem a strong assumption but has empirical validity. Evidence from psychology shows that people tend to neglect their own self-serving biases but recognise others' biases (Babcock et al. (1995)). For example, we might be able to correctly predict that tomorrow our flatmate will defer going to the gym to a later day, but fail to predict that we will put exercise off as well.

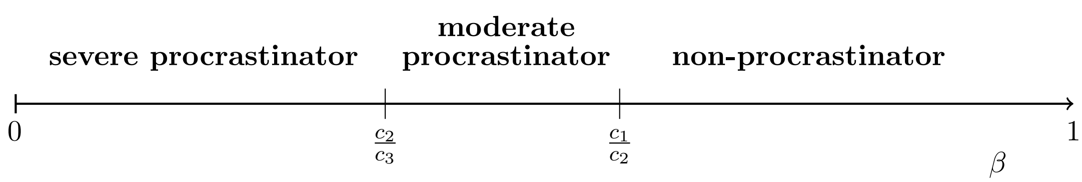
> "It is much easier, as well as far more enjoyable, to identify and label the mistakes of others than our own" – Daniel Kahneman, *Thinking fast and slow* (p. 3)

6.2. Equilibria

I will now show that a naïve player is not able to avoid bad company - a player's capacity to avoid the exposure to peer-enhanced temptation requires her to be aware of her own and her peer's self-control problems.

Definition 10 (Types under naïvete)**.** A naïve player's type is given by the strategy she would choose in isolation. Then, for $i \in \{A, B\}$, player i's type is (i) "severe procrastinator" if $\tilde{\mathbf{s}}_i^n = (0,0)$, i.e. if $\beta_i < \frac{c_2}{c_3}$; (ii) "moderate procrastinator" if $\tilde{\mathbf{s}}_i^n = (0,1)$, i.e. if $\frac{c_1}{c_2} > \beta_i \geqslant \frac{c_2}{c_3}$; (iii) "non-procrastinator" if $\tilde{\mathbf{s}}_i^n = (1,1)$, i.e. if $\beta_i \geqslant \frac{c_1}{c_2}$.[17]

The figure below illustrates the types under naïvete for $\mathbf{c} = (2, 3.5, 10)$.



Proposition 12. *Suppose that A is a severe, sophisticated, procrastinator and B is a moderate, naïve procrastinator. If $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_2}{c_3(1-\kappa)}$, then the unique equilibrium of the procrastination game $\mathcal{G}$ will be $(\mathbf{s}_A^s, \mathbf{s}_B^n) = ((0,(0,0)),(0,(0,1)))$.*

Proof. See Appendix A.

When B is naïve, he will no longer be able to avoid A's bad company, as he will fail to foresee the additional temptation A's presence will generate in the second period. In the first

[17] Under naïvete an individual's completion date varies monotonically with her degree of present-bias. A naif cannot foresee that, if she does not do the task in the first period, she may end up doing it in the last one.

period, he delays as he thinks he will do the task in the second period. But in the second period, he will not be able to resist the temptation to delay further as A's company makes delaying additionally tempting. Therefore, as in ODR 1999, also in a strategic setting naïvete exacerbates procrastination.

Note that, if A deviated from her optimal behaviour and did the task in the first period, then B would be able to do the task in the second period, as he would not be exposed to peer-enhanced temptation in the second period.

7. Conclusion

This paper has developed a strategic model of time-inconsistent procrastination to investigate the impact of social interaction on procrastination behaviour when people value each other's company. The key and novel feature of the model is that present-biased people faced with an onerous task prefer to do this task when others do, as company makes the task feel less unpleasant. This simple assumption turns the decision of when to perform the task into a dynamic coordination game between present-biased players. The model is used to establish if and when the company of a peer is beneficial in reducing procrastination, and thus how principals can match people to each other to improve their welfare and reduce inefficient delay.

I find that interaction can lead to new, welfare-improving outcomes relative to the case in which people act in isolation. Whether interaction mitigates or exacerbates procrastination will crucially depend on each player's type, which is given by their would-be behaviour in isolation.

The interaction between two heterogeneous procrastinators – two people who both procrastinate in isolation but to a different extent – will weakly mitigate procrastination. Either they behave as in isolation, or one of them does the task earlier, or both of them do. In the case in which delay is reduced for one player (avoidance of bad company), the least procrastinating player does the task earlier than she would in isolation to avoid the additional temptation that her peer's company would generate. Thus, she uses bad company as a commitment device to mitigate her self-control problem. In the case in which delay is reduced for both players (mutual reduction of procrastination), they coordinate to do the task earlier than each of them would in isolation. Each of them uses the company of the other as a commitment device to mitigate their own self-control problem.

The interaction between two people who exhibit the same procrastination behaviour in isolation will weakly mitigate procrastination. Behaving as in isolation will always be an equilibrium, but there can also be additional equilibria where the players coordinate on an earlier completion date. However, in case of multiple outcomes, the "better" coordinated outcomes are not expected to be chosen. Finally, in some cases interaction may be harmful.

These results have two important implications. First, principals *can* help people procrastinate less by simply pairing them up. Second, who is matched with whom matters. Some matches are better than others, and some matches may be harmful. Interestingly, under time-inconsistency the efficient matching – the matching that minimises procrastination – is not always stable. Thus, a principal aiming at reducing delay may want to design the matching.

As an ancillary contribution, my model can serve as a microfounded model of peer effects. It describes novel and surprising mechanisms through which peers can influence each other's behaviour, thereby suggesting that microfounding peer effects can lead to a better understanding of the all the possible ways through which people affect the decisions of others.

This paper raises a number of theoretical and experimental questions that future research can address. First, in this paper it is assumed that people know each other's time-preferences. While this is plausible in the case of close social ties (e.g. spouses and siblings), it may be less so in the case of more distant social ties (e.g. coworkers). A natural extension would be to develop an incomplete information version of my model and use it to determine whether and how people should be matched with each other when they do not know each other's preferences.

Second, this model involves only two players. Future work can explore the impact of interaction on the procrastination behaviour of a network of players, and how such impact varies with the network's characteristics.

Third, since the existence of peer preferences can turn any single-person decision problem into a game, it is worth exploring whether there are other types of decisions where peer preferences might play a role and, as in this paper, lead to new and welfare-improving outcomes.

Finally, future work could explore alternative ways through which people may influence each other's procrastination behaviour. For example, a person's decision to delay a task in a given period may be influenced by whether her peers have completed the task in the past.

Appendix

A. Proofs

Proof of Propositions 1, 2 and 3

Consider a procrastination game $\mathcal{G}$, where A is a severe procrastination and B is a moderate procrastinator. The PPE of the game, derived by standard backward induction, are the following.

If $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1}{c_2}$, the PPE are:

(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(1,(0,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_2}{c_3(1-\kappa)}$,

(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,1)))$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_2}{c_3(1-\kappa)}$,

(iii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(0,(1,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B \geq \frac{c_2}{c_3(1-\kappa)}$,

(vi) $(\mathbf{s}_A, \mathbf{s}_B) \in \{(((1,(0,0)),(1,(1,1)));((0,(0,0)),(0,(1,1)))\}$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B \geq \frac{c_2}{c_3(1-\kappa)}$.

It follows that the interaction between A and B is weakly beneficial.

If $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1}{c_2}$, the PPE are only:

(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(1,(0,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,1)))$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$.
It follows that the interaction between A and B is beneficial.

Proof of Proposition 4

Consider a procrastination game $\mathcal{G}$, where A and B are two severe procrastinators. The PPE of the game, derived by backward induction, are the following.
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(0,(0,0)))$ iff $\beta_i < \frac{c_1(1-\kappa)}{c_3}$, and
(ii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((0,(0,0)),(0,(0,0))); ((1,(0,0)),(1,(0,0)))\}$ otherwise.

Consider a procrastination game $\mathcal{G}$, where A and B are two moderate procrastinators. The PPE of the game, derived by standard backward induction, are the following.
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(1,1)),(0,(1,1)))$ iff $\frac{c_1(1-\kappa)}{c_2} > \beta_i \geq \frac{c_2}{c_3(1-\kappa)}$,[18]
(ii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((0,(1,1)),(0,(1,1))); ((1,(1,1)),(1,(1,1))), ((1,(0,0)),(1,(0,0)))\}$ otherwise.

Proof of Proposition 5

Consider a procrastination game $\mathcal{G}$ where A and B are two non-procrastinators. Using backward induction, the following PPE are derived.
(a) If $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(1,1)),(1,(1,1)))$ iff $\beta_i \geq \frac{c_1}{c_2(1-\kappa)}$ for at least one i,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((1,(1,1)),(1,(1,1))), ((0,(1,1)),(0,(1,1)))\}$ otherwise.
(b) If $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(1,1)),(1,(1,1)))$ iff $\beta_i \geq \frac{c_1}{c_2(1-\kappa)}$ for at least one i,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((1,(1,1)),(1,(1,1))); ((0,(1,1)),(0,(1,1))); ((1,(0,0)),(1,(0,0)))\}$ otherwise.[19]

Consider a procrastination game $\mathcal{G}$ where A and B are two impatient non-procrastinators. The PPE of the game, derived by backward induction, are the following.
(a) If $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((1,(1,1)),(1,(1,1))), ((0,(0,0)),(0,(0,0)))\}$ iff $\beta_i < \frac{c_1}{c_3(1-\kappa)}$ $\forall i$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,0)))$ iff $\frac{c_2(1-\kappa)}{c_3} > \beta_i \geq \frac{c_1}{c_3(1-\kappa)}$ for at least one i,
(iii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((1,(1,1)),(1,(1,1))), ((0,(0,0)),(0,(0,0))), ((0,(1,1)),(0,(1,1)))\}$ iff $\beta_i \geq \frac{c_2(1-\kappa)}{c_3}$ $\forall i$.
(b) If $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((1,(0,0)),(1,(0,0))), ((0,(0,0)),(0,(0,0)))\}$ iff $\beta_i < \frac{c_1}{c_3(1-\kappa)}$ $\forall i$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,0)))$ iff $\frac{c_2(1-\kappa)}{c_3} > \beta_i \geq \frac{c_1}{c_3(1-\kappa)}$ for at least one i,[20]

[18] $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(1,1)),(0,(1,1)))$ is the unique equilibrium if $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1(1-\kappa)}{c_2}$. If $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1(1-\kappa)}{c_2}$, then $(\mathbf{s}_A, \mathbf{s}_B) \in \{((0,(1,1)),(0,(1,1))); ((1,(1,1)),(1,(1,1)))\}$.

[19] $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,0)))$ is an equilibrium only if $\beta_i < \frac{c_2}{c_3(1-\kappa)}$ for all i.

[20] This case occurs only if $\frac{c_1}{c_3(1-\kappa)} < \frac{c_2(1-\kappa)}{c_3}$.

(iii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((1,(1,1)),(1,(1,1))); ((1,(0,0)),(1,(0,0))); ((0,(1,1)),(0,(1,1)))\}$ iff $\beta_i \geq \frac{c_2(1-\kappa)}{c_3}$ $\forall i$.[21]

Proof of Proposition 6

Consider a procrastination game $\mathcal{G}$, where A is a severe procrastination and B is a non-procrastinator. The PPE of the game, derived by backward induction, are the following.
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(1,(1,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(1,1)))$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$.
Now suppose that $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1}{c_2}$. If $\beta_B \geq \frac{c_2}{c_3(1-\kappa)}$ the PPE are (i) and (ii) as above. If $\beta_B < \frac{c_2}{c_3(1-\kappa)}$, the PPE are $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(1,(0,0)))$ if $\beta_A < \frac{c_1(1-\kappa)}{c_3}$, and $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,0)))$ if $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$.

Consider a procrastination game $\mathcal{G}$, where A is a severe procrastination and B is an impatient non-procrastinator. The PPE of the game, derived by backward induction, are the following.
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,0)))$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B \geq \frac{c_1}{c_3(1-\kappa)}$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(0,(0,0)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_1}{c_3(1-\kappa)}$,
(iii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(1,(0,0)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B \geq \frac{c_1}{c_3(1-\kappa)}$,
(iv) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((0,(0,0)),(0,(0,0))); ((1,(0,0)),(1,(0,0)))\}$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_1}{c_3(1-\kappa)}$.

Proof of Proposition 7

Consider a procrastination game $\mathcal{G}$, where A is a moderate procrastination and B is a non-procrastinator. The PPE of the game, derived by backward induction, are the following.
(a) If $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(1,1)),(0,(1,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_2}$ and $\beta_B < \frac{c_1}{c_2(1-\kappa)}$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((0,(1,1)),(0,(1,1))); ((1,(1,1)),(1,(1,1)))\}$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_2}$ and $\beta_B < \frac{c_1}{c_2(1-\kappa)}$,
(iii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(1,1)),(1,(1,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_2}$ and $\beta_B \geq \frac{c_1}{c_2(1-\kappa)}$,
(iv) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(1,1)),(1,(1,1)))$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_2}$ and $\beta_B \geq \frac{c_1}{c_2(1-\kappa)}$.
(b) If $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(1,1)),(1,(1,1)))$ iff $\beta_B \geq \frac{c_1}{c_2(1-\kappa)}$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((1,(1,1)),(1,(1,1))); ((0,(1,1)),(0,(1,1)))\}$ iff $\frac{c_1}{c_2(1-\kappa)} > \beta_B \geq \frac{c_2}{c_3(1-\kappa)}$,
(iii) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((1,(1,1)),(1,(1,1))); ((0,(1,1)),(0,(1,1))), ((1,(0,0)),(1,(0,0)))\}$ iff $\beta_B < \frac{c_2}{c_3(1-\kappa)}$.
Consider a procrastination game $\mathcal{G}$, where A is an impatient non-procrastinator and B a moderate procrastinator. The PPE of the game, derived by backward induction, are the following.
(a) If $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) \in \{((0,(0,0)),(0,(1,1))); ((1,(0,0)),(1,(1,1)))\}$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B \geq \frac{c_2}{c_3(1-\kappa)}$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(1,(0,0)))$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_2}{c_3(1-\kappa)}$,

[21] $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(1,1)),(1,(1,1)))$ is an equilibrium only if $\beta_i \geq \frac{c_1(1-\kappa)}{c_2}$ for all i.

(iii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(0,(1,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B \geq \frac{c_2}{c_3(1-\kappa)}$,
(iv) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,0)))$ iff $\beta_A \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_2}{c_3(1-\kappa)}$.
(b) If $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,0)))$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(1,(0,0)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$.

Proof of Proposition 8

Consider a procrastination game $\mathcal{G}$, where A is an impatient non-procrastinator and B a non-procrastinator. The PPE of the game, derived by backward induction, are the following.
(a) If $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1}{c_2}$, the PPE are:
(i) $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(1,1)))$ iff $\beta_A < c_2(1-\kappa)c_3$,
(ii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(1,1)),(0,(1,1)))$ iff $\beta_A \geq c_2(1-\kappa)c_3$ and $\beta_B < \frac{c_1}{c_2(1-\kappa)}$,
(iii) $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(1,1)),(1,(1,1)))$ iff $\beta_A \geq c_2(1-\kappa)c_3$ and $\beta_B \geq \frac{c_1}{c_2(1-\kappa)}$.

Proof of Proposition 9

The proof is by contradiction. As there are four possible combinations of players of the same type, the following four cases must be considered.

Case (i). A and B are two severe procrastinators. For Proposition 4, $(a_{A,2}(a_{B,1}), a_{B,2}(a_{A,1})) = ((0,0),(0,0))$ is the unique NE of $\mathcal{G}^2$ and $(a_{A,1}, a_{B,1}) = (0,0)$ is *a* NE of $\mathcal{G}^1$. Suppose that $(a_{A,1}, a_{B,1}) = (0,0)$ is not risk-dominant. Then $\beta_A\beta_B > (\frac{c_1}{c_3})^2$, which contradicts the initial assumption. It follows that $(a_{A,1}, a_{B,1}) = (0,0)$ is risk-dominant. Then, $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(0,0)),(0,(0,0)))$ is risk-dominant.

Case (ii). A and B are two moderated procrastinators. For Proposition 4, $(a_{A,2}(a_{B,1}), a_{B,2}(a_{A,1})) = ((1,1),(1,1))$ is *a* NE of $\mathcal{G}^2$. Suppose that it is not risk-dominant. Then $\beta_A\beta_B < (\frac{c_2}{c_3})^2$, which contradict the initial assumption. It follows that $(a_{A,2}(a_{B,1}), a_{B,2}(a_{A,1})) = ((1,1),(1,1))$ is the risk-dominant NE of $\mathcal{G}^2$. In $t = 1$ the players will anticipate that and play a game $\mathcal{G}^1$ where they decide whether doing the task immediately or in the second period. $(a_{A,1}, a_{B,1}) = (0,0)$ is *a* NE of $\mathcal{G}^1$. Suppose that it is not risk-dominant. Then $\beta_A\beta_B > (\frac{c_1}{c_2})^2$, which contradicts the initial assumption. It follows that $(a_{A,1}, a_{B,1}) = (0,0)$ is the risk-dominant NE of $\mathcal{G}^1$. Then, $(\mathbf{s}_A, \mathbf{s}_B) = ((0,(1,1)),(0,(1,1)))$ is risk-dominant.

Case (iii). A and B are two non-procrastinators. For Proposition 5, if $\mathcal{G}^2$ has multiple equilibria, then $(a_{A,2}(a_{B,1}), a_{B,2}(a_{A,1})) = ((1,1),(1,1))$ is one of them. Suppose that it is not risk-dominant. Then $\beta_A\beta_B < (\frac{c_2}{c_3})^2$, which contradicts the initial assumption. It follows that $(a_{A,2}(a_{B,1}), a_{B,2}(a_{A,1})) = ((1,1),(1,1))$ is risk-dominant. In $t = 1$ the players will anticipate that and play a game $\mathcal{G}^1$ where they decide whether doing the task immediately or in the second period. $(a_{A,1}, a_{B,1}) = (1,1)$ is *a* NE of $\mathcal{G}^1$. Suppose that it is not risk-dominant. Then $\beta_i < \frac{c_1}{c_2}$, which contradicts the initial assumption. It follows that $(a_{A,1}, a_{B,1}) = (1,1)$ is risk-dominant. Thus, $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(1,1)),(1,(1,1)))$ is risk-dominant.

Case (iv). A and B are two impatient non-procrastinators. For Proposition 5, if $\mathcal{G}^2$ has multiple equilibria, then $(a_{A,2}(a_{B,1}), a_{B,2}(a_{A,1})) = ((0,0),(0,0))$ is one of them. Suppose that it is not risk-dominant. Then $\beta_A\beta_B > (\frac{c_2}{c_3})^2$, which contradicts the initial assumption. It follows that $(a_{A,2}(a_{B,1}), a_{B,2}(a_{A,1})) = ((0,0),(0,0))$ is risk-dominant. In $t = 1$ the players will anticipate that and play a game $\mathcal{G}^1$ where they decide whether doing the task immediately or in the third period. When $\mathcal{G}^1$ has multiple equilibria, $(a_{A,1}, a_{B,1}) = (1,1)$ is one of them. Suppose that it is not risk-dominant. Then, $\beta_A\beta_B < (\frac{c_1}{c_3})^2$, which contradict the initial assumption. It follows that $(a_{A,1}, a_{B,1}) = (1,1)$ is risk-dominant. Thus, $(\mathbf{s}_A, \mathbf{s}_B) = ((1,(0,0)),(1,(0,0)))$ is risk-dominant.

Proof of Proposition 10

The proof is by contradiction.

Part a. Suppose that the matching μ is positively assortative but not stable. Then either at least one agent prefers being single to her current partner, or there will be a blocking pair $\{i,j\}$, where $i \in \Omega_x$ and $j \in \Omega_{-x}$. Neither of these options are possible. Trivially, two agents of the same type will strictly prefer to be with each other than to be single for any $\kappa > 0$. Moreover, two extreme procrastinators will prefer to be with each other than to each be with a moderate procrastinato, because they will do the task in the last period in either case, but in the former case the cost of doing the task will be lower due to company. It follows that if μ is positively assortative, then it is stable.

Part b. Suppose that the matching μ is stable but not positively assortative. Then two extreme procrastinators will prefer to be with each other than with their current partners, which contradicts the assumption that μ is stable. It follows that if μ is stable, then it is positively assortative.

Note that it is true that two agents always exist because Ω_A and Ω_B are even.

Proof of Proposition 11

The proof is by contradiction.

Part a. Suppose that the matching μ is negatively assortative but not stable. Then either at least one agent prefers being single to her current partner, or there will be a blocking pair $\{i,j\} \in \Omega_x$. Neither of these options are possible. An extreme procrastinator and a moderate one will strictly prefer being with each other than being single, because when matched with each other each of them will do the task earlier and in company, thereby facing a cost $c_1(1-\kappa)$, whereas when by themselves one faces the cost c_2 and the other c_3. It is always true that $c_1(1-\kappa) < c_2 < c_3$. Similarly, an extreme procrastinator and a moderate procrastinator will strictly prefer being with each other than being each with her own type, because each of them will face a cost $c_1(1-\kappa)$, whereas when each is matched with her own type one faces the cost $c_2(1-\kappa)$ and the other $c_3(1-\kappa)$. It is always true that $c_1(1-\kappa) < c_2(1-\kappa) < c_3(1-\kappa)$. It follows that if μ is negatively assortative, then it is stable.

Part b. Suppose that the matching μ is stable but not negatively assortative. Then a moderate procrastinator and an extreme procrastinator will prefer to be with each other than with their current partners, which contradicts the assumption that μ is stable. It follows that if μ is stable, then it is negatively assortative.

Proof of Proposition 12

Consider a procrastination game $\mathcal{G}$, where A is a severe, sophisticated procrastinator and B a moderate, naïve procrastinator.

The PPNE of the game are the following.

(a) If $\frac{c_2}{c_3(1-\kappa)} < \frac{c_1}{c_2}$, the PPNE are:

(i) $(\mathbf{s}_A^s, \mathbf{s}_B^n) = ((0,(0,0)),(0,(0,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_2}{c_3(1-\kappa)}$,

(ii) $(\mathbf{s}_A^s, \mathbf{s}_B^n) \in \{((0,(0,0)),(0,(0,1))); ((1,(0,0)),(1,(0,0)))\}$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B < \frac{c_2}{c_3(1-\kappa)}$,

(iii) $(\mathbf{s}_A^s, \mathbf{s}_B^n) = ((0,(0,0)),(0,(1,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B \geq \frac{c_2}{c_3(1-\kappa)}$,

(iv) $(\mathbf{s}_A^s, \mathbf{s}_B^n) \in \{((0,(0,0)),(0,(1,1))); ((1,(0,0)),(1,(1,1)))\}$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$ and $\beta_B \geq \frac{c_2}{c_3(1-\kappa)}$.

(a) If $\frac{c_2}{c_3(1-\kappa)} \geq \frac{c_1}{c_2}$, the PPNE are only:

(i) $(\mathbf{s}_A^s, \mathbf{s}_B^n) = ((0,(0,0)),(0,(0,1)))$ iff $\beta_A < \frac{c_1(1-\kappa)}{c_3}$,

(ii) $(\mathbf{s}_A^s, \mathbf{s}_B^n) \in \{((0,(0,0)),(0,(0,1)); ((1,(0,0)),(1,(0,0)))\}$ iff $\beta_A \geq \frac{c_1(1-\kappa)}{c_3}$.

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