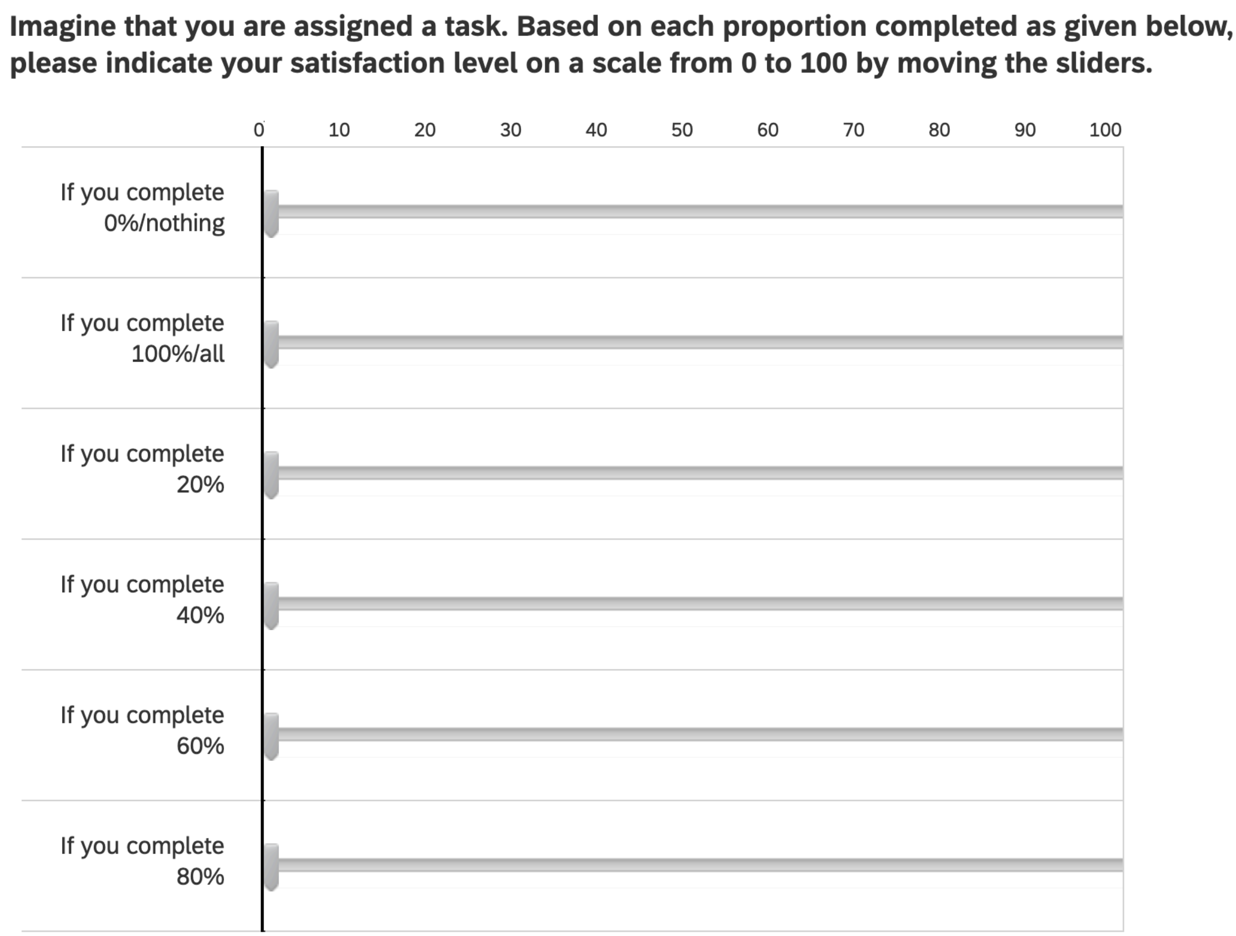
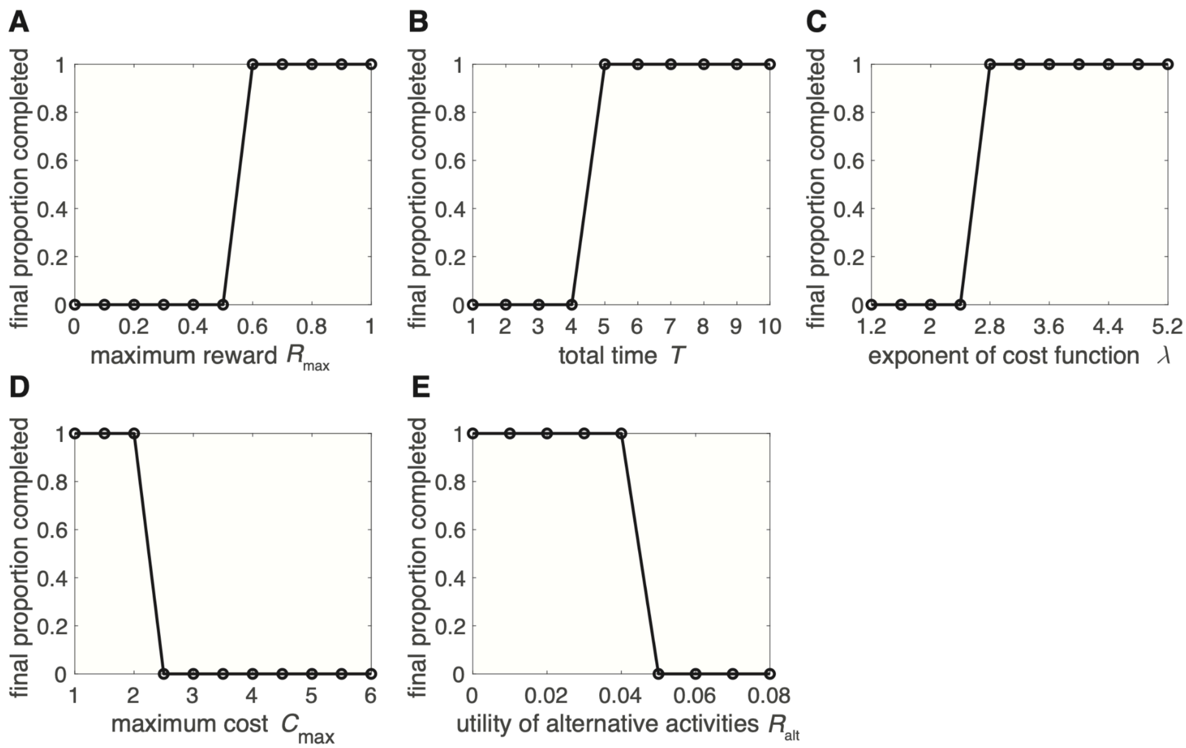
Supplemental Materials



Supplementary Figure 1. Questionnaire used to validate the perfectionism parameter in our theory. Participants rated their satisfaction levels (0-100) for six different completion percentages in a hypothetical task.



Supplementary Figure 2. Final proportion completed as a function of (A) maximum reward, (B) total time, (C) exponent of cost function, (D) maximum cost, and (E) utility of alternative activities, showing sharp transitions between not working at all and full task completion.

Simulation results for exponential discounting

The parameter set we use for running simulations is shared across different situations, with variations of some parameters in each situation. We refer to this shared parameter set as the standard parameter set: $T \in [2, 10]$, $R_{max} \in (0, 1)$, $\gamma \in (0, 1)$, $C_{max} \in (0, 2)$, $\lambda \in (1, 10)$, $\beta \in (0.1, 10)$, $R_{alt} \in (0, 0.01R_{max})$.

The necessary parameter space for the pattern "a delay before ramping up" is $\lambda > 1$, $\gamma < 1$. To confirm this finding, we drew a total of 10,000 parameter combinations using the standard parameter set. We found that the additional effort $(a_{t+1} - a_t)$ is always greater than or equal to 0, meaning that the time course of work is always ramping up. When γ is smaller, delay $(a_t = 0)$ is more likely to happen.

The necessary parameter space for the pattern "working last-minute" is $\lambda < 1$. To confirm this finding, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 1)$. We found that the number of non-zero efforts in any time course of work is either 0 or 1. When there is a non-zero effort, it is always applied on the last day.

The necessary parameter space for the pattern “not working at all” is $R_{max} - C_{max} < R_{alt}$, if $R_{max} - C_{max} > R_{alt}$, agents always choose to work on the task. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the following variations: 1) $\lambda \in (0, 10)$; 2) in the condition when $R_{max} - C_{max} < R_{alt}$, $R_{alt} \in (max(0,\ R_{max} - C_{max}),\ 5)$; 3) in the condition when $R_{max} - C_{max} > R_{alt}$, $C_{max} \in (0,\ R_{max})$, $R_{alt} \in (0,\ R_{max} - C_{max})$. We found that the final proportion completed can be either positive or 0 when $R_{max} - C_{max} < R_{alt}$; However, the final proportion is always positive when $R_{max} - C_{max} > R_{alt}$. So $R_{max} - C_{max} < R_{alt}$ is a necessary condition to have the pattern “not working at all”.

Under a lower maximum reward, agents procrastinate more and finish less work in the end (The final reward decreases). They pay a lower total cost, and the net utility decreases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work progress, one under a lower R_{max}, and another under a higher R_{max}. We compare the severity of procrastination, final proportion completed, and total cost under two maximum reward values and confirm the finding: under a lower maximum reward, agents procrastinate more, finish less work in the end (the final reward decreases), pay a lower total cost, and the net utility decreases.

Under a lower maximum cost, when $R_{alt} = 0$, agents procrastinate less and finish more work in the end (The final reward increases). The change in total cost is bidirectional, and the net utility decreases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work, one under a lower C_{max} and another under a higher C_{max}. We compare the severity of procrastination, final proportion completed, and total cost under two maximum cost values and confirm the finding. When $R_{alt} > 0$, all the relationships are bidirectional.

Under a lower utility of alternative activities, agents procrastinate less and finish more work in the end (The final reward increases). The change in the total cost is bidirectional, and the net utility increases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work, one under a lower R_{alt} and another under a higher R_{alt}. We compare the severity of procrastination, the final proportion completed, and the total cost under two maximum cost values and confirm the findings.

Under a lower discount rate γ (stronger temporal discounting), agents procrastinate more and finish less work in the end (The final reward decreases). The change in the total cost is bidirectional, and the net utility decreases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work, one under a lower γ and another under a higher γ. We compare the severity of procrastination, the final proportion completed, and the total cost under two discount rates and confirm the findings.

Agents with convex cost function, compared to those with concave cost function, have less severity of procrastination. The change in final proportion completed (higher final reward) and total cost are bidirectional. The net utility increases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work, one under the convex cost function and another under the concave cost function. We compare the severity of procrastination, the final proportion completed, and the total cost under two maximum cost values and confirm the findings.

Among agents with a convex cost function, when $R_{alt} = 0$, an agent with a larger λ procrastinates more and finishes more work in the end (higher final reward). The change in the total cost and net utility are bidirectional. When $R_{alt} > 0$, all the relationships are bidirectional.

For agents with high perfectionism (as long as $\beta > \lambda$), the final proportion completed is either 0 or 1. For agents with low perfectionism ($\beta < \lambda$), the final proportion completed is between 0 and 1. We confirmed this by drawing a total of 10,000 parameter combinations with the standard parameter set with the variation $\lambda \in (0, 10)$.

Given a longer total time, agents switch from not working at all to working all day and finish more work in the end (Here, we only discuss the case of a convex cost function. Please see the reason in the main paper). The change in the total cost is bidirectional. The net utility increases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set. We found that the number of days of delay divided by *T* switches from 1 to 0 as the total time increases. The final proportion completed increases (the final reward increases), and the change in the total cost is bidirectional. The net utility increases. Therefore, the simulations confirm the findings.

Simulation results for hyperbolic discounting

We test whether the conclusion with exponential discounting still holds when we approximate the *Q* value according to hyperbolic discounting. The standard parameter space to run parameter combinations is: $T \in [2, 10]$, $R_{max} \in (0, 1)$, $k \in (e^{-9}, e^{1})$, $C_{max} \in (0, 2)$, $\lambda \in (1, 10)$, $\beta \in (0.1, 10)$, $R_{alt} \in (0, 0.01\alpha)$.

The necessary parameter space for the pattern “a delay before ramping up” is $\lambda > 1$, $k > 0$. ($k = 0$ is equivalent to $\gamma = 1$) To confirm this, we drew a total of 10,000 parameter combinations with the standard parameter set. We found that the additional effort $a_{t+1} - a_t$ is mostly (99%)

equal to or larger than 0, but not always, meaning that the time course of work is mostly ramping up but sometimes fluctuates. But the necessary parameter space to find the pattern is $\lambda > 1,\ k > 0$.

The necessary parameter space for the pattern "working last-minute" is $\lambda < 1$. To confirm this finding, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 1)$. We found that the number of non-zero efforts in any time course of work is either 0 or 1. When there is a non-zero effort, the effort is always on the last day.

The necessary parameter space for the pattern "not working at all" is $R_{max} - C_{max} < R_{alt}$, if $R_{max} - C_{max} > R_{alt}$, agents always choose to work on the task. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the following variation: 1) $\lambda \in (0, 10)$; 2) in the condition when $R_{max} - C_{max} < R_{alt}$, $R_{alt} \in (max(0,\ R_{max} - C_{max}),\ 5)$; 3) in the condition when $R_{max} - C_{max} > R_{alt}$, $C_{max} \in (0,\ R_{max})$, $R_{alt} \in (0,\ R_{max} - C_{max})$. We found that the final proportion completed can be either positive or 0 when $R_{max} - C_{max} < R_{alt}$; However, the final proportion is always positive when $R_{max} - C_{max} > R_{alt}$. So $R_{max} - C_{max} < R_{alt}$ is a necessary condition to have the pattern "not working at all".

Under a lower maximum reward, agents procrastinate more and finish less work in the end (The final reward decreases). The change in the total cost and net utility is bidirectional. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work, one under a lower R_{max}, and another under a higher R_{max}. We compare the severity of procrastination, the final proportion completed, and the total cost under two maximum reward values and confirm the findings.

Under a lower maximum cost, when $R_{alt} = 0$, agents procrastinate less and finish more work in the end (The final reward increases). The change in total cost is bidirectional, and the net utility decreases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work progress, one under a lower C_{max} and another under a higher C_{max}. We compare the severity of procrastination, final proportion completed, total cost, and net utility under two maximum cost values and confirm the finding. When $R_{alt} > 0$, all the relationships are bidirectional.

Under a lower utility of alternative activities, agents procrastinate less and finish more work in the end (The final reward increases). The change in the total cost is bidirectional, and the net utility increases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work progress, one under a lower R_{alt} and another under a higher

R_{alt}. We compare the severity of procrastination, the final proportion completed, and the total cost under two maximum cost values and confirm the findings.

Under a higher discount rate k_{DR} (stronger temporal discounting), agents procrastinate more and finish less work in the end (The final reward decreases). The change in the total cost and net utility are bidirectional. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work progress, one under a lower k_{DR} and another under a higher k_{DR}. We compare the severity of procrastination, the final proportion completed, and the total cost under two discount rates and confirm the findings.

Agents with a convex cost function, compared to those with a concave cost function, have less severity of procrastination. The change in final proportion completed, total cost, and net utility is bidirectional. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set with the variation $\lambda \in (0, 10)$. In each parameter combination, we simulated two time courses of work progress, one under the convex cost function and another under the concave cost function. We compare the severity of procrastination, the final proportion completed, and the total cost under two maximum cost values and confirm the findings.

Among agents with a convex cost function, when $R_{alt} = 0$, an agent with a larger λ procrastinates less and finishes more work in the end. The change in the total cost and net utility are bidirectional. When $R_{alt} > 0$, all the relationships are bidirectional.

In terms of perfectionism, we drew a total of 10,000 parameter combinations using the standard parameter set with the following variation: $\lambda \in (0, 10)$. For agents with high perfectionism (as long as $\beta > \lambda$) and low perfectionism ($\beta < \lambda$), the final proportion completed is between 0 and 1. However, the final proportion completed for only a small proportion of agents with high perfectionism is between 0 and 1 (only 1 case in 1000 simulations, and the value is 0.13, which is close to 0.), compared to the large proportion of agents whose final proportion completed is between 0 and 1 (257 cases in 1000 simulations, and the mean value is 0.44$\pm$0.33.) A diversity of relationships between perfectionism and procrastination is qualitatively held.

Given a longer total time, agents switch from not working at all to working all day and finish more work in the end (Here, we only discuss the case of a convex cost function. Please see the reason in the main paper). The change in the total cost is bidirectional. The net utility increases. To confirm this, we drew a total of 10,000 parameter combinations using the standard parameter set. We found that the number of days of delay divided by T switches from 1 to 0 as the total time increases. The final proportion completed increases, and the change in the total cost is bidirectional. The net utility increases. Therefore, the simulations confirm the findings.

In terms of Immediate Reward interventions, we simulated 10,000 trials. The effects of immediate reward interventions on the severity of procrastination, average task completion day, average final proportion completed, and various utilities are as follows. In each simulation, offering immediate rewards reduces the severity of procrastination (average severity of procrastination for Control condition, LI (Low Immediacy), MI (Medium Immediacy), and HI (High Immediacy) schedules are respectively 5.13, 2.35, 1.59, and 0.60). On average, the higher the immediacy level of interventions, the lower the severity of procrastination (it does not always hold for every single simulation). Offering immediate reward, in every single simulation, helps agents complete the task earlier than the deadline (average task completion day are respectively 10, 4,10, 3.89, and 9.04). Offering immediate reward helps agents, on average, get more work done (average final proportion completed is respectively 0.77, 0.80, 0.81, and 0.83) (it does not always hold for every single simulation). The higher the immediacy level of interventions, the higher the final proportion of completed interventions (although this does not always hold true for every single simulation). In terms of utilities, offering immediate reward increases the final reward (average final reward for Control condition, LI, MI, and HI schedules are respectively 0.446, 0.450, 0.456, and 0.460). The higher the immediacy level of interventions, the higher the final proportion completed. Offering immediate rewards increases the total cost (average total cost are respectively 0.038, 0.094, 0.080, and 0.063). Offering immediate rewards reduces the net utility, with an average net utility of 0.408, 0.356, 0.376, and 0.397, respectively.

For examining the Intermediate Deadlines interventions, we simulated 10,000 trials. The effects of the Intermediate Deadlines intervention on the severity of procrastination, average task completion day, average final proportion completed, and various utilities are as follows. Intermediate deadlines, in every single simulation, help reduce the severity of procrastination (average days of delay for Control and Intermediate Deadlines are 13.63 and 4.73). Importantly, because of the first intermediate deadline on the 7th day, 91.87% of participants start to work before the 7th day. This is in contrast to only 17.26% of agents who start to work before the 7th day under the control condition. In addition, intermediate deadlines in every single simulation help agents complete the task earlier. More agents complete the task in the Intermediate Deadlines condition than in the Control condition. Also, in contrast to the Control condition, where the task completion is always on the last day, there are agents who complete the task earlier than the deadline (i.e., on the 7th or 14th day). Finally, intermediate deadlines in every single simulation help agents complete more work (the average final proportion completed for control and intermediate deadlines is 0.80 and 0.92, respectively). In terms of utilities, intermediate deadlines increase the final reward (average final reward for control and intermediate deadlines are 0.45 and 0.48), increase the total cost (average total cost is 0.033 and 0.069), and decrease the net utility (average net utility is 0.42 and 0.41).