

Online Appendix

EC.1. Proof

Proof of Propositions 1 and 6 We give a formal proof of Proposition 6. Proposition 1 can be directly obtained by setting $\underline{\Pi}_C = \underline{\Pi}_S = 0$. Maximizing the Nash product in (3), we have $[\Pi_S^m(\Psi^m, \hat{r}^m(\Psi^m)) - \underline{\Pi}_S]/\theta = [\Pi_C^m(\Psi^m, \hat{r}^m(\Psi^m)) - \underline{\Pi}_C]/(1 - \theta)$. System coordination is achieved under the following conditions: C1: $\theta(\Pi^* - \underline{\Pi}_C - \underline{\Pi}_S) = \Pi_S^m(\Psi^m, r^*) - \underline{\Pi}_S$, and C2: $r^* = \hat{r}^m(\Psi^m)$. For each contract, we find θ such that C1 and C2 hold in the Nash bargaining solution, as well as the corresponding contract terms.

1. Contract FP : $\Pi_S^{FP}(p, r) = p\mathbb{E}_Z[e^{-\alpha Z/r}] - c(r)$. C2 is equivalent to $d\Pi_S^{FP}/dr(p, r = r^*) = 0$. It can be verified that $\hat{p}^{FP} = Q$ is the unique solution to C2 and $\Pi_S^{FP}(Q, r^*) = \Pi^*$. Combined with C1, $\Phi^{FP} = \left\{ \frac{\Pi^* - \underline{\Pi}_S}{\Pi^* - \underline{\Pi}_C - \underline{\Pi}_S} \right\}$, which is $\{1\}$ when $\underline{\Pi}_C = 0$ and is an empty set otherwise.
2. Contracts TF and $TF+$: $\Pi_S^{TF}(p, \beta, r) = \Pi_S^{TF+}(p, \beta, r) = \beta + p\mathbb{E}_Z[e^{-\alpha Z/r}] - c(r)$. Similar to contract FP , we have $\hat{p}^{TF} = \hat{p}^{TF+} = Q$ and $\Pi_S^{TF}(Q, \beta, r^*) = \Pi_S^{TF+}(Q, \beta, r) = \beta + \Pi^*$. C1 requires that $\hat{\beta}^{TF} = \hat{\beta}^{TF+} = -(1 - \theta)(\Pi^* - \underline{\Pi}_S) - \theta\underline{\Pi}_C \leq 0$. Recall that $\beta^{TF+} \geq 0$, whereas β^{TF} can be negative. Therefore, $\Phi^{TF} = [0, 1]$ and $\Phi^{TF+} = \left\{ \frac{\Pi^* - \underline{\Pi}_S}{\Pi^* - \underline{\Pi}_C - \underline{\Pi}_S} \right\}$, which is $\{1\}$ when $\underline{\Pi}_C = 0$ and is an empty set otherwise.
3. Contract TB : $\Pi_S^{TB}(p, \beta, r) = p\mathbb{E}_Z[e^{-(\alpha+\beta)Z/r}] - c(r)$. For a fixed time-incentive parameter β , C2 results in $\hat{p}^{TB}(\beta) = \frac{\alpha Q \mathbb{E}_Z[Z e^{-\alpha Z/r^*}]}{(\alpha+\beta)\mathbb{E}_Z[Z e^{-(\alpha+\beta)Z/r^*}]}$. Given $p = \hat{p}^{TB}(\beta)$ and $r = r^*$, the subcontractor's profit is $\delta_S^{TB}(\beta) \equiv \Pi_S^{TB}(\hat{p}^{TB}(\beta), \beta, r^*)$. To simultaneously satisfy condition C1, we must have $\delta_S^{TB}(\beta) = \theta(\Pi^* - \underline{\Pi}_C) + (1 - \theta)\underline{\Pi}_S$. Let $\underline{\delta}_S^{TB} = \min_{\beta \geq 0} \{\delta_S^{TB}(\beta)\}$. It is easy to see that $\max_{\beta \geq 0} \delta_S^{TB}(\beta) \geq \delta_S^{TB}(\beta = 0) = \Pi^*$. Therefore, C1 can only hold when $\theta \in \left[\max \left\{ \frac{\underline{\delta}_S^{TB} - \underline{\Pi}_S}{\Pi^* - \underline{\Pi}_C - \underline{\Pi}_S}, 0 \right\}, 1 \right]$. It also requires that $\hat{\beta}^{TB} = \arg_{\beta \geq 0} \{\delta_S^{TB}(\beta) = \theta(\Pi^* - \underline{\Pi}_C) + (1 - \theta)\underline{\Pi}_S\}$ and $\hat{p}^{TB} = \frac{\alpha \mathbb{E}_Z[Z e^{-\alpha Z/r^*}]}{(\alpha + \hat{\beta}^{TB}) \mathbb{E}_Z[Z e^{-(\alpha + \hat{\beta}^{TB})Z/r^*}]} Q$.
4. Contract CS : $\Pi_S^{CS}(p, \beta, r) = p\mathbb{E}_Z[e^{-\alpha Z/r}] - (1 - \beta)c(r)$. Contract CS always achieves system coordination, and that $\hat{p}^{CS} = (1 - \hat{\beta}^{CS})Q$ and $\hat{\beta}^{CS} = \frac{(1-\theta)(\Pi^* - \underline{\Pi}_S) + \theta\underline{\Pi}_C}{\Pi^*}$.
5. Contract $C+$: Contract $C+$ is a special case of contract CS and the proof is omitted. \square

Proof of Proposition 2. For bargaining unit i (i.e., the client and subcontractor i), maximizing the Nash product $[\Pi_i^m(\Psi_i^m, \hat{r}_i^m(\Psi_i^m), \emptyset) - \underline{\Pi}_i]^{\theta_i} [\Pi_C^m(\Psi^m, \hat{r}^m(\Psi^m)) - \underline{\Pi}_C]^{1-\theta_i}$, we have $\Pi_i^m(\Psi_i^m, \hat{r}_i^m(\Psi_i^m), \emptyset)/\theta_i = \Pi_C^m(\Psi^m, \hat{r}^m(\Psi^m))/(1 - \theta_i)$. When $\theta \in \Phi$, the n Nash bargaining solutions have a unique Nash equilibrium where $\Pi_i^m(\Psi_i^m, \hat{r}_i^m(\Psi_i^m), \emptyset) = \Theta_i(\theta) \left[\sum_{j \in [n]} \Pi_j^m(\Psi_j^m, \hat{r}_j^m(\Psi_j^m), \emptyset) + \Pi_C^m(\Psi^m, \hat{r}^m(\Psi^m)) \right]$. System coordination is achieved under the following conditions: C1: $\Theta_i(\theta)\Pi^* = \Pi_i^m(\Psi_i^m, r_i^*, \emptyset)$, and C2: $r_i^* = \hat{r}_i^m(\Psi_i^m)$, $\forall i \in [n]$. For each contract type, we find θ such that C1 and C2 hold in the Nash-Nash solution, as well as the corresponding contract terms.

1. Contract FP : $\Pi_i^{FP}(p_i, r_i, \emptyset) = p_i \mathbb{E}[e^{-\alpha Z_i/r_i}] - c_i(r_i)$. The first-order condition corresponding to C2 results in $\hat{p}_i^{FP} = \frac{(r_i^*)^2 c_i'(r_i^*)}{\alpha \mathbb{E}[Z_i e^{-\alpha Z_i/r_i^*}]}$. Given $p_i = \hat{p}_i^{FP}$ and $r_i = r_i^*$, subcontractor i 's profit is $\delta_i^{FP} = \Pi_i^{FP}(\hat{p}_i^{FP}, r_i^*) = \frac{(r_i^*)^2 c_i'(r_i^*) \mathbb{E}[e^{-\alpha Z_i/r_i^*}]}{\alpha \mathbb{E}[Z_i e^{-\alpha Z_i/r_i^*}]} - c_i(r_i^*)$. C1 holds when $\Theta_i(\boldsymbol{\theta}) = \delta_i^{FP}/\Pi^*$, $\forall i \in [n]$.
2. Contracts TF and $TF+$: $\Pi_i^{TF}(p_i, \beta_i, r_i, \emptyset) = \Pi_i^{TF+}(p_i, \beta_i, r_i, \emptyset) = \beta_i + p_i \mathbb{E}[e^{-\alpha Z_i/r_i}] - c_i(r_i)$. Regardless of the down payment β_i , C2 results in $\hat{p}_i^{TF} = \hat{p}_i^{TF+} = \frac{(r_i^*)^2 c_i'(r_i^*)}{\alpha \mathbb{E}[Z_i e^{-\alpha Z_i/r_i^*}]}$. Given $p_i = \hat{p}_i^{TF} = \hat{p}_i^{TF+}$ and $r_i = r_i^*$, subcontractor i 's profit with down payment β_i is $\delta_i^{TF}(\beta_i) = \delta_i^{TF+}(\beta_i) = \Pi_i^{TF}(\hat{p}_i^{TF}, \beta_i, r_i^*) = \Pi_i^{TF+}(\hat{p}_i^{TF+}, \beta_i, r_i^*) = \beta_i + \delta_i^{FP}$. C1 requires that $\hat{\beta}_i^{TF} = \hat{\beta}_i^{TF+} = \Theta_i(\boldsymbol{\theta})\Pi^* - \delta_i^{FP}$. Recall that $\hat{\beta}_i^{TF+} \geq 0$, whereas $\hat{\beta}_i^{TF}$ can be negative. Therefore, contract $TF+$ can only coordinate the system when $\boldsymbol{\theta} \in \Phi$ and $\Theta_i(\boldsymbol{\theta}) \geq \delta_i^{FP}/\Pi^*$, whereas contract TF coordinates the system for all $\boldsymbol{\theta} \in \Phi$.
3. Contract TB : $\Pi_i^{TB}(p_i, \beta_i, r_i, \emptyset) = p_i \mathbb{E}[e^{-(\alpha+\beta_i)Z_i/r_i}] - c_i(r_i)$. For a fixed time-incentive parameter β_i , C2 results in $\hat{p}_i^{TB}(\beta_i) = \frac{(r_i^*)^2 c_i'(r_i^*)}{(\alpha+\beta_i) \mathbb{E}[Z_i e^{-(\alpha+\beta_i)Z_i/r_i^*}]}$. Given $p_i = \hat{p}_i^{TB}(\beta_i)$ and $r_i = r_i^*$, subcontractor i 's profit with time-incentive parameter β_i is $\delta_i^{TB}(\beta_i) = \Pi_i^{TB}(\hat{p}_i^{TB}(\beta_i), \beta_i, r_i^*) = \frac{(r_i^*)^2 c_i'(r_i^*) \mathbb{E}[e^{-(\alpha+\beta_i)Z_i/r_i^*}]}{(\alpha+\beta_i) \mathbb{E}[Z_i e^{-(\alpha+\beta_i)Z_i/r_i^*}]} - c_i(r_i^*)$. Let $\underline{\delta}_i^{TB} = \min_{\beta_i \geq 0} \{\delta_i^{TB}(\beta_i)\}$ and $\bar{\delta}_i^{TB} = \max_{\beta_i \geq 0} \{\delta_i^{TB}(\beta_i)\}$. C1 holds when $\boldsymbol{\theta} \in \Phi$ and $\Theta_i(\boldsymbol{\theta}) \in [\underline{\delta}_i^{TB}/\Pi^*, \bar{\delta}_i^{TB}/\Pi^*]$, $\forall i \in [n]$. It also requires that $\hat{\beta}_i^{TB} = \arg_{\beta_i \geq 0} \{\delta_i^{TB}(\beta_i) = \Theta_i(\boldsymbol{\theta})\Pi^*\}$, $\forall i \in [n]$, and therefore, $\hat{p}_i^{TB} = \frac{(r_i^*)^2 c_i'(r_i^*)}{(\alpha+\hat{\beta}_i^{TB}) \mathbb{E}[Z_i e^{-(\alpha+\hat{\beta}_i^{TB})Z_i/r_i^*}]}$.
4. Contract CS : $\Pi_i^{CS}(p_i, \beta_i, r_i, \emptyset) = p_i \mathbb{E}[e^{-\alpha Z_i/r_i}] - (1 - \beta_i)c_i(r_i)$. For a fixed cost-sharing ratio β_i , C2 results in $\hat{p}_i^{CS}(\beta_i) = (1 - \beta_i)\hat{p}_i^{FP}$. Given $p_i = \hat{p}_i^{CS}(\beta_i)$ and $r_i = r_i^*$, subcontractor i 's profit with cost-sharing ratio β_i is $\delta_i^{CS}(\beta_i) = \Pi_i^{CS}(\hat{p}_i^{CS}(\beta_i), \beta_i, r_i^*) = (1 - \beta_i)\delta_i^{FP}$. It is easy to verify that $\delta_i^{CS}(\beta_i)$ is monotone in β_i and that $\delta_i^{CS}(1) = 0 \leq \delta_i^{CS}(\beta_i) \leq \delta_i^{CS}(0) = \delta_i^{FP}$, $\forall \beta_i \in [0, 1]$. C1 holds when $\Theta_i(\boldsymbol{\theta}) \in [0, \delta_i^{FP}/\Pi^*]$, $\forall i \in [n]$. It also requires that $\hat{\beta}_i^{CS} = 1 - \frac{\Theta_i(\boldsymbol{\theta})\Pi^*}{\delta_i^{FP}}$ and $\hat{p}_i^{CS} = (1 - \hat{\beta}_i^{CS})\hat{p}_i^{FP}$, $\forall i \in [n]$. \square

Proof of Lemma 1 We first show that when the system is coordinated, all subcontractors except for the first one must receive zero expected profit. We then show that this can only occur when $\boldsymbol{\theta} \in \Phi_S$. Assume there exists an equilibrium under contract terms Ψ^m , where the system is coordinated and there exists a subcontractor $i \in \{2, \dots, n\}$ with a positive equilibrium expected profit. Consider the negotiation between the client and subcontractor 1 under contract m , given contract terms Ψ_j^m and work rate $r_j = r_j^*$ for $j \in \{2, \dots, n\}$. Let \hat{r}_1^m denote the work rate resulting from this negotiation. By the coordination assumption, \hat{r}_1^m should be equal to the system optimal work rate r_1^* . We will derive a contradiction by showing $\hat{r}_1^m < r_1^*$.

Given work rate r_j^* and contract terms Ψ_j^m for $j \in \{2, \dots, n\}$, the sum of the client's and subcontractor 1's profits is given by $\Pi_{1,C}^m(r_1) \equiv \left(Q \prod_{j=2}^n \mathbb{E}[e^{-\alpha T_j}] - \sum_{j=2}^n \mathbb{E}[\rho^m(\Psi_j^m, T_j, C_j(r_j, T_j))e^{-\alpha T_j}] \prod_{l=2}^{j-1} \mathbb{E}[e^{-\alpha T_l}] \right) \mathbb{E}[e^{-\alpha T_1}] - c_1(r_1) \Big|_{r_j=r_j^*, j \in \{2, \dots, n\}}$, which is concave in r_1 .

1. Contract FP : $\Pi_1^{FP}(p_1, r_1, \emptyset) = p_1 \mathbb{E}[e^{-\alpha Z_1/r_1}] - c_1(r_1)$. Assume $\hat{r}_1^{FP} \geq r_1^*$. To induce the work rate \hat{r}_1^{FP} , the equilibrium payment \hat{p}_1^{FP} satisfies $\hat{p}_1^{FP} \geq Q \prod_{j=2}^n \mathbb{E}[e^{-\alpha T_j}] - \sum_{j=2}^n c_j(r_j) \prod_{l=2}^{j-1} \mathbb{E}[e^{-\alpha T_l}]|_{r_j=r_j^*, j \in \{2, \dots, n\}}$, which is strictly larger than $Q \prod_{j=2}^n \mathbb{E}[e^{-\alpha T_j}] - \sum_{j=2}^n \mathbb{E}[\rho^{FP}(\Psi_j^{FP}, T_j, C_j(r_j, T_j))e^{-\alpha T_j}] \prod_{l=2}^{j-1} \mathbb{E}[e^{-\alpha T_l}]|_{r_j=r_j^*, j \in \{2, \dots, n\}}$ as there exists $i \in \{2, \dots, n\}$ such that $\mathbb{E}[\rho^{FP}(\Psi_i^{FP}, T_i, C_i(r_i, T_i))e^{-\alpha T_i}] > c_i(r_i)|_{r_i=r_i^*}$. Then, we have $\Pi_1^{FP}(\hat{p}_1^{FP}, r_1^*, \emptyset) > \Pi_{1,C}^{FP}(r_1^*)$, and the client obtains a strictly negative profit. Thus, $\hat{r}_1^{FP} < r_1^*$.
2. Contracts TF and $TF+$: $\Pi_1^{TF}(p_1, \beta_1, r_1, \emptyset) = \Pi_1^{TF+}(p_1, \beta_1, r_1, \emptyset) = p_1 \mathbb{E}[e^{-\alpha Z_1/r_1}] + \beta_1 - c_1(r_1)$. The proof for $\hat{r}_1^{TF+} < r_1^*$ is similar to that for $\hat{r}_1^{FP} < r_1^*$ and is omitted. Because contract TF can induce subcontractor 1 to exert any positive work rate r_1 by setting $p_1 = (r_1)^2 c_1'(r_1) / (\alpha \mathbb{E}[Z_1 e^{-\alpha Z_1/r_1}])$, while achieving an arbitrary profit division by adjusting the down payment β_1 , $\Pi_{1,C}(r_1)$ will be maximized through bargaining, i.e., $\Pi_{1,C}^{TF}(\hat{r}_1^{TF}) = \max_{r_1} \{\Pi_{1,C}^{TF}(r_1)\}$. Since $\Pi_{1,C}^{TF}(r_1)$ is concave, we have the first-order condition that $d\Pi_{1,C}^{TF}(r_1)/dr_1|_{r_1=\hat{r}_1^{TF}} = 0$. Comparing this condition with the first-order condition in (5) with $j=1$, we have $\partial \Pi(r) / \partial r_1|_{r_1=\hat{r}_1^{TF}, r_j=r_j^*, j \in \{2, \dots, n\}} > 0$ and therefore $\hat{r}_1^{TF} < r_1^*$ because at least one subcontractor in $\{2, \dots, n\}$ has a strictly positive equilibrium profit.
3. Contract TB : $\Pi_1^{TB}(p_1, \beta_1, r_1, \emptyset) = p_1 \mathbb{E}[e^{-(\alpha+\beta_1)Z_1/r_1}] - c_1(r_1)$. Subcontractor 1's profit when induced to exert r_1 given β_1 is $\delta_1^{TB}(\beta_1, r_1) = \frac{(r_1)^2 c_1'(r_1) \mathbb{E}[e^{-(\alpha+\beta_1)Z_1/r_1}]}{(\alpha+\beta_1) \mathbb{E}[Z_1 e^{-(\alpha+\beta_1)Z_1/r_1}]} - c_1(r_1)$. Let $\{\hat{p}_1^{TB}, \hat{\beta}_1^{TB}\}$ denote the equilibrium contract terms for subcontractor 1. Let $\tilde{r}_1^{TB} = \arg \max_{r_1} \{\Pi_{1,C}^{TB}(r_1)\}$. We can easily show that $\tilde{r}_1^{TB} < r_1^*$. When $\theta_1 \in [\underline{\delta}_1^{TB} / \Pi_{1,C}^{TB}(\tilde{r}_1^{TB}), 1]$, where $\underline{\delta}_1^{TB} = \min_{\beta_1 \geq 0} \delta_1^{TB}(\beta_1, \tilde{r}_1^{TB})$, we have $\hat{r}_1^{TB} = \tilde{r}_1^{TB} < r_1^*$. So we only consider the case where $\theta_1 < \underline{\delta}_1^{TB} / \Pi_{1,C}^{TB}(\tilde{r}_1^{TB})$. Assume $\hat{r}_1^{TB} > \tilde{r}_1^{TB}$. As \hat{r}_1^{TB} and $\hat{\beta}_1^{TB}$ maximize the Nash product given in (6), we have $(\theta_1 \Pi_{1,C}^{TB} - \delta_1^{TB}) \frac{\partial \delta_1^{TB}}{\partial r_1} + (1 - \theta_1) \delta_1^{TB} \frac{d\Pi_{1,C}^{TB}}{dr_1} \Big|_{r_1=\hat{r}_1^{TB}, \beta=\hat{\beta}_1^{TB}} = 0$. From this equation and the assumption $\hat{r}_1^{TB} > \tilde{r}_1^{TB}$, it can be verified that $\theta_1 \Pi_{1,C}^{TB}(\hat{r}_1^{TB}) - \delta_1^{TB}(\hat{\beta}_1^{TB}, \hat{r}_1^{TB}) > 0$. We have $\delta_1^{TB}(\hat{\beta}_1^{TB}, \tilde{r}_1^{TB}) < \delta_1^{TB}(\hat{\beta}_1^{TB}, \hat{r}_1^{TB})$ and $\Pi_{1,C}^{TB}(\tilde{r}_1^{TB}) > \Pi_{1,C}^{TB}(\hat{r}_1^{TB})$. There exists an $\theta_1' \in [\underline{\delta}_1^{TB} / \Pi_{1,C}^{TB}(\tilde{r}_1^{TB}), 1]$, such that $\theta_1' \Pi_{1,C}^{TB}(\tilde{r}_1^{TB}) = \delta_1^{TB}(\hat{\beta}_1^{TB}, \tilde{r}_1^{TB})$. Besides, we have $\theta_1 \Pi_{1,C}^{TB}(\hat{r}_1^{TB}) - \delta_1^{TB}(\hat{\beta}_1^{TB}, \hat{r}_1^{TB}) < \theta_1 \Pi_{1,C}^{TB}(\tilde{r}_1^{TB}) - \delta_1^{TB}(\hat{\beta}_1^{TB}, \tilde{r}_1^{TB}) = -(\theta_1 - \theta_1') \Pi_{1,C}^{TB}(\tilde{r}_1^{TB}) < 0$, where the last inequality holds because $\theta_1' \geq \underline{\delta}_1^{TB} / \Pi_{1,C}^{TB}(\tilde{r}_1^{TB}) > \theta_1$. This contradicts the previous result that $\theta_1 \Pi_{1,C}^{TB}(\hat{r}_1^{TB}) - \delta_1^{TB}(\hat{\beta}_1^{TB}, \hat{r}_1^{TB}) > 0$. Thus, $\hat{r}_1^{TB} \leq \tilde{r}_1^{TB} < r_1^*$.
4. Contract CS : $\Pi_1^{CS}(p_1, \beta_1, r_1, \emptyset) = p_1 \mathbb{E}[e^{-\alpha T_1}] - (1 - \beta_1)c_1(r_1)$. The proof for $\hat{r}_1^{CS} < r_1^*$ is similar to that for $\hat{r}_1^{TF} < r_1^*$ and is omitted.

Therefore, for $m \in \{FP, TF+, TF, TB, CS\}$, we have $\hat{r}_1^m < r_1^*$, which contradicts the assumption that the system is coordinated.

We have shown that when the system is coordinated, all subcontractors except the first one must receive zero expected profit. We now show that this is only possible when $\theta \in \Phi_S$. To achieve system coordination, for each subcontractor, two additional conditions need to be satisfied simultaneously:

C1: $\Theta_i(\boldsymbol{\theta})\Pi^* = \Pi_i^m(\Psi_i^m, r_i^*, (r_j^*)_{j \in \mathcal{P}_i})$, and C2: $r_i^* = \hat{r}_i^m(\Psi_i^m)$. To satisfy C1, we have $\Theta_i(\boldsymbol{\theta}) = 0$, $\forall i \in \{2, \dots, n\}$. As we only consider the case where at most one subcontractor has full bargaining power, Φ_S is the largest set of bargaining power structures satisfying $\Theta_i(\boldsymbol{\theta}) = 0$, $\forall i \in \{2, \dots, n\}$. \square

Proof of Proposition 3 The proof is similar to that of a parallel project, except that all subcontractors except the first one obtain zero expected profit as shown by Lemma 1. To achieve system coordination, for each subcontractor, two conditions need to be satisfied simultaneously:

C1: $\Theta_i(\boldsymbol{\theta})\Pi^* = \Pi_i^m(\Psi_i^m, r_i^*, (r_j^*)_{j \in \mathcal{P}_i})$, and C2: $r_i^* = \hat{r}_i^m(\Psi_i^m)$. According to Lemma 1, we consider the case where $\boldsymbol{\theta} \in \Phi_S$. Then, condition C1 is equivalent to conditions $\Pi_1^m(\Psi_1^m, r_1^*, \emptyset) = \theta_1\Pi^*$ and $\Pi_i^m(\Psi_i^m, r_i^*, (r_j^*)_{j \in \mathcal{P}_i}) = 0$, $\forall i \in \{2, \dots, n\}$.

1. Contract FP : $\Pi_i^{FP}(p_i, r_i, (r_j)_{j \in \mathcal{P}_i}) = (p_i \mathbb{E}[e^{-\alpha Z_i/r_i}] - c_i(r_i)) \prod_{j=1}^{i-1} \mathbb{E}[e^{-\alpha Z_j/r_j}]$. Condition C2 results in $\hat{p}_i^{FP} = \frac{(r_i^*)^2 c_i'(r_i^*)}{\alpha \mathbb{E}[Z_i e^{-\alpha Z_i/r_i^*}]}$. Given $p_i = \hat{p}_i^{FP}$ and $r_i = r_i^*$, subcontractor i 's profit discounted to the outset of task i is $\delta_i^{FP} = \frac{(r_i^*)^2 c_i'(r_i^*) \mathbb{E}[e^{-\alpha Z_i/r_i^*}]}{\alpha \mathbb{E}[Z_i e^{-\alpha Z_i/r_i^*}]} - c_i(r_i^*)$. Contract FP achieves system coordination if $\theta_1\Pi^* = \delta_1^{FP}$, $0 = \delta_i^{FP}$, $\forall i \in \{2, \dots, n\}$, and $\boldsymbol{\theta} \in \Phi_S$. As $\delta_i^{FP} > 0$, contract FP never achieves the system coordination.
2. Contracts $TF+$ and TF : $\Pi_i^{TF}(p_i, \beta_i, r_i, (r_j)_{j \in \mathcal{P}_i}) = \Pi_i^{TF+}(p_i, \beta_i, r_i, (r_j)_{j \in \mathcal{P}_i}) = (\beta_i + p_i \mathbb{E}[e^{-\alpha Z_i/r_i}] - c_i(r_i)) \prod_{j=1}^{i-1} \mathbb{E}[e^{-\alpha Z_j/r_j}]$. Condition C2 results in $\hat{p}_i^{TF} = \hat{p}_i^{TF+} = \hat{p}_i^{FP}$. Given $p_i = \hat{p}_i^{TF} = \hat{p}_i^{TF+}$ and $r_i = r_i^*$, subcontractor i 's profit discounted to the outset of task i is $\delta_i^{TF}(\beta_i) = \delta_i^{TF+}(\beta_i) = \beta_i + \delta_i^{FP}$. Contract $TF+$ achieves system coordination if $\theta_1\Pi^* \in [\delta_1^{FP}, \Pi^*]$, $0 \in [\delta_i^{FP}, \Pi^*]$, $\forall i \in \{2, \dots, n\}$, and $\boldsymbol{\theta} \in \Phi_S$. As $\delta_i^{FP} > 0$, contract $TF+$ never achieves the system coordination. Contract TF always achieves system coordination if $\boldsymbol{\theta} \in \Phi_S$. When the system coordinates, we have $\hat{p}_i^{TF} = \hat{p}_i^{FP}$, $\forall i \in [n]$, $\hat{\beta}_1^{TF} = \theta_1\Pi^* - \delta_1^{FP}$, $\hat{\beta}_i^{TF} = -\delta_i^{FP}$, $\forall i \in \{2, \dots, n\}$. As $\delta_1^{FP} = \Pi^*$ in serial projects, we can further simplify $\hat{\beta}_1^{TF}$ as $\hat{\beta}_1^{TF} = -(1 - \theta_1)\Pi^*$.
3. Contract TB : $\Pi_i^{TB}(p_i, \beta_i, r_i, (r_j)_{j \in \mathcal{P}_i}) = (p_i \mathbb{E}[e^{-(\alpha+\beta_i)Z_i/r_i}] - c_i(r_i)) \prod_{j=1}^{i-1} \mathbb{E}[e^{-\alpha Z_j/r_j}]$. Condition C2 results in $\hat{p}_i^{TB}(\beta_i) = \frac{(r_i^*)^2 c_i'(r_i^*)}{(\alpha+\beta_i) \mathbb{E}[Z_i e^{-(\alpha+\beta_i)Z_i/r_i^*}]}$. Given $p_i = \hat{p}_i^{TB}(\beta_i)$ and $r_i = r_i^*$, subcontractor i 's profit discounted to the outset of task i is $\delta_i^{TB}(\beta_i) = \frac{(r_i^*)^2 c_i'(r_i^*) \mathbb{E}[e^{-(\alpha+\beta_i)Z_i/r_i^*}]}{(\alpha+\beta_i) \mathbb{E}[Z_i e^{-(\alpha+\beta_i)Z_i/r_i^*}]} - c_i(r_i^*)$. Let $\underline{\delta}_i^{TB} = \min_{\beta_i \geq 0} \{\delta_i^{TB}(\beta_i)\}$, $\bar{\delta}_i^{TB} = \max_{\beta_i \geq 0} \{\delta_i^{TB}(\beta_i)\}$ denote the lower and upper bounds of $\delta_i^{TB}(\beta_i)$. Contract TB achieves system coordination if $\theta_1\Pi^* \in [\underline{\delta}_1^{TB}, \bar{\delta}_1^{TB}]$, $0 \in [\underline{\delta}_i^{TB}, \bar{\delta}_i^{TB}]$, $\forall i \in \{2, \dots, n\}$, and $\boldsymbol{\theta} \in \Phi_S$. As $\underline{\delta}_i^{TB} > 0$, contract TB never achieves the system coordination.
4. Contract CS : $\Pi_i^{CS}(p_i, \beta_i, r_i, (r_j)_{j \in \mathcal{P}_i}) = (p_i \mathbb{E}[e^{-\alpha Z_i/r_i}] - (1 - \beta_i)c_i(r_i)) \prod_{j=1}^{i-1} \mathbb{E}[e^{-\alpha Z_j/r_j}]$. Condition C2 results in $\hat{p}_i^{CS}(\beta_i) = (1 - \beta_i)\hat{p}_i^{FP}$. Given $p_i = \hat{p}_i^{CS}(\beta_i)$ and $r_i = r_i^*$, subcontractor i 's profit discounted to the outset of task i is $\delta_i^{CS}(\beta_i) = (1 - \beta_i)\delta_i^{FP}$. The profit of subcontractor i under contract CS , $\delta_i^{CS}(\beta_i)$, is a monotone function of β_i . Besides, we have $\delta_i^{CS}(\beta_i = 1) = 0$, and $\delta_i^{CS}(\beta_i = 0) = \delta_i^{FP}$. As $\delta_1^{FP} = \Pi^*$, contract CS always achieves system coordination if $\boldsymbol{\theta} \in \Phi_S$. When the system coordinates, we have $\hat{p}_i^{CS} = (1 - \hat{\beta}_i^{CS})\hat{p}_i^{FP}$, $\forall i \in [n]$, $\hat{\beta}_1^{CS} = 1 - \theta_1$, $\hat{\beta}_i^{CS} = 1$, $\forall i \in \{2, \dots, n\}$. \square

Proof of Proposition 4 We first show that when the system is coordinated, any subcontractor $j \in \mathcal{N}_2$ must receive zero expected profit by deriving a contradiction. We then show that zero expected profit for any subcontractor $j \in \mathcal{N}_2$ can only occur when $\boldsymbol{\theta} \in \Phi^{TF}$ and derive corresponding coordinating contract terms, where Φ^{TF} is defined in Proposition 4.

Assume there exists an equilibrium, where the system is coordinated and there exists a subcontractor $l \in \mathcal{N}_2$ with a positive equilibrium expected profit. Consider the negotiation between the client and subcontractor i where $i \in \mathcal{P}_l$. In other words, task i is the precedent task of task l . Task i must exist; otherwise, l does not belong to \mathcal{N}_2 . Assume $r_j = r_j^*$ for $j \in [n] \setminus \{i\}$. Let \hat{r}_i^{TF} denote the work rate resulting from this negotiation. By the coordination assumption, \hat{r}_i^{TF} should be equal to the system optimal work rate r_i^* . We will derive a contradiction by showing $\hat{r}_i^{TF} \neq r_i^*$.

Given work rate r_j^* and contract terms $\{p_j, \beta_j\}$ for $j \in [n] \setminus \{i\}$, the sum of the client's and subcontractor i 's profits is given by $\Pi_{i,C}^{TF}(r_i) \equiv Q\mathbb{E}[e^{-\alpha S_D}] - c_i(r_i)\mathbb{E}[e^{-\alpha S_i}] - \sum_{j \in [n] \setminus \{i\}} \left(\beta_j + p_j \mathbb{E}[e^{-\alpha T_j}] \right) \mathbb{E}[e^{-\alpha S_j}] \Big|_{r_j=r_j^*, j \in [n] \setminus \{i\}}$. Contract TF can induce subcontractor i to exert any positive work rate r_i by setting the final payment $p_i = (r_i)^2 c'_i(r_i) / (\alpha \mathbb{E}[Z_i e^{\alpha Z_i / r_i}])$, while achieving an arbitrary profit division by adjusting the down payment β_i . Therefore, $\Pi_{i,C}^{TF}(r_i)$ will be maximized through bargaining, i.e., $\Pi_{i,C}^{TF}(\hat{r}_i^{TF}) = \max_{r_i} \{\Pi_{i,C}^{TF}(r_i)\}$. As \hat{r}_i^{TF} is finite and nonzero, the following first-order condition must be satisfied: $\frac{d\Pi_{i,C}^{TF}(r_i)}{dr_i} \Big|_{r_i=\hat{r}_i^{TF}} = Q \frac{\partial \mathbb{E}[e^{-\alpha S_D}]}{\partial r_i} - c'_i(r_i)\mathbb{E}[e^{-\alpha S_i}] - \sum_{j \in \{j' \in [n] | i \in \mathcal{P}_{j'}\}} \left(\beta_j + p_j \mathbb{E}[e^{-\alpha T_j}] \right) \frac{\partial \mathbb{E}[e^{-\alpha S_j}]}{\partial r_i} \Big|_{r_i=\hat{r}_i^{TF}, r_j=r_j^*, j \in [n] \setminus \{i\}} = 0$. Comparing this condition with the first-order condition in (5), we have $\partial \Pi(\mathbf{r}) / \partial r_i \Big|_{r_i=\hat{r}_i^{TF}, r_j=r_j^*, j \in [n] \setminus \{i\}} > 0$ and therefore $\hat{r}_i^{TF} \neq r_i^*$. This is because that the expected discount rate $\mathbb{E}[e^{-\alpha S_j}]$ is strictly increasing in r_i , $j \in \{j' \in [n] | i \in \mathcal{P}_{j'}\}$ and at least one subcontractor whose task is task i 's successor tasks (i.e., subcontractor l) has strictly positive equilibrium profit. Thus, in equilibrium, any subcontractor $j \in \mathcal{N}_2$ must receive zero expected profit.

To achieve system coordination, for each subcontractor, two extra conditions need to be satisfied simultaneously: C1: $\Theta_i(\boldsymbol{\theta})\Pi^* = \Pi_i^{TF}(p_i, \beta_i, r_i, \{r_j\}_{j \in \mathcal{P}_i})$, and C2: $r_i^* = \hat{r}_i^{TF}(p_i)$. Recall that for any $i \in \mathcal{N}_2$, condition $\Pi_i^{TF}(p_i, \beta_i, r_i, \{r_j\}_{j \in \mathcal{P}_i}) = 0$ must be satisfied in equilibrium. Combining this condition with C1, we have $\Theta_i(\boldsymbol{\theta}) = 0$ for $i \in \mathcal{N}_2$. As we only consider the case where at most one subcontractor has the full bargaining power over the client, contract TF achieves system coordination when $\boldsymbol{\theta} \in \Phi^{TF} = \{\boldsymbol{\theta} \mid \theta_i \in [0, 1), i \in \mathcal{N}_1, \theta_j = 0, j \in \mathcal{N}_2\} \cup \{\boldsymbol{\theta} \mid \exists i \in \mathcal{N}_1, \theta_i = 1, \theta_j \in [0, 1), j \in [n] \setminus \{i\}\}$.

When $\boldsymbol{\theta} \in \Phi^{TF}$, the first order condition in C2 results in $\hat{p}_i^{TF} = (r_i^*)^2 c'_i(r_i^*) / (\alpha \mathbb{E}[Z_i e^{\alpha Z_i / r_i^*}]) = \hat{p}_i^{FP}$, where \hat{p}_i^{FP} is given in Proposition 2. Given $\boldsymbol{\theta} \in \Phi^{TF}$ and $p_i = \hat{p}_i^{TF}$, the subcontractor's profit is $\beta_i + \delta_i^{FP}$ where δ_i^{FP} is given in equation (8). Condition (1) requires that $\hat{\beta}_i^{TF} = \Theta_i(\boldsymbol{\theta})\Pi^* - \delta_i^{FP}$. Specifically, for $i \in \mathcal{N}_2$, we have $\hat{\beta}_i^{TF} = -\delta_i^{FP}$. \square

Proof of Proposition 5 Under the delayed payment regime, we give a complete proof for projects with multiple parallel tasks and omit the counterpart for projects with multiple serial tasks.

Contracts FP and $TF+$ are special cases of contract TF . A necessary condition for coordination under contract TF is also a necessary condition for coordination under contract FP or $TF+$. Therefore, we do not need to analyze contracts FP and $TF+$ separately.

For contracts TF , TB , and CS , we will show that when the system is coordinated, any subcontractor must receive a zero final payment. As the delayed final payments must be nonzero, system coordination cannot be achieved under the delayed payment regime. Assume there exists an equilibrium, where the system is coordinated and there exists a subcontractor l who receives a nonzero final payment (i.e., $p_l > 0$). Given work rate r_j^* and contract terms Ψ_j^m for $j \in [n] \setminus \{i\}$, consider the negotiation between the client and subcontractor i , where $i \neq l$. Let $\hat{r}_i^{m,D}$ denote the work rate resulting from this negotiation. By the coordination assumption, $\hat{r}_i^{m,D}$ should be equal to the system optimal work rate r_i^* . We will derive a contradiction by showing $\hat{r}_i^{m,D} < r_i^*$.

1. Contract TF : $\Pi_i^{TF,D}(p_i, \beta_i, \mathbf{r}) = p_i \mathbb{E}[e^{-\alpha S_D}] + \beta_i - c_i(r_i)$. The sum of the client's and subcontractor i 's profit is given by $\Pi_{i,C}^{TF,D}(r_i) \equiv (Q - \sum_{j \in [n] \setminus \{i\}} p_j) \mathbb{E}[e^{-\alpha S_D}] - c_i(r_i) - \sum_{j \in [n] \setminus \{i\}} \beta_j$. Contract TF can induce subcontractor i to exert any positive work rate r_i by setting the final payment p_i , while achieving an arbitrary profit division by adjusting the down payment β_i . Therefore, $\Pi_{i,C}^{TF,D}(r_i)$ will be maximized through bargaining, i.e., $\Pi_{i,C}^{TF,D}(\hat{r}_i^{TF,D}) = \max_{r_i} \{\Pi_{i,C}^{TF,D}(r_i)\}$. The equilibrium work rate $\hat{r}_i^{TF,D}$ can be verified to be strictly smaller than r_i^* as $p_l > 0$, $l \neq i$.
2. Contract TB : $\Pi_i^{TB,D}(p_i, \beta_i, \mathbf{r}) = p_i \mathbb{E}[e^{-(\alpha+\beta_i)S_D}] - c_i(r_i)$. Subcontractor i 's profit when induced to exert r_i given β_i is $\delta_i^{TB,D}(\beta_i, r_i) = \mathbb{E}[e^{-(\alpha+\beta_i)S_D}] c'_i(r_i) / (\partial \mathbb{E}[e^{-(\alpha+\beta_i)S_D}] / \partial r_i) - c_i(r_i)$. The sum of the client's and subcontractor i 's profit is given by $\Pi_{i,C}^{TB,D}(r_i) \equiv Q \mathbb{E}[e^{-\alpha S_D}] - c_i(r_i) - \sum_{j \in [n] \setminus \{i\}} p_j \mathbb{E}[e^{-(\alpha+\beta_j)S_D}]$. Let $\{\hat{p}_i^{TB,D}, \hat{\beta}_i^{TB,D}\}$ denote the equilibrium contract terms for subcontractor i . Let $\tilde{r}_i^{TB,D} = \arg \max_{r_i} \{\Pi_{i,C}^{TB,D}(r_i)\}$, which satisfies $\tilde{r}_i^{TB,D} < r_i^*$ as $p_l > 0$, $l \neq i$. When $\theta_i \in [\underline{\delta}_i^{TB,D} / \Pi_{i,C}^{TB,D}(\tilde{r}_i^{TB,D}), 1]$, where $\underline{\delta}_i^{TB,D} = \min_{\beta_i \geq 0} \delta_i^{TB,D}(\beta_i, \tilde{r}_i^{TB,D})$, we have $\hat{r}_i^{TB,D} = \tilde{r}_i^{TB,D} < r_i^*$. So we only consider the case where $\theta_i < \underline{\delta}_i^{TB,D} / \Pi_{i,C}^{TB,D}(\tilde{r}_i^{TB,D})$. Assume $\hat{r}_i^{TB,D} > \tilde{r}_i^{TB,D}$. As $\hat{r}_i^{TB,D}$ and $\hat{\beta}_i^{TB,D}$ maximize the Nash product given in (6), we have $(\theta_i \Pi_{i,C}^{TB} - \delta_i^{TB,D}) \frac{\partial \delta_i^{TB,D}}{\partial r_i} + (1 - \theta_i) \delta_i^{TB,D} \frac{d \Pi_{i,C}^{TB,D}}{d r_i} \Big|_{r_i = \hat{r}_i^{TB,D}, \beta_i = \hat{\beta}_i^{TB,D}} = 0$. From this equation and the assumption $\hat{r}_i^{TB,D} > \tilde{r}_i^{TB,D}$, it can be shown that $\theta_i \Pi_{i,C}^{TB,D}(\hat{r}_i^{TB,D}) - \delta_i^{TB,D}(\hat{\beta}_i^{TB,D}, \hat{r}_i^{TB,D}) > 0$. We have $\delta_i^{TB,D}(\hat{\beta}_i^{TB,D}, \tilde{r}_i^{TB,D}) < \delta_i^{TB,D}(\hat{\beta}_i^{TB,D}, \hat{r}_i^{TB,D})$ and $\Pi_{i,C}^{TB,D}(\tilde{r}_i^{TB,D}) > \Pi_{i,C}^{TB,D}(\hat{r}_i^{TB,D})$. There exists an $\theta'_i \in [\underline{\delta}_i^{TB,D} / \Pi_{i,C}^{TB,D}(\tilde{r}_i^{TB,D}), 1]$, such that $\theta'_i \Pi_{i,C}^{TB,D}(\tilde{r}_i^{TB,D}) = \delta_i^{TB,D}(\hat{\beta}_i^{TB,D}, \tilde{r}_i^{TB,D})$. Besides, we have $\theta_i \Pi_{i,C}^{TB,D}(\hat{r}_i^{TB,D}) - \delta_i^{TB,D}(\hat{\beta}_i^{TB,D}, \hat{r}_i^{TB,D}) < \theta_i \Pi_{i,C}^{TB,D}(\tilde{r}_i^{TB,D}) - \delta_i^{TB,D}(\hat{\beta}_i^{TB,D}, \tilde{r}_i^{TB,D}) = -(\theta'_i - \theta_i) \Pi_{i,C}^{TB,D}(\tilde{r}_i^{TB,D}) < 0$, where the last inequality holds because $\theta'_i \geq \underline{\delta}_i^{TB,D} / \Pi_{i,C}^{TB,D}(\tilde{r}_i^{TB,D}) > \theta_i$. This contradicts the previous result that $\theta_i \Pi_{i,C}^{TB,D}(\hat{r}_i^{TB,D}) - \delta_i^{TB,D}(\hat{\beta}_i^{TB,D}, \hat{r}_i^{TB,D}) > 0$. Thus, $\hat{r}_i^{TB,D} \leq \tilde{r}_i^{TB,D} < r_i^*$.

3. Contract CS : $\Pi_i^{CS,D}(p_i, \beta_i, \mathbf{r}) = p_i \mathbb{E}[e^{-\alpha S_D}] - (1 - \beta_i)c_i(r_i)$. Subcontractor i 's profit when induced to exert a work rate of r_i given β_i is $\delta_i^{CS,D}(\beta_i, r_i) = (1 - \beta_i)(\mathbb{E}[e^{-\alpha S_D}]c'_i(r_i)/(\partial \mathbb{E}[e^{-\alpha S_D}]/\partial r_i) - c_i(r_i))$. The sum of the client's and subcontractor i 's profit is given by $\Pi_{i,C}^{CS,D}(r_i) \equiv (Q - \sum_{j \in [n] \setminus \{i\}} p_j) \mathbb{E}[e^{-\alpha S_D}] - c_i(r_i) - \sum_{j \in [n] \setminus \{i\}} \beta_j c_j(r_j)$. Let $\tilde{r}_i^{CS,D} = \arg \max_{r_i} \{\Pi_{i,C}^{CS,D}(r_i)\}$, which satisfies $\tilde{r}_i^{CS,D} < r_i^*$ as $p_l > 0, l \neq i$. As $\delta_i^{CS,D}(1, \tilde{r}_i^{CS,D}) = 0$ and $\delta_i^{CS,D}(0, \tilde{r}_i^{CS,D}) \geq \Pi_{i,C}^{CS,D}(\tilde{r}_i^{CS,D})$, contract CS can induce subcontractor i to exert the work rate $\tilde{r}_i^{CS,D}$ and achieve an arbitrary profit division by adjusting p_i and β_i . Therefore, $\Pi_{i,C}^{CS,D}(r_i)$ will be maximized through bargaining, i.e., $\hat{r}_i^{CS,D} = \tilde{r}_i^{CS,D}$. Therefore, $\hat{r}_i^{CS,D} < r_i^*$.

Therefore, any subcontractor must receive a zero final payment when the system is coordinated, which completes the proof. \square

EC.2. Modeling and Analysis of Sequential Negotiation

At the start of task i , the realized information is $\{\Psi_j^m, t_j, c_j\}_{j=1}^{i-1}$, where Ψ_j^m is the contract term with subcontractor j and t_j and c_j are the realized duration and cost of task j . The client's disagreement point is given by $\underline{\Pi}_C^{m,i}(\{\Psi_j^m, t_j, c_j\}_{j=1}^{i-1}) = -\sum_{j=1}^{i-1} \rho^m(\Psi_j^m, t_j, c_j) e^{-\alpha \sum_{l=1}^j t_l}$. Subcontractor i 's disagreement point is his external earnings while waiting for the completion of precedent tasks, which is denoted as $\underline{\Pi}_i(\{t_j\}_{j=1}^{i-1})$.

Although the disagreement points depend on the realized information of past task duration, cost, and payment, we will show that the negotiated contract term $\hat{\Psi}_i^m$ is independent of the realized information $\{\Psi_j^m, t_j, c_j\}_{j=1}^{i-1}$ for any $i \in [n]$. The intuition is that subcontractors' earning when waiting for precedent tasks to be completed and the client's payments for completed tasks are essentially a *sunk cost* instead of an *opportunity cost* and therefore does not affect the negotiation outcome. Assume that the negotiated contract terms for tasks $i+1$ to n (i.e., $\{\hat{\Psi}_j^m\}_{j=i+1}^n$) are independent of $\{\Psi_l^m, t_l, c_l\}_{l=1}^{i-1}$. Consider the two-stage game between the client and subcontractor i . In the implementation stage, given contract term Ψ_i^m , subcontractor i chooses an optimal work rate $\hat{r}_i^m(\Psi_i^m)$ to maximize his profit. By exerting work rate r_i , subcontractor i 's expected profit is given by $\Pi_i^m(\Psi_i^m, r_i, \{t_j\}_{j=1}^{i-1}) = \left(\mathbb{E}[\rho^m(\Psi_i^m, T_i, C_i(r_i, T_i)) e^{-\alpha T_i}] - c_i(r_i) \right) e^{-\alpha \sum_{j=1}^{i-1} t_j} + \underline{\Pi}_i(\{t_j\}_{j=1}^{i-1})$, which is concave in r_i . We can obtain subcontractor i 's optimal work rate $\hat{r}_i^m(\Psi_i^m)$.

Consider the contracting stage. Given the contract term Ψ_i^m , work rate r_i , realized information $\{\Psi_j^m, t_j, c_j\}_{j=1}^{i-1}$, and anticipated contract terms $\{\hat{\Psi}_j^m\}_{j=i+1}^n$, the client's profit is given by $\Pi_C^{m,i}(\Psi_i^m, r_i, \{\Psi_j^m, t_j, c_j\}_{j=1}^{i-1}, \{\hat{\Psi}_j^m\}_{j=i+1}^n)$
 $= \left(Q \mathbb{E}[e^{-\alpha \sum_{j=i}^n T_j}] - \mathbb{E}[\rho^m(\Psi_i^m, T_i, C_i(r_i, T_i)) e^{-\alpha T_i}] - \sum_{j=i+1}^n \mathbb{E}[\rho^m(\hat{\Psi}_j^m, T_j, C_j(r_j, T_j)) e^{-\alpha T_j}] \mathbb{E}[e^{-\alpha \sum_{l=i}^{j-1} T_l}] \right)$
 $\cdot e^{-\alpha \sum_{j=1}^{i-1} t_j} + \underline{\Pi}_C^{m,i}(\{\Psi_j^m, t_j, c_j\}_{j=1}^{i-1}) \Big|_{r_j = \hat{r}_j^m(\hat{\Psi}_j^m), j \in \{i+1, \dots, n\}}$. Applying the Nash bargaining solution, which states that if an agreement is reached, the negotiated contract term Ψ_i^m solves the following

problem: $\max_{\Psi_i^m} \{ [\Pi_i^m - \underline{\Pi}_i]^{\theta_i} [\Pi_C^{m,i} - \underline{\Pi}_C^{m,i}]^{1-\theta_i} \mid r_i = \hat{r}_i^m(\Psi_i^m), \Pi_i^m \geq \underline{\Pi}_i, \Pi_C^{m,i} \geq \underline{\Pi}_C^{m,i} \}$. Simplify the objective to

$$\left[\mathbb{E}[\rho^m(\Psi_i^m, T_i, C_i(r_i, T_i))e^{-\alpha T_i}] - c_i(r_i) \right]^{\theta_i} \left[\tilde{Q}_i \mathbb{E}[e^{-\alpha T_i}] - \mathbb{E}[\rho^m(\Psi_i^m, T_i, C_i(r_i, T_i))e^{-\alpha T_i}] \right]^{1-\theta_i} e^{-\alpha \sum_{j=1}^{i-1} t_j},$$

where $\tilde{Q}_i = Q\mathbb{E}[e^{-\alpha \sum_{j=i+1}^n T_j}] - \sum_{j=i+1}^n \mathbb{E}[\rho^m(\hat{\Psi}_j^m, T_j, C_j(r_j, T_j))e^{-\alpha T_j}] \mathbb{E}[e^{-\alpha \sum_{l=i+1}^{j-1} T_l}]$. As we assume that the anticipated contract terms $\{\hat{\Psi}_j^m\}_{j=i+1}^n$ are irrelevant to the realized information $\{\Psi_l^m, t_l, c_l\}_{l=1}^{i-1}$, the negotiated contract term $\hat{\Psi}_i^m$ also is. It is straightforward to verify that this claim holds for the boundary case where $i = n$. That is, the negotiated contract term $\hat{\Psi}_n^m$ is irrelevant to the realized information $\{\Psi_j^m, t_j, c_j\}_{j=1}^{n-1}$. According to an inductive argument, our claim that the negotiated contract term $\hat{\Psi}_i^m$ is irrelevant to the realized information $\{\Psi_j^m, t_j, c_j\}_{j=1}^{i-1}$ for any $i \in [n]$ is true. Based on this irrelevance property, we next give a formal proof of Lemma 2 and Proposition 7.

Proof of Lemma 2 Analogous to the proof of Lemma 1, the proof of Lemma 2 consists of two steps. We first show that when the system is coordinated, the expected profit of all subcontractors except for the first one should be equal to their disagreement points (i.e., $\Pi_2^m - \underline{\Pi}_2 = \dots = \Pi_n^m - \underline{\Pi}_n = 0$). The detailed proof for this step is omitted.

We then show that this can only occur when $\theta_2 = \dots = \theta_n = 0$ for the sequential negotiation. Specifically, consider the negotiation between the client and subcontractor i ($i \in \{2, \dots, n\}$) given the realized duration, cost, and payment information of previous tasks. Assume that all the other subcontractors are induced to exert the system optimal work rate. One necessary condition to achieve system coordination is $\theta_i (\Pi_i^m + \Pi_C^{m,i} - \underline{\Pi}_i - \underline{\Pi}_C^{m,i}) \big|_{\mathbf{r}=\mathbf{r}^*} = \Pi_i^m - \underline{\Pi}_i \big|_{\mathbf{r}=\mathbf{r}^*}$ or, equivalently, $\theta_i \left(\tilde{Q}_i \mathbb{E}[e^{-\alpha T_i}] - c_i(r_i) \right) e^{-\alpha \sum_{j=1}^{i-1} t_j} = \Pi_i^m - \underline{\Pi}_i \big|_{\mathbf{r}=\mathbf{r}^*}$. As $\Pi_{i+1}^m - \underline{\Pi}_{i+1} = \dots = \Pi_n^m - \underline{\Pi}_n = 0$, we have $\tilde{Q}_i \mathbb{E}[e^{-\alpha T_i}] - c_i(r_i) = Q\mathbb{E}[e^{-\alpha \sum_{j=i}^n T_j}] - \sum_{j=i}^n c_j(r_j) \mathbb{E}[e^{-\alpha \sum_{l=i}^{j-1} T_l}]$, which is strictly larger than zero when $\mathbf{r} = \mathbf{r}^*$ for any $i \in \{2, \dots, n\}$. So, the condition $\theta_i = 0$ has to be satisfied for $i \in \{2, \dots, n\}$. \square

Proof of Proposition 7 Consider the negotiation between the client and subcontractor i given the realized information of previous tasks. Assume that all the other subcontractors are induced to exert the system optimal work rate. To achieve system coordination, two conditions need to be satisfied simultaneously: C1: $\theta_i \left(\tilde{Q}_i \mathbb{E}[e^{-\alpha T_i}] - c_i(r_i) \right) e^{-\alpha \sum_{j=1}^{i-1} t_j} = \Pi_i^m(p_i, r_i, (t_j)_{j=1}^{i-1}) - \underline{\Pi}_i(\{t_j\}_{j=1}^{i-1}) \big|_{\mathbf{r}=\mathbf{r}^*}$, and C2: $r_i^* = \hat{r}_i^m(\Psi_i^m)$. According to Lemma 2, we consider the case where $\boldsymbol{\theta} \in \Lambda_S$. Then, condition C1 is equivalent to condition $\mathbb{E}[\rho^m(\Psi_1^m, Z_1/r_1^*, C_1(r_1^*, Z_1/r_1^*))e^{-\alpha Z_1/r_1^*}] - c_1(r_1^*) = \theta_1 \Pi^*$ if $i = 1$ and $\mathbb{E}[\rho^m(\Psi_i^m, Z_i/r_i^*, C_i(r_i^*, Z_i/r_i^*))e^{-\alpha Z_i/r_i^*}] - c_i(r_i^*) = 0$ if $i \in \{2, \dots, n\}$. Notice that both conditions C1 and C2 are irrelevant to the realized information. This is a consequence of the irrelevance property we identified before. Therefore, we do not need to check the equilibrium conditions using the backward induction. Instead, we could examine the equilibrium conditions for all subcontractors simultaneously as in the proof of Proposition 3. The coordinating result can be directly obtained. \square