Optimal task design: to integrate or separate planning and implementation?[1][2]

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Abstract

Integrating planning and implementation, by having one agent perform both tasks, may be effective in encouraging planning activity whose outcome is not observable. Emphasizing its information generating role, we find that planning activity is best encouraged by partially integrating the tasks. This is because the value of information is non-monotonic in the degree of task integration. Therefore, the threat of using a second agent to implement the project may relax the moral hazard constraint associated with the planning task. The project size is distorted to increase the value of information, and there can be over-investment relative to the first best.

1 Introduction

The planning stage of a project or the development stage in a product cycle often consists of acquiring information essential for successful implementation, for example, information about the production environment or project profitability. In many instances this information is not contractible, which creates a moral hazard problem in the planning stage. Furthermore, if the outcome of planning activity is private information of the agent, there is also a subsequent hidden information problem at the implementation stage. The optimal task-design problem would have to address both of these issues simultaneously, and the impact of the informational content of planning activity on task design has not been emphasized much in the literature. A notable exception is the insightful paper by Lewis and Sappington (1997). They argue that it may be optimal to completely separate the planning and implementation tasks by assigning these tasks to two different agents. Their insight is that information learned in the implementation stage can be used to discipline the planning agent. Using a hidden-information model with observable cost and an unobservable cost-reducing effort, they show that if the payment to the planning agent can be based on the implementation cost, a principal can costlessly provide incentives for planning activity as well as truthful revelation of the planning information by fully separating the tasks.

In this paper, we want to argue that it is also important to study this task design problem where the principal cannot base the planning agent's contract on implementation cost. As noted by Laffont and Tirole (1988) in a related context, it may not be feasible or desirable to base the planning agent's payment on the cost generated by the implementation agent. It could be the case that implementation takes a long time and it is not feasible to delay paying or penalizing the planning agent until then. The cost data at the implementation stage can be subject to manipulation by the principal and the implementation agent at the expense of the planning agent. In the presence of cost uncertainty and risk aversion or limited penalties, fully separating tasks may not be optimal. In sum, while the implementation cost may be a useful incentive device in contracting with the planning agent, in many cases its scope will be limited.

One way to reward an agent for planning effort is then by integrating the two tasks and letting the same agent do both. The agent engages in the planning activity anticipating information-based rent in the implementation phase.[1] This is the same intuition as in the system of patents, which is also a second best response to reward innovative ideas that can not be directly traded. The reward for innovation is administered by granting monopoly rights to the patent holder. In this paper, however, we argue that *partially* integrating the tasks of planning and implementation may be optimal since it provides stronger incentive for acquiring planning information.

To illustrate our ideas, we extend the standard hidden information model developed by Baron and Myerson (1982), where project size is observable but not project cost. Planning consists of acquiring information about an implementation cost parameter. In the planning stage, the agent can shirk, remain uninformed, and yet claim to be informed.[2] We show that partial integration of tasks occurs in equilibrium in that the principal invites a second agent to implement the project when the cost parameter is above a cut-off level. For low costs, increasing the cut-off level or the region of integration makes planning activity more attractive, but raising integration above a certain level discourages planning effort by increasing the payoff from remaining uninformed. This implies that the value of information to the planning agent from learning the project cost is non-monotonic in the region of integration, and that partial integration is optimal.

It is well known that in some instances the agent performing R&D also implements the project, while in others a different agent does the implementation. Similarly, a multinational may hire a local agent to carry out preliminary studies of local conditions, and may or may not send a manager from the center to establish and run their local subsidiary. Our analysis implies that incentive to acquire information plays an important role in the replacement decision. Often, the division of tasks seem to occur according to professions, e.g., primary care physicians or "gate keepers" and specialists in health care, solicitors and barristers in the UK legal system, analysts and fund managers. Our results suggest that the borders of these professions may be determined to some extent by considerations of in-

[1] See Lewis and Sappington (1997), and Crémer, Khalil, and Rochet (1998a) for the role of information-based rent in providing planning incentives.

[2] Just as in Lewis and Sappington (1993), the possibility of ignorance, if the agent does not acquire information, introduces a mass point at the mean of the distribution. They show how this has significant implications on optimal quantity schedules. We emphasize its role in determining the opportunity cost of acquiring information, which implies that the value of information function is non-monotonic in the region of integration.

formation acquisition. More generally, the roles of the collectors of information may extend beyond what is implied by the principle of comparative advantage and specialization in the traditional sense.

We note that our findings are related to pre-existing results. It has been shown that the threat of shut-down or termination, especially when a replacement agent is available, can reduce the cost of inducing information revelation (see e.g., Demski, Sappington and Spiller (1987) and Sen (1996)). However, these papers do not consider a first-stage moral hazard problem, which can make it costly to replace the first agent. This is shown in the literature on second sourcing, which considers this first-stage moral hazard problem as well like we do. Various authors have shown that termination and replacement may still be optimal but at the cost of tightening the moral hazard constraint. The possible use of a second source can discourage first stage production (Anton and Yao (1987)), investment (Laffont and Tirole (1988)), or R&D effort (Riordan and Sappington (1989)). On the contrary, we show that separation and replacement can provide stronger incentive for planning activity and relax the moral hazard constraint when the up-front investment is in information gathering instead of traditional cost reduction. Thus, introducing another agent for implementation can relax not only the information revelation constraint but also the moral hazard constraint in planning activity.

In addition to Lewis and Sappington (1997), discussed already, others have also investigated the problem of providing incentive to acquire information. Lambert (1986) studies the problem of providing incentive to a manager to learn about riskiness of projects, and Crémer, Khalil, Rochet (1998a) study the properties of production contracts that motivate or deter information acquisition.[3] These papers do not address the issue of task separation. Hirao (1993) shows that the decision to integrate or separate tasks depends on what the principal knows about the agent's information. Whereas Hirao has found either separation or integration of tasks to be optimal, we demonstrate the optimality of partial integration. This is significant since then the decision to separate or integrate depends on the outcome of the planning stage, which may be more appealing.

Our message is complementary to that of Arrow (1975), which says that upstream vertical integration may occur to acquire critical planning information. We emphasize the

[3] Brocas and Carrillo (2004) show that individuals may be willing to acquire information to be able to influence others' decisions.

need for downstream integration of tasks to encourage upstream units to acquire planning information. Aghion and Tirole (1997) point out that allocation of authority in an organization influences an agent's initiative or incentive to acquire information, and Dewatripont and Tirole (1999) argue that creation of advocates for and against issues provides the best incentive to acquire information when there are competing causes.[4]

Riordan and Sappington (1987), Baron and Besanko (1992) and Gilbert and Riordan (1995) show that complementarity of tasks and correlation between private information in two stages of production can determine if it is optimal to integrate or separate tasks. Dana (1993) also points out the importance of correlation between private information in determining the integration of horizontal tasks. These papers do not consider information acquisition.

The rest of the paper is organized as follows. In section 2, we present the base model. Section 3 is the main section where we develop the problem faced by the principal and present the main results. In section 4, we explore some extensions and conclude the paper.

2 Model

A principal needs to hire agents to accomplish a project, and we assume all parties are risk neutral. The project involves two phases or tasks, *planning* and *implementation*. The principal may potentially deal with two agents, $A1$ and $A2$. If he chooses the same agent for both tasks, we say that he has chosen task *integration*. If he chooses one agent for planning and another for implementation, we say that he has chosen task *separation*. The principal values the project according to the function $V(q)$, where $q \geq 0$ is the size of the project. The function $V(\cdot)$ is strictly concave, twice differentiable on $[0, +\infty)$, and satisfies the Inada conditions, $V'(0) = +\infty$ and $V'(+\infty) = 0$. The cost of the project is βq, which is borne by the agent. We can interpret this as the agent's cost of effort for implementing a project of size q, and it depends on the state or environment, which is parameterized by β. In return for completing the project, the principal pays the agent a non-negative monetary transfer t.

The parameter β is drawn from the interval $[\underline{\beta}, \bar{\beta}]$ according to the distribution function

[4] There is also a literature on eliciting information using multiple experts. The classic reference is Crawford and Sobel (1982) and recent contributions can be found in Wolinsky (2002).

$F(\beta)$, with the associated density function $f(\beta)$, which is differentiable and strictly positive. We make the standard assumption that $F(\beta)/f(\beta)$ is non-decreasing. Unless otherwise stated, the expectation operator $E[\cdot]$ will be used with respect to this distribution, and we define its mean by

$$\tilde{\beta} \stackrel{\text{def}}{=} E(\beta) = \int_{\underline{\beta}}^{\bar{\beta}} \beta f(\beta) d\beta.$$

Before introducing our model of possible separation of planning and implementation, we briefly present two well-known single-agent benchmarks: the full-information case and the informed-agent or Baron-Myerson (1982) case. If β is common knowledge at the outset, the principal implements the efficient project size, denoted by $q^*(\beta)$, which satisfies the following condition:

$$V'(q^*(\beta)) \stackrel{\text{def}}{=} \beta \qquad \forall \beta. \tag{1}$$

The agent receives just his reservation payoff. Next, if β is private information to the agent at the outset, the principal deals with an informed agent, while his belief on β is common knowledge and given by $F(\beta)$. Then the optimal project size, denoted by $q^b(\beta)$, satisfies the following condition:

$$V'(q^b(\beta)) \stackrel{\text{def}}{=} \beta + \frac{F(\beta)}{f(\beta)} \qquad \forall \beta. \tag{2}$$

It is easily checked that $q^b(\beta)$ is non-increasing, $q^b(\beta) < q^*(\beta)$ for all $\beta > \underline{\beta}$, and $q^b(\underline{\beta}) = q^*(\underline{\beta})$. As is well known, the agent commands an information rent, and the principal distorts the project size downward to reduce this rent.

Returning to our model, where all three parties share the same belief $F(\beta)$ about β, the principal first offers publicly observable contracts to $A1$ and $A2$. The contract specifies project size and payments, as well as the separation-integration policy based on what the agent reports after the planning task. The planning task is for $A1$ to identify the profitability of a project, which we assume to be determined by the cost parameter β.[5] Given the contracts, $A1$ decides whether to gather information on β. If he does, it costs him $c > 0$ and he learns β without error.[6] This is his only opportunity to learn the cost parameter β. If $A1$ decides not to gather information, he will have to implement the project without knowing β if he implements the project. This simple and insightful way to model planning was first

[5] We argue in the conclusion section that the task design issues we raise remain even if the principal could introduce ex ante competition to dissipate rent instead of an exclusive contract with one agent.

[6] We discuss imperfect learning in the conclusion section.

introduced by Lewis and Sappington (1993), and it allows us to focus on the information content of planning activity that is critical in making implementation decisions.[7]

To make planning or information gathering relevant in our model, we impose the following assumptions. The first two assumptions make information valuable to the principal while the last assumption makes information valuable to the agent. The last assumption also implies that the principal faces a moral hazard problem in the planning task followed by an adverse selection problem in the implementation task.

- If the choice were available, the principal would prefer to hire an informed agent rather than an uninformed agent.[8]
- The planning cost c is small enough that it is optimal to induce information gathering.
- The information gathered by the agent is private and unverifiable and the act of information gathering is not observable to the principal.

We assume that $A2$ cannot gather information on β.[9] Thus, the contract with $A2$ is only for the implementation task. The reservation payoffs for all parties are assumed to be zero, and the agents are protected from termination penalties by limited liability protection in that they are free to leave the principal's employment at any time.[10]

[7] This type of information has also been referred to as productive by Crémer, Khalil, and Rochet (1998a). See also Crémer, Khalil, and Rochet (1998b) for the case where information gathering is for strategic reasons only.

[8] His payoff from dealing with an informed agent is derived from the Baron-Myerson contract, while his payoff from dealing with an uninformed agent is derived from the ex ante efficient contract. We assume that

$$E\left[V(q^b(\beta)) - \left(\beta + \frac{F(\beta)}{f(\beta)}\right) q^b(\beta)\right] > V(q^*(\tilde{\beta})) - \tilde{\beta} q^*(\tilde{\beta}).$$

It is possible that this condition does not hold. For more on this issue, see Crémer, Khalil, and Rochet (1998a).

[9] Instead, we could have assumed that $A2$ can also gather information at some cost. We discuss this issue in detail in the conclusion section, and here we briefly outline the intuition. The principal could hire possibly a sequence of agents, each facing a possibility of termination. However, it is not difficult to see that as long as planning cost is positive, there will always be a final agent who will be induced to implement the project without acquiring information. In our model, we simply assume that $A2$ is the final agent.

[10] We assume limited termination penalties, which are common in practice (see for instance Sappington (1983)). Technically, this assumption allows us to avoid a trivial solution of moral hazard with risk neutral agents: making the agents bear all the risk. In addition, we implicitly assume that the agents cannot

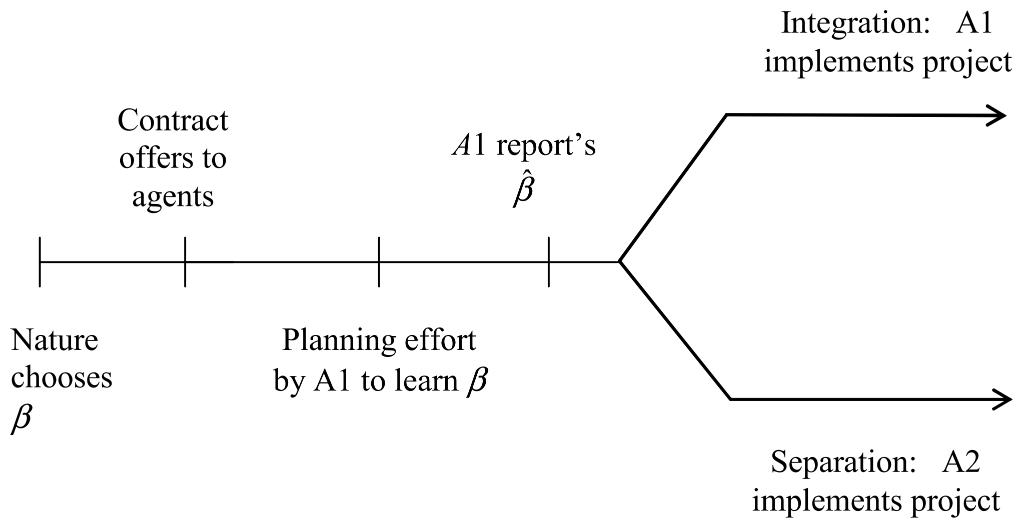

Figure 1: The timing of the game

The timing of the interaction between the principal and agents goes as follows. Under symmetric information, the principal offers or commits to contracts for both agents. Then $A1$ decides whether to acquire information about β at cost c. After the planning task, $A1$ makes a public report of his finding $\hat{\beta} \in [\underline{\beta}, \bar{\beta}]$ which does not have to be truthful since information is private and unverifiable. Based on this announcement and the given contracts, either $A1$ implements the project or he is separated and $A2$ is invited to implement. We summarize the timing of the game in Figure 1 and present details of the principal's contract offers to $A1$ and $A2$ in the next section.

3 The task-design problem

In this section, we first explain contract offers to $A1$ and $A2$ in detail and derive the constraints faced by the principal in his contract offers. We then state the principal's problem and show the optimal contract in a situation where a project has two phases: planning and implementation. A key finding of the paper is the non-monotonicity in

implement the project on their own outside the employment of the principal. This could be due to financial limitations, lack of expertise in creating value, or clauses in employees' contracts. If they could, "selling the project" could be an option for the principal, or there would be countervailing incentives. In particular, there would be reward for acquiring planning information independent of those provided by the principal.

the value of information function presented in proposition 1. This implies that partial integration of tasks provides the strongest incentive to acquire planning information and that partial integration is optimal.

3.1 Contracting with $A1$

The contract to $A1$ is a menu $\{q_1(\hat{\beta}), t_1(\hat{\beta}), r(\hat{\beta})\}$ consisting of project size, associated payments, and an indicator of integration. However, from existing results in related models,[11] it is clear that the indicator $r(\hat{\beta})$ can be replaced with a break-out rule $\beta_s \in [\underline{\beta}, \bar{\beta}]$, in that the tasks are integrated for $\hat{\beta} \leq \beta_s$, i.e., $A1$ is asked to produce $q_1(\hat{\beta})$ and is paid a transfer $t_1(\hat{\beta})$. If $\hat{\beta} > \beta_s$, tasks are separated and the principal contracts with $A2$ to implement the project, while $A1$ receives and produces zero. This follows immediately from incentive compatibility for the agent, and we also derive it formally as lemma 1 in the appendix. We can define the region or degree of integration by the interval $[\underline{\beta}, \beta_s]$. Note that since $A2$ cannot acquire information, it is without loss of generality to not base $A1$'s contract on q_2.[12]

Given this contract, $A1$'s payoff from reporting $\hat{\beta} \leq \beta_s$ when the true marginal cost is β is given by

$$U_1(\hat{\beta}|\beta) = t_1(\hat{\beta}) - \beta q_1(\hat{\beta}), \tag{3}$$

and for reporting $\hat{\beta} > \beta_s$, his payoff is zero. The revelation principle is applicable in this set up, and the following incentive compatibility constraint holds in equilibrium:

$$U_1(\beta) \geq U_1(\hat{\beta}|\beta) \;\; \forall \hat{\beta}, \beta, \tag{IC}$$

where $U_1(\beta) \stackrel{\text{def}}{=} U_1(\beta|\beta)$. Participation requires that[13]

$$U_1(\beta) \geq 0 \;\; \forall \beta. \tag{IR}$$

When $A1$ decides whether to gather information, he compares his payoff with and without information. If $A1$ becomes informed of the marginal cost β, then (IC) implies that

[11] See e.g., Riordan and Sappington (1989), and Laffont and Tirole (1988).

[12] The contract offer to $A1$ could be made contingent not only $\hat{\beta}$ but also q_2, which is the only verifiable outcome from a contract with $A2$. However, since $A2$ does not gather information about β, q_2 is also at best contingent on $A1$'s report $\hat{\beta}$. Thus, the contract contingent on $\hat{\beta}$ and q_2 is equivalent to the contract contingent on $\hat{\beta}$ only.

[13] In cases where $A1$ is separated, the participation constraint is a zero liability constraint.

he will receive $U_1(\beta)$. If $A1$ does not acquire information, he will still have to make an announcement $\hat{\beta}$. Then, (IC) implies that he cannot do better than reporting $\tilde{\beta}$, the mean of the distribution, which will yield him $U_1(\tilde{\beta})$.[14] We can then define the *value of information* to the agent by

$$v^I \stackrel{\text{def}}{=} E[U_1(\beta)] - U_1(\tilde{\beta}),$$

which is the difference in the agent's expected payoff with and without information. Since information is valuable to the principal, the optimal contract will need to satisfy the following information gathering constraint to induce $A1$ to perform the planning task:

$$v^I \geq c. \tag{IG}$$

$A1$ will gather information if the value of information is larger than the planning cost c.

Note that the agent faces two costs of acquiring information, the explicit cost c, and the opportunity cost captured as $U(\tilde{\beta})$, the rent he would get by remaining uninformed. Note also that the principal will not be able to distinguish between an uninformed agent and an informed agent who happens to discover that the true state is $\tilde{\beta}$. We will see below that this constrains the principal in the provision of incentives and plays a critical role behind one of our main findings that the value of information to the agent is non-monotonic in β_s.

To summarize, the optimal contract with $A1$ must satisfy the constraints (IR), (IC), and (IG) to induce participation, truthful revelation, and information gathering, respectively. We next move to the contract with $A2$.

3.2 Contracting with $A2$

The principal invites $A2$ to implement the project when $A1$ reports $\hat{\beta} > \beta_s$. Given the (IG) constraint, the principal knows that $A1$ will acquire information about the true β.[15] If $A1$ learns that $\beta < \beta_s$, (IC) implies that he will strictly prefer to report truthfully. If he learns that $\beta > \beta_s$, he will strictly prefer to report $\hat{\beta} > \beta_s$ and obtain zero, rather than report

[14] Formally, it can be seen by the following:

$$\max_{\hat{\beta}} E\left[U_1(\hat{\beta}|\beta)\right] = \max_{\hat{\beta}} U_1(\hat{\beta}|\tilde{\beta}) = U_1(\tilde{\beta}),$$

where the final step follows from (IC).

[15] The (IG) constraint plays an important role in the principal's inference problem. If (IG) were not satisfied and $\beta_s < \tilde{\beta}$, the principal could not even infer if $A1$ was informed since an uninformed $A1$ would also be indifferent between announcing any $\hat{\beta} \in (\beta_s, \bar{\beta}]$, including $\tilde{\beta}$.

$\hat{\beta} < \beta_s$ and earn a negative payoff. However, since his payoff is identically equal to zero for all $\hat{\beta} > \beta_s$, $A1$ is indifferent between any report $\hat{\beta} \in (\beta_s, \bar{\beta}]$.[16] Therefore, when the principal hears a report $\hat{\beta} > \beta_s$, he can only infer that the report must be coming from an informed $A1$ and that the true $\beta \in (\beta_s, \bar{\beta}]$, nothing more.[17] This creates an endogenous separation cost due to information loss, which is novel to the literature. This separation cost will decrease as the region of separation shrinks and will disappear for β_s close to $\bar{\beta}$.[18]

Therefore, the principal and $A2$ contract under symmetric beliefs that β is drawn from the interval $(\beta_s, \bar{\beta}]$ according to the density $f_s(\beta) = \frac{f(\beta)}{1-F(\beta_s)}$, and that the expected marginal cost is $\tilde{\beta}_s$, where

$$\tilde{\beta}_s \stackrel{\text{def}}{=} \int_{\beta_s}^{\bar{\beta}} \beta f_s(\beta) d\beta.$$

Then, the contract with $A2$ is *ex ante* efficient for the interval $(\beta_s, \bar{\beta}]$:

$$\begin{aligned} q_2 &= q^*(\tilde{\beta}_s), \\ t_2 &= \tilde{\beta}_s q^*(\tilde{\beta}_s), \end{aligned}$$

but project size q_2 and the transfer t_2 do not change with realized β since the state is unknown for $\beta > \beta_s$. For later use, we denote by $M(\tilde{\beta}_s)$ the principal's surplus from this contract at each β, where

$$M(\tilde{\beta}_s) \stackrel{\text{def}}{=} V(q^*(\tilde{\beta}_s)) - \tilde{\beta}_s q^*(\tilde{\beta}_s).$$

Even though $A2$'s expected rent is zero, note that there is a cost of task separation due to information loss. Separation implies that the size of the project cannot be made contingent on the true β over the interval $(\beta_s, \bar{\beta}]$. However, note that this loss disappears as β_s becomes very close to $\bar{\beta}$. This is because almost no uncertainty remains when contracting with $A2$ on the 'small' interval $(\beta_s, \bar{\beta}]$, and the principal and $A2$ contract under almost full information.

[16] In equilibrium, $U(\beta_s) = 0$, so $A1$ will be indifferent between all $\hat{\beta} \in [\beta_s, \bar{\beta}]$ when he discovers a $\beta > \beta_s$.

[17] This way of modeling also represents the case where the principal is restricted to using an indirect mechanism $t_1(q_1)$ without possibility of communication. In such a case, no information about β would be revealed when there is separation.

[18] In contrast, if we assumed that $A1$'s report is truthful when he is indifferent between any report $\hat{\beta} \in (\beta_s, \bar{\beta}]$, as in Riordan and Sappington (1989), there would be no loss from separation. We show in section 4 that partial integration would be still optimal.

3.3 Partial task-integration to increase the value of information

We are now ready to present the principal's optimization problem. Since we have already identified the optimal contract with $A2$, here we only need to characterize the optimal contract with $A1$. The principal's problem is to choose $\{q_1(\beta), t_1(\beta), \beta_s\}$ to solve the following problem:

$$\max \int_{\underline{\beta}}^{\beta_s} \left[V\left(q_1(\beta)\right) - t_1(\beta)\right] f(\beta) d\beta + \int_{\beta_s}^{\overline{\beta}} M(\tilde{\beta}_s) f(\beta) d\beta,$$

$$s.t.\ (IR), (IC), (IG), \text{and } \underline{\beta} \leq \beta_s \leq \bar{\beta}.$$

Except for the information gathering constraint (IG), the principal faces a Baron-Myerson or informed-agent problem for $\beta \leq \beta_s$, i.e., the agent will earn a rent, but the project size can be made contingent on the realized state. On the complementary interval, $\beta > \beta_s$, the principal receives the ex ante first-best payoff, i.e., no (expected) rent is paid, but the project size is insensitive to the realized state due to the loss of information. If not for the (IG) constraint, the optimal task design would balance the trade-off between information rent and the loss of information. Our key contributions rely on the effect of the binding (IG) constraint. The main results are summarized in the proposition below.

Proposition 1 *(a) The value of information v^I is strictly positive for $\beta_s > \underline{\beta}$ and non-monotonic in the region of integration: it increases with β_s for $\beta_s < \tilde{\beta}$, but decreases with β_s for $\beta_s > \tilde{\beta}$. (b) Partial task-integration is optimal, i.e., $\underline{\beta} < \beta_s < \bar{\beta}$.*

Proof. See the appendix. ■

Before providing intuition behind these results, we briefly explain why our result of partial integration differs from the result of full separation identified in Lewis and Sappington (1997). The key difference is due to the fact that in their model the project cost is observable. In particular, the observable implementation cost incurred by $A2$ can provide information about the truthfulness of $A1$'s report.[19] With full task separation and cost-based payments, the principal can use the correlation of the realized cost and the true cost parameter to costlessly discipline $A1$ for *acquiring and revealing* information. In our model, since only the project size q is observable and not the project cost βq, the principal

[19] It is because A2 does not have an incentive to shirk since A2 and the principal contract under symmetric information and cost-based payments are used.

is not able to verify the truthfulness of $A1$'s report.[20] Then $A1$ would prefer not to acquire information and just collect the planning cost c if there were full separation. This implies that full separation does not occur in equilibrium in our model. The only way to induce $A1$ to acquire and reveal information is then by having some integration and letting him earn rent in those states. Furthermore, we show that partial integration is optimal since it provides the strongest planning incentives.

The first point in part (a) of the proposition follows from a well-known property of incentive compatibility constraints (IC) which implies that $U(\beta)$ is convex. Then Jensen's inequality establishes the result that the expected utility of β is larger than the utility of expected β.

Non-monotonicity of the value of information is more subtle. The value of information initially increases with the region of integration since $A1$ obtains rents in more states. However, as the region of integration increases further so that $A1$ would be invited to implement the project even when he is not informed, the value of information falls. To understand the latter, remember that the value of information is the benefit of becoming informed, $E[U(\beta)]$, minus the opportunity cost, $U(\tilde{\beta})$, the rent of $A1$ when he is uninformed; $A1$ will claim to have learned $\tilde{\beta}$ if he remains uninformed. Since the principal cannot distinguish between an uninformed agent and an informed agent who learns $\tilde{\beta}$, an uninformed agent also earns a positive rent, $U(\tilde{\beta})$, as the region of integration expands beyond $\tilde{\beta}$. The value of information falls with integration beyond $\tilde{\beta}$ as the opportunity cost increases for sure whereas the benefit of becoming informed increases in expectation.

Given the non-monotonicity of the value of information v^I as a function of β_s, part (b) readily follows. The planning agent has to be invited to implement the project sufficiently often to induce planning effort, but inviting him too often would discourage planning effort since the opportunity cost of being informed becomes larger. Furthermore, the principal will also experience an initial efficiency gain by reducing the region of integration from full integration ($\beta_s = \bar{\beta}$) since the contract with $A2$ is almost fully efficient for β close to $\bar{\beta}$.[21]

Notice that partial integration is optimal even when the (IG) constraint is not binding,

[20] Thus, the two approaches can be reconciled if βq, instead of q, were observable and contractible in our model. Of course, if both q and βq are observable in our model, there is no agency cost, and the task-design problem is therefore vacuous.

[21] Under full integration ($\beta_s = \bar{\beta}$), the optimal contract is the Baron-Myerson contract, which involves yielding rent to the agent and distortion in project size given by (2).

i.e., when the need to induce planning effort is not an issue. Then, the principal chooses the degree of integration to balance the trade-off between yielding information rent in case of integration and the cost due to loss of information in case of separation without considering the need to induce planning effort. However, if the (IG) constraint is binding, the non-monotonicity in v^I pushes the optimal degree of integration toward the mean of the states.

This effect can be emphasized by looking at the comparative statics with respect to the planning cost c (see the appendix for the formal derivation of the comparative statics). An increase in planning cost c implies that v^I will have to be increased if the (IG) constraint is binding. Given the non-monotonic shape of the v^I function, this is achieved by increasing β_s if $\beta_s < \tilde{\beta}$, and decreasing β_s if $\beta_s > \tilde{\beta}$. Thus, the consideration of the provision of planning incentives makes β_s close to $\tilde{\beta}$.

Finally, having discussed the role of degree of integration, we now briefly describe how the optimal project size $q_1(\beta)$, given by (13) in the appendix, is chosen to address the need to provide incentive for the planning task as summarized in the following corollary.

Corollary 1 *For $\beta \leq \tilde{\beta}$, the optimal project size $q_1(\beta)$ under integration, given by (13), is larger than or equal to the Baron-Myerson level $q^b(\beta)$. For $\beta > \tilde{\beta}$, it is smaller than or equal to $q^b(\beta)$, provided that $\beta_s > \tilde{\beta}$.*

Proof. It immediately follows from comparing (2) to (13). ■

If the (IG) constraint is not binding, the need to induce planning effort is not an issue, and it is easy to see that the optimal project size equals the Baron-Myerson level: $q_1(\beta) = q^b(\beta)$ for $\beta \leq \beta_s$, where $q^b(\beta)$ is defined in (2). So, the question of interest is how the project size will differ from the Baron-Myerson level when (IG) is binding. The project size would be distorted from $q^b(\beta)$ to increase v^I. Increasing $q_1(\beta)$ increases the benefit of becoming informed, $E[U(\beta)]$, but if $\beta > \tilde{\beta}$ it increases for certain the opportunity cost of becoming informed, $U(\tilde{\beta})$, as well. Thus, the optimal $q_1(\beta)$ is made larger than $q^b(\beta)$ for $\beta < \tilde{\beta}$ and smaller than $q^b(\beta)$ for $\beta > \tilde{\beta}$. Of course, $q_1(\beta)$ for $\beta > \tilde{\beta}$ is only relevant if $\beta_s > \tilde{\beta}$ since $A1$ does not implement the project for $\beta > \beta_s$. We note that, just as in Lewis and Sappington (1997), for large enough planning costs, the project size may even be increased above the first best level $q^*(\beta)$ for $\beta < \tilde{\beta}$.[22]

[22] One interesting difference, however, is that in our model with a continuum of types, the uninformed

4 Extensions and conclusion

We have argued that integration of tasks can be a useful incentive tool to provide incentive for planning activity that results in unobservable information, but it is partial integration of tasks that provides stronger incentives. The key was in exposing the shape of the value of information function, which is non-monotonic in the region of integration.

In our model there is a separation cost due to information loss, which would be absent if we had assumed that $A1$ announces truthfully when he is indifferent between announcing different states. By exploring this assumption here, we are able to clarify further the role of cost observability and re-emphasize what Lewis and Sappington (1997) have shown: cost-based contracts can achieve two things simultaneously at zero incentive cost — induce truthful information revelation and also provide incentive for planning effort. If cost is not observable, as we have assumed, even if $A1$ announces truthfully when he is separated, there would be partial integration because some integration is necessary to induce planning effort. However, since there would be perfect information when contracting with $A2$, this contract would be fully efficient and the principal would prefer to separate earlier, i.e., the region of integration would be smaller.[23]

A comparison of our model with that of Lewis and Sappington's offers a testable implication regarding the degree of integration-separation. We can expect a greater degree of task-separation in projects where the project outcome can be used to infer the outcome of planning activity, all else the same. For example, our analysis suggests that it is more likely that a firm will outsource the planning phase of a project (full separation) if the project outcome or cost can be used to provide incentives for planning. As we argued at the outset, this is likely to happen, for instance, if the cost data is transparent, and implementation does not occur with a long lag. Otherwise, the firm is likely to choose an inside agent to perform both planning and implementation. Our analysis also suggests that tasks are more

agent's incentive to announce $\tilde{\beta}$ remains unchanged as c increases, whereas it does change in Lewis and Sappington (1997) in their binary setup, which results in the super high-powered reward structure.

[23] Other than the objective function, the principal's problem would be identical to that in section 3.3. The objective function is changed to reflect the absence of information loss:

$$\int_{\underline{\beta}}^{\beta_s} \left[V\left(q_1(\beta)\right) - t_1(\beta)\right] f(\beta)d\beta + \int_{\beta_s}^{\overline{\beta}} M(\beta)f(\beta)d\beta,$$

where $M(\beta) = \left[V(q^*(\beta)) - \beta q^*(\beta)\right]$, is the *ex post* rather than the *ex ante* efficient surplus $M(\tilde{\beta}_s)$.

likely to be separated in traditional, well-established industries, while they are more likely to be integrated in new, fast-changing, and emerging industries. Due to the lack of previous experiences, comparable examples or stereotypes, the project outcome in new industries can hardly be used to infer the outcome of planning activity.

Our analysis can be extended in several directions. First, we assumed that $A2$ cannot gather information. This would be the case where $A1$ has a significant comparative advantage in information gathering over other agents available to the principal, or where there is not enough time for planning once $A1$ has done his task. If $A2$ could also gather information on β and this information could be used to contract with $A1$, the principal could use correlated information to write a more efficient contract with $A1$ as is well known.[24] On the other hand, if $A2$'s information gathering is not observable, the principal may face a similar contracting situation with $A2$ as he did with $A1$, but with one notable difference. Information is less valuable to the principal since the interval of uncertainty has shrunk. This captures the notion that we often learn something even when the first expert we interact with is not the one eventually hired to complete the job. In general, Crémer, Khalil, and Rochet (1998a) have shown that the principal may want to induce or deter an agent to gather information and characterized the optimal contracts that achieve those objectives. The novel part here is that while information acquisition is desirable when contracting with $A1$, it may not be when contracting with $A2$. Since $A1$ narrows down the range of unknown possibilities, it may not be necessary to incur information gathering cost a second time by inducing $A2$ to gather information. We can extend our model further to the case where the principal faces a sequence of agents who can gather information. The number of agents who will be brought into the planning task decreases with the planning cost. Put differently, the cheaper the planning cost, the more agents will be involved sequentially in the planning task. This has implications regarding the size of the firm in information production.

Second, instead of exclusive contracting for the planning task, the principal could bring multiple agents into a spot competition. For instance, if the planning task could be auctioned off, as in the second-sourcing model of Riordan and Sappington (1989), rent to the

[24] See Lewis and Sappington (1997) or Crémer and McLean (1985) for the correlated information argument. Gromb and Martimort (2003) present a principle of incentives for expertise, which says that an expert or planning agent is rewarded if his recommendation is either confirmed by facts or other experts' recommendations. See Wolinsky (2002) and references therein for costs associated eliciting information from multiple experts or planning agents.

planning agent would no longer be costly to the principal. In that case, the (ex ante identical) agents would bid away the expected rent. If information gathering constraint were not binding, there would be full-integration since there would be no cost of integration, and providing incentive to gather information would not be an issue. However, if information gathering constraint were binding, partial integration would again be optimal in order to provide proper incentives for the planning task. Note that the project size would now be distorted from the full-information level rather than the Baron-Myerson level.

Third, we can allow $A1$ to choose planning effort from a continuum and allow the effort choice to determine the probability of becoming informed, which introduces the possibility that $A1$ is uninformed in equilibrium. Would this alter the information gathering constraint, the key to the shape of the value of information function, and affect our main results? We can argue that it would not. The properties of the value of information that we have identified remain the same even in this framework, and partial integration is going to again provide the strongest incentive for planning effort.[25]

Finally, in addition to the separation cost due to loss of information, we could have also included a fixed separation cost due to the operational costs of switching the agents as in Riordan and Sappington (1989). In that case, given that this additional separation cost is not too high, partial integration would still be optimal if the information gathering constraint is binding. Full integration can occur only if the information gathering constraint is *not* binding. The additional separation cost makes separation more costly, which creates a possibility for full integration to be optimal. This may indeed happen when the need to induce planning effort is not an issue, but if the information gathering constraint is binding, the non-monotonicity in the value of information will again imply that some separation is needed to raise the value of information.

In the paper, we abstracted from issues of comparative advantage by assuming that agents are equally productive in implementation. In reality comparative advantage plays

[25] To see this formally, suppose, as in Lewis and Sappington (1993) and Kessler (1998), that $A1$ is informed with probability p, while he receives a null signal s_0 with probability $(1-p)$. Planning effort consists of choosing p at cost $\psi(p)$, where this cost function is convex, and $A1$ chooses p to maximize $[pEU(\beta)+(1-p)U(s_0)-\psi(p)]$. We will have $U(s_0)=U(\tilde{\beta})$ in equilibrium, and the agent's first order condition for planning effort is given by $EU(\beta)-U(\tilde{\beta})=\psi'(p)$. It shows that compared to the discrete planning effort model we used, the value of information function is virtually the same, but a fixed constant planning cost is replaced with an increasing marginal cost of planning effort.

an obvious role in the allocation of tasks. Also, standard incentive schemes can be applied for planning activity to the extent that outcomes of planning activity are observable. Our analysis comes to bear as this outcome becomes difficult to trade upon and compensation for planning activity cannot be based on information revealed in the implementation process.

Appendix

Before proceeding to prove lemma 1, it is useful to formally define the principal's integration-separation decision as $r(\hat{\beta}) \in \{0, 1\}$, which is an indicator of whether the principal chooses integration ($r(\hat{\beta}) = 1$) or separation ($r(\hat{\beta}) = 0$) contingent on $A1$'s report.

Lemma 1 *There exists* $\beta_s \in [\underline{\beta}, \bar{\beta}]$, *such that* $r(\hat{\beta}) = 1$ *for* $\hat{\beta} \leq \beta_s$ *and* $r(\hat{\beta}) = t_1(\hat{\beta}) = 0$ *for* $\hat{\beta} > \beta_s$.

Proof. We will show the following: if $r(\beta') = 0$, for $\beta' \in [\underline{\beta}, \bar{\beta}]$, then $r(\beta) = 0$ for all $\beta > \beta'$. Given that $\beta'' > \beta'$ and $r(\beta') = 0$, suppose to the contrary that $r(\beta'') = 1$. For incentive compatibility, $U_1(\beta'') \geq U_1(\beta'|\beta'')$ and $U_1(\beta') \geq U_1(\beta''|\beta')$. Since $U_1(\beta') = U_1(\beta'|\beta'') = t_1(\beta')$, the above implies $U_1(\beta'') \geq U_1(\beta''|\beta')$, which is a contradiction because

$$\begin{aligned} U_1(\beta'') &= t_1(\beta'') - \beta'' q_1(\beta''), \\ U_1(\beta''|\beta') &= t_1(\beta'') - \beta' q_1(\beta''), \end{aligned}$$

$\beta' < \beta''$, and $q_1(\beta'') > 0$. Since $q_1(\hat{\beta}) = 0$ when $r(\hat{\beta}) = 0$, $t_1(\hat{\beta})$ is constant for $\hat{\beta} > \beta_s$. Then it is optimal for the principle to set $t_1(\hat{\beta}) = 0$ for $\hat{\beta} > \beta_s$. ■

Proof of proposition 1

Given lemma 1, we know that for $\beta \leq \beta_s$, the (IC) is equivalent to the two conditions:

$$U_1'(\beta) = -q_1(\beta), \tag{4}$$

$$q_1'(\beta) \leq 0, \tag{5}$$

where (4) is obtained from (IC) using the envelope theorem and (5) is the associated second order condition. For $\beta > \beta_s$, lemma 1 shows that $U_1(\beta) = 0$. For $\beta \leq \beta_s$, integrating (4) gives

$$U_1(\beta) = U_1(\beta_s)F(\beta_s) + \int_{\beta}^{\beta_s} q_1(s)ds. \tag{6}$$

Using integration by parts, we have

$$\int_{\underline{\beta}}^{\beta_s} U_1(\beta) f(\beta) d\beta = U_1(\beta_s) F(\beta_s) + \int_{\underline{\beta}}^{\beta_s} q_1(\beta) F(\beta) d\beta. \tag{7}$$

For $\beta \leq \beta_s$, using (6) and (7), the expression for the value of information becomes

$$v^I = \int_{\underline{\beta}}^{\beta_s} \left[F(\beta) - 1_{\tilde{\beta}} \right] q_1(\beta) d\beta, \tag{8}$$

where

$$1_{\tilde{\beta}} = \begin{cases} 1 \text{ if } \beta > \tilde{\beta} \text{ and } \beta_s > \tilde{\beta}, \\ 0 \;\; \text{otherwise.} \end{cases}$$

Of course, $v^I = 0$ for $\beta > \beta_s$. Differentiating v^I in (8) gives

$$\frac{\partial \left[\int_{\underline{\beta}}^{\beta_s} \left[F(\beta) - 1_{\tilde{\beta}} \right] q_1(\beta) d\beta \right]}{\partial \beta_s} = \begin{cases} > 0 \text{ if } \beta_s < \tilde{\beta}, \\ < 0 \;\; \text{otherwise,} \end{cases}$$

which proves the second point in part (a). Given the shape of v^I, the first point in part (a) follows from the facts that $v^I = 0$ for $\beta_s = \underline{\beta}$ and that $v^I > 0$ for $\beta_s = \underline{\bar{\beta}}$.

For the proof of part (b), we use the incentive constraints (4), (5), and lemma 1, to express the individual rationality constraint as follows:

$$U_1(\beta_s) \geq 0. \tag{9}$$

Using (8), the information gathering constraint becomes

$$\int_{\underline{\beta}}^{\beta_s} \left[F(\beta) - 1_{\tilde{\beta}} \right] q_1(\beta) d\beta \geq c. \tag{10}$$

Using the definition of $U_1(\beta)$ and lemma 1, we can replace $t_1(\beta)$ in the principal's objective function. Then, using (7), the principal's problem becomes

$$\max \int_{\underline{\beta}}^{\beta_s} \left[V\left(q_1(\beta)\right) - \left(\beta + \frac{F(\beta)}{f(\beta)} \right) q_1(\beta) \right] f(\beta) d\beta + \int_{\beta_s}^{\bar{\beta}} M(\tilde{\beta}_s) f(\beta) d\beta - U_1(\beta_s) F(\beta_s) \tag{11}$$

$$s.t. \; (5), (9), (10), \text{ and } \underline{\beta} \leq \beta_s \leq \bar{\beta}.$$

From this, it must be the case that the constraint (9) is binding, i.e., $U_1(\beta_s) = 0$, since otherwise the principal can increase his payoff by decreasing $U_1(\beta_s)$. Then, using (6), we obtain

$$U_1(\beta) = \int_{\beta}^{\beta_s} q_1(s)ds \qquad \forall \beta \leq \beta_s.$$

Ignoring (5), we can write the Lagrangian as

$$L = \int_{\underline{\beta}}^{\beta_s} \left[V\left(q_1(\beta)\right) - \left(\beta + \frac{F(\beta)}{f(\beta)}\right) q_1(\beta) \right] f(\beta) d\beta + \int_{\beta_s}^{\overline{\beta}} M(\tilde{\beta}_s) f(\beta) d\beta$$
$$+ \lambda \left[\int_{\underline{\beta}}^{\beta_s} \left[F(\beta) - 1_{\tilde{\beta}} \right] q_1(\beta) d\beta - c \right]. \tag{12}$$

Pointwise optimization yields the optimality condition for $q_1(\beta)$:

$$V'(q_1(\beta)) = \beta + \frac{F(\beta)}{f(\beta)} - \lambda \frac{F(\beta) - 1_{\tilde{\beta}}}{f(\beta)} \qquad \forall \beta \leq \beta_s, \tag{13}$$

when $q_1(\beta)$ is monotonic. Notice that if $\lambda > 1$, over-investment occurs in that $q_1(\beta)$ given by (13) is larger than $q_1^*(\beta)$ for $\beta < \tilde{\beta}$. However, if $\lambda > 1$, the standard hazard rate assumption may not guarantee the monotonicity of $q_1(\beta)$ given by (13). In such a case, we would have bunching on $q_1(\beta)$ since incentive compatibility would be violated otherwise.

Since the Lagrangian (12) may not be well behaved in β_s, a standard first order condition for β_s cannot be immediately used. However, note that we only need to show that we do not have corner solutions in β_s when the (IG) is binding. If (IG) is binding, $\lambda > 0$, and we must have $c > 0$; then (10) implies that $\beta_s > \underline{\beta}$. Next we argue that $\beta_s < \bar{\beta}$. Suppose that $\beta_s = \bar{\beta}$ and that separation occurs only at $\bar{\beta}$. Then $\tilde{\beta}_s = \bar{\beta}$, and $M(\tilde{\beta}_s) = M\left(\bar{\beta}\right)$, which is the full-information surplus at $\bar{\beta}$. Therefore, the derivative of (12) with respect of β_s, evaluated at $\bar{\beta}$ is:

$$\left\{ \left[V\left(q_1(\bar{\beta})\right) - \left(\bar{\beta} + \frac{1}{f(\bar{\beta})}\right) q_1(\bar{\beta}) \right] - M\left(\bar{\beta}\right) \right\} f\left(\bar{\beta}\right).$$

Condition (13) implies that the optimal $q_1(\bar{\beta}) = q^b\left(\bar{\beta}\right)$ if $\beta_s = \bar{\beta}$. Therefore the above derivative is strictly negative, which contradicts $\beta_s = \bar{\beta}$ and we have completed the proof.

■

Comparative statics

For the comparative statics, we rewrite the Lagrangian (12) as

$$L = \int_{\underline{\beta}}^{\beta_s} Y(q_1(\beta), \beta, \lambda) f(\beta) d\beta + \int_{\beta_s}^{\overline{\beta}} M(\tilde{\beta}_s) f(\beta) d\beta,$$

where

$$Y(q_1(\beta), \beta, \lambda) \overset{def}{=} \left[V\left(q_1(\beta)\right) - \left(\beta + \frac{F(\beta)}{f(\beta)}\right) q_1(\beta) \right] + \lambda \frac{F(\beta) - 1_{\tilde{\beta}}}{f(\beta)} q_1(\beta).$$

Assuming that the Lagrangian is well behaved around the optimal β_s and that $q_1(\beta)$ is monotonic, the solution satisfies:

$$Y_q(q_1(\beta, \lambda), \beta, \lambda) = 0 \qquad \forall\, \beta \leq \beta_s, \tag{14}$$

$$Y(q_1(\beta_s, \lambda), \beta_s, \lambda) f(\beta_s) - \left[M(\tilde{\beta}_s) + H(\tilde{\beta}_s) \right] f(\beta_s) = 0, \tag{15}$$

$$G(\beta_s, \lambda) \geq c, \tag{16}$$

where $Y_q \overset{def}{=} \frac{\partial Y}{\partial q_1}$, $q_1(\beta, \lambda)$ is defined by (14), $H(\tilde{\beta}_s) \overset{def}{=} \frac{1}{f(\beta_s)} \int_{\beta_s}^{\overline{\beta}} q^*(\tilde{\beta}_s) \frac{\partial \tilde{\beta}_s}{\partial \beta_s} f(\beta) d\beta$, and $G(\beta_s, \lambda) \overset{def}{=} \int_{\underline{\beta}}^{\beta_s} \left[F(\beta) - 1_{\tilde{\beta}} \right] q_1(\beta, \lambda) d\beta$. Note that $\frac{\partial \tilde{\beta}_s}{\partial \beta_s} > 0$.

If $\lambda = 0$, there is no effect of a change in c on β_s. If $\lambda > 0$, (16) becomes an equality. Then the effect of c can be captured by the following:

$$(Y_s - M_s - H_s) \frac{\partial \beta_s}{\partial c} + Y_\lambda \lambda_c = 0, \tag{17}$$

$$G_s \frac{\partial \beta_s}{\partial c} + G_\lambda \lambda_c = 1, \tag{18}$$

where the subscripts, s, λ, and c, represent the derivatives with respect to them. From proposition (1) and the definition of Y, we have

$$G_s \begin{cases} > 0 \text{ if } \beta_s < \tilde{\beta} \\ < 0 \text{ if } \beta_s > \tilde{\beta} \end{cases}, \quad \text{and} \quad Y_\lambda \begin{cases} > 0 \text{ if } \beta_s < \tilde{\beta} \\ < 0 \text{ if } \beta_s > \tilde{\beta} \end{cases}.$$

We also know that $G_\lambda > 0$, and the local SOC implies that $Y_s - M_s - H_s \leq 0$.

Take the case of $\beta_s < \tilde{\beta}$ first. Suppose that $\frac{\partial \beta_s}{\partial c} < 0$. Then (17) implies that $\lambda_c \leq 0$, but then (18) implies that $\frac{\partial \beta_s}{\partial c} \geq 0$, which leads a contradiction. So we must have that $\frac{\partial \beta_s}{\partial c} \geq 0$ for $\beta_s < \tilde{\beta}$, which implies that $\lambda_c \geq 0$. Next, consider the case $\beta_s > \tilde{\beta}$. Suppose that $\frac{\partial \beta_s}{\partial c} > 0$. Then (17) implies that $\lambda_c \leq 0$, but then (18) implies that $\frac{\partial \beta_s}{\partial c} \leq 0$, which is a contradiction. So we must have that $\frac{\partial \beta_s}{\partial c} \leq 0$ for $\beta_s > \tilde{\beta}$.

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