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**Not Invented Here**

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# Not Invented Here*

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**Abstract**

We consider the problem of inducing agents who are concerned with their careers to reveal their private information about a project which has originated with one of them. A successful project raises the inventor's chance of promotion, at his peer's expense. Thus, the peer has an incentive to promote the inventor's bad project to see him fail, but to denigrate his most promising projects. Moreover, there is an incentive for junior workers to push their own work no matter what the perceived quality is, but an incentive for senior workers to suppress their own ideas in order not to have a big failure that ruins their career. In case of disagreement among the agents, the optimal policy is to promote the agent who is more likely to have been truthful, not necessarily the one most suitable for promotion. This policy is not renegotiation proof. Within the class of renegotiation-proof mechanisms, *self assessment* (where no peer report is submitted) is always optimal. Exaggeration is a less serious problem than denigration in this model. It is risky strategy to exaggerate, since at best you can convince the principal to implement an un-promising project which is likely to fail. It is safer to denigrate, since if a promising project is stopped due to an unfair peer report, the principal will never learn the project's true quality.

## 1 Introduction

Career concerns create incentives for agents to misrepresent the quality of the work of their colleagues as well as their own work. In this paper, we identify four such effects. First, there is an incentive to promote a colleague's *bad* project to see him fail. Second, there is an incentive for senior workers to denigrate the work of junior workers to stop them getting ahead. Third, there is an incentive for junior workers to take risks and promote their own work no matter what the perceived quality is, as they have little to lose. A fourth effect is that there is an incentive for more senior

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workers to suppress *their own* ideas in order not to have a big failure that ruins their reputation. We refer to these four effects as, respectively, *flattery*, *Not-Invented-Here* (or NIH), *exaggeration*, and *false modesty* effects. We investigate the problem of designing optimal contracts in the presence of these effects.

There are two agents in our model. One of them (the *inventor*) has developed a blueprint for a project. Both agents (but not the principal) observe the same signal about the quality of the blueprint, and the principal has to decide whether or not to implement the project. The quality of the project is correlated with the talent of the inventor and becomes known if and only if the project is implemented. The agents' careers are at stake: at the end of the game the principal must promote one of the agents, and she would prefer to promote the most talented one. Career concerns give the agents a reason to misrepresent their information. We compare different information gathering systems: (i) *Self assessment*: the inventor makes an assessment of the project. (ii) *Peer review*: the agent who did not develop the project (the *peer*) makes an assessment of it. (iii) *Multiple reports*: both agents make assessments.

If the principal can commit to a mechanism, she cannot lose anything by collecting multiple reports. As the principal only wants to implement good projects, an optimal mechanism with multiple reports will have the property that if both agents agree that the project is good, it is implemented, and if they agree it is bad, it is not implemented. If the project is implemented its quality is observed by the principal, and this reveals information about the talent of the agent who produced the project. If a project is not implemented, the principal will never learn its true quality. Therefore, she should commit to implementing the project whenever the agents disagree, as this gives her information that helps relax the truthtelling constraints, and is costless because in equilibrium the agents will not disagree. However, as the wrong agent may be deliberately promoted in order to relax the ex ante truth-telling constraints, this mechanism is not *renegotiation-proof*. Reporting processes within the firm may be difficult to commit to for the principal because, although the success or failure of a project may in some cases be verifiable by an outside party, the *messages* sent by the agents may not be. Thus, renegotiation may be hard to avoid.

Self assessment is optimal in the class of renegotiation-proof mechanisms.[1] The policy of self-assessment is credible: when the inventor reports his project is good, the principal does want to go ahead with it; when he reports it is bad, she does want to scrap it (the inventor tells the truth in equilibrium), and the promotion decision agrees with the principal's beliefs. One intuition for why self assessment works well is the following. If the inventor convinces the principal to implement the project by exaggerating the quality, and the project is unsuccessful, the agent's career is damaged. This mitigates his incentives to exaggerate. On the other hand, if a promising project is stopped due to an unfair peer report, the principal will never learn the project's true quality. Therefore, denigration is a more difficult problem than exaggeration.

[1]If the principal cannot commit, it is well-known that having more information is not always advantageous. See Dewatripont and Maskin [4].

Coleman [3], page 443, characterizes the NIH-syndrome as "a lack of motivation, interest, and effort concerning ideas that originated outside a group, either elsewhere in the firm or in another firm. The group's investigation into an idea that originated elsewhere seems often to result in only a catalogue of reasons why the idea will not be useful." Coleman conjectures that the incentive to denigrate other people's work arises because "If an idea is clearly another's, an actor appears to have an interest in seeing the idea fail. This interest appears to arise because the success or failure of others' ideas provides a benchmark for evaluating one's own performance. By demonstrating the defects in another's idea, one justifies not having had the idea oneself; by allowing the idea's potential to be realized, one would be relatively worse off, because that would raise the standard for evaluation of one's own work." Coleman adds that "The NIH syndrome is the opposite of what generally occurs when an innovator is given control of the development of his innovation. With that control he has a strong interest in seeing the idea successfully carried through to implementation." The last sentence seems to suggest a problem of exaggeration. However, while the literature generally considers NIH a serious difficulty, it does not appear that the incentive to exaggerate the quality of one's own ideas is a big issue. Our main result is consistent with this. The optimal renegotiation-proof contract is very simple: let the agent who developed the project evaluate it, but do not ask his colleagues for their opinion.

An important point of our paper is that the situation is different depending on who developed the project. If the agent who developed the project is a "senior worker" who is far ahead in his career and has a good chance of being promoted even if his new project is not implemented, the situation is different from the case where he is a junior worker whose only hope of promotion is a successful project. This is illustrated by the following quote:

> "{A} reason creativity dies is peer pressure. Individuals begin to think, If *he* fails he'll look bad and I'll get ahead. The message then is, Don't make a mistake your peers could exploit. Interestingly, years ago an executive with General Mills showed us...research on risk taking in the organization....The researchers found that ..high risk taking described entry level employees. They had little .. personal stakes in the organization and, consequently, felt they had little or nothing to lose. [T]he lowest risk taking was an arena peopled by middle management. These folks had a large career investment in the organization, essentially no security, lots of peer group pressure and competition and a lot to lose." [5]

A junior worker who has a long way to promotion has nothing to lose and everything to gain from being enthusiastic about all projects, both his own (exaggeration) and his senior colleagues (flattery). The senior worker who is close to being promoted has nothing to gain and everything to lose from a risky project, and so will have a reason to denigrate both his own work (false modesty) and others (NIH). In our model, this is revealed by the fact that which truth-telling constraints are binding depend on the seniority of the inventor. It turns out that if the principal can commit, he will ask a junior worker to evaluate a senior worker (but it is not useful to let a senior worker evaluate a junior worker). Without commitment, both junior and senior workers should assess their own work.

In the economics literature, a number of papers consider a supervisor's evaluation of a subordinate (Prendergast and Topel [11] and Tirole [13]). They focus on rather different issues than our paper such as collusion and the effect of favoritism on optimal performance evaluation. Baker, Gibbons and Murphy [1] present several models on the use of subjective performance measures in optimal incentive schemes and present results on the substitutability and complementarity of (objective) explicit and (subjective) implicit incentive schemes. The fact that incentive schemes and promotion policies can cause agents to behave destructively to further their own careers at the expense of others is of course well known (Lazear [7], Milgrom [9] and Itoh [6]), although in this literature there is no adverse selection and consequently no predictions about optimal information systems. Rotemberg and Saloner [12] analyze a model of a different kind of conflict within the firm: the production and sales departments disagree about business strategy, and try to present arguments that damage the other side's position. Somewhat closer to our setup is Carmichael [2], who shows the optimality of tenure contracts. An interesting analysis of incentives to be aggressive and conservative in self-assessment is Prendergast and Stole [10]. None of these papers analyze the principal's choice between self- assessment, peer review and multiple reports, which is the focus of our paper.

# 2 The Model

## 2.1 The Time Line

There are two agents and a principal. Each agent $i$ can be *Good* or *Bad* type, denoted $T \in \{G, B\}$. An agent's type is not observable to anyone, including himself. The agents' types are uncorrelated random variables. Let $\lambda_i$ be the prior probability that agent $i$ is a good type.

One of the agents, say (without loss of generality) agent 1, has developed a blueprint (or "project"). There is no moral hazard: the existence of a project, as well as the quality of the project, is exogenously given and cannot be changed by any action taken by the agents. A project can be *Good* or *Bad* quality, denoted $v \in \{G, B\}$. Good projects are *successful* if implemented, and bad projects *unsuccessful*. The quality of the project is perfectly correlated with the agent's type: good agents produce good projects, bad agents produce bad projects.[2] To persons with specialized knowledge, such as the agents, it is clear if the project is promising or not, but the principal lacks the knowledge to make this judgement. Formally, each agent (but not the principal) observes a signal $\sigma$ which is (imperfectly) correlated with the quality of the project.

[2] This is assumed for convenience. Imperfect but positive correlation between types and projects would not change our basic results.

The signal is either good ($\sigma = g$) or bad ($\sigma = b$). Both agents observe *the same signal*. Thus, if the project looks promising to one agent, it looks promising to the other agent too. The case where the agents might honestly disagree in their evaluations is more complicated and we postpone this to future work. Under our assumption, two truthful reports do not contain more information than one truthful report. However, by collecting two reports the principal can relax the truth telling constraints. In particular, she knows that some agent is lying if they disagree (although she does not know which one). However, we will show that when renegotiation is possible, the principal prefers to collect only one report. Moreover, this should always be the inventor's own evaluation.

After the project has been generated and the signal observed, the game goes as follows.

**Time** $t = 1$. Each agent $i$ sends a *message* $m_i \in M_i$, where $M_i$ is agent $i$'s message space.

**Time** $t = 2$. The principal receives the instruction "implement the project" or the instruction "don't implement the project" from the mechanism. The instruction "implement the project" is received with probability $h(m)$ where $m = (m_1, m_2)$. The principal does not observe the messages,[3] only the instruction whether or not to implement.

**Time** $t = 3$. The outcome of the project is realized and becomes public knowledge. The set of possible outcomes of a project is

$$Y \equiv \{G, B, \emptyset\}$$

where $G$ (resp. $B$) denotes the outcome: the inventor's project was implemented at time 2 and successful (resp. unsuccessful), and $\emptyset$ denotes the outcome: the inventor's project was not implemented. If $Y = G$ then the principal makes a profit $G > 0$ from the project, if $Y = B$ she makes $B < 0$. The principal immediately finds out a project's true quality if she implements it. If she does not implement it, she never learns the true quality.

**Time** $t = 4$. The principal receives the instruction "promote agent 1" or the instruction "promote agent 2" from the mechanism, together with an instruction about what wages to pay. The instruction "promote agent 1" is received with probability $\theta^y(m)$ if $m = (m_1, m_2)$ were the messages and $y \in Y$ the outcome. The wages can depend on the messages, the outcome of the project, and whether or not the agent is promoted.

The outcome of the project, the output (instructions) of the mechanism and the principal's actions are all verifiable to an outside party (a court) so that the principal cannot unilaterally renege on the contract. In Section 3 we make the additional assumption that the principal can commit never to propose a new contract to the agents even if it would be a Pareto-improvement. This assumption is relaxed in

[3]We can suppose that the mechanism destroys the messages after it has received them. Nothing would be gained by allowing the principal to observe the actual messages (or some noisy signal thereof).

Section 4. Notice that as we allow the mechanism to give randomized instructions to the principal, there is no loss of generality in restricting the agents to pure strategies (and, in particular, to truthful ones).

The agents are risk neutral, but there is *limited liability*: all wages must be non-negative.

At time $t = 4$, the principal must assign one of the agents to a difficult task which requires skilled labor. We call this a *promotion*.[4] The value to the principal of promoting a good type is $\Delta > 0$, the value of promoting a bad type is zero. The quality of the project is valuable information for the promotion decision: if the project has been implemented, the inventor's type has been revealed for sure (good if successful, bad otherwise). However, we shall assume that a failed project is sufficiently costly ($B \ll 0$) so that the principal does not want to implement unpromising projects only to get more information about the agents. The agents' incentives to misrepresent information are driven by the desire to be promoted. Let the non-pecuniary value of being promoted be $R > 0$. Thus, if the agent is promoted and gets paid $w$ his total payoff is $w + R$.

Many theories can be used to explain why it is desirable to be promoted. Rather than assuming a non-pecuniary benefit, we can suppose promotions are publicly observed and are a good signal to the labor market (other firms are also concerned with the quality of workers). The promotion decision is the only aspect of the firm observable to outsiders (they cannot observe, for example, the quality of the project or reports about it). Let $R > 0$ denote the market wage of a promoted agent, i.e. the wage other firms are willing to pay for an agent they know have been promoted. Then, the agent who gets the promotion must receive a wage of at least $R$, or else he will go to some other firm. Suppose also that each agent is so valuable to his present firm that the firm always wants to match any outside offer. The outside market thus serves only to bid up reservation wages. The promoted agent must be paid at least $R$ and the other agent at least zero (the normalized minimum wage). This is the same as our model, except for the trivial modification that the firm would always pay $R$ to the promoted agent so the constant $R$ would be subtracted from the firm's profit.

## 2.2 Conditional probabilities

The signal $\sigma$ is accurate with probability $q$, $\frac{1}{2} < q < 1$. Let $p(\sigma)$ denote the probability that the project of is of good quality, conditional on the signal $\sigma \in \{g, b\}$. By Bayes' rule,

$$
\begin{aligned}
p(g) &= \frac{\lambda_1 q}{\lambda_1 q + (1 - \lambda_1)(1 - q)} > \lambda_1 \\
p(b) &= \frac{\lambda_1 (1 - q)}{\lambda_1 (1 - q) + (1 - \lambda_1) q} < \lambda_1
\end{aligned}
$$

[4] This does not necessarily mean that he becomes a "supervisor" or that he performs an administrative task rather than a technical one.

If

$$p(b) > \lambda_2$$

we call the inventor the *senior worker* and the peer the *junior worker*. In this case, the inventor is ahead in his career and is a better candidate for promotion even after a bad signal about his project. The inventor is *well ahead* if in addition

$$p(b) - \frac{R}{\Delta} \geq \lambda_2$$

If

$$p(b) < \lambda_2$$

then the inventor is called the junior worker and the peer the senior worker. In this case, the inventor is a worse candidate for promotion after a bad signal.

Conditional on a good signal, the project is assumed to be profitable:

$$p(g)G + (1 - p(g))B > 0 \tag{1}$$

Bad projects make losses, but they have an informational value as they reveal the agent's type. Thus, if the value of promoting the right agent is high compared to the cost of implementing a bad project, implementing projects with bad signals might be desirable in order to obtain information about agent 1's type. The problem is uninteresting if the optimal policy is always to implement the project regardless of the signal, so we assume that expected losses, conditional on a bad signal, are big compared to the value of promoting the right agent:

$$p(b)G + (1 - p(b))B \leq -\Delta \max \{p(b)(1 - \lambda_2),\ (1 - p(b))\lambda_2\} \tag{2}$$

This assumption guarantees (Lemma 1) that the optimal decision of whether to implement a project or not depends on the signal. Finally, in order to avoid a multiplication of different cases and to simplify the exposition, we make the reasonable assumption that $R$, the value to the agent of being promoted, is small compared to the cost to the principal of promoting the wrong agent:

$$R < \Delta \min\{\lambda_2, 1 - \lambda_2\} \tag{3}$$

This assumption guarantees (Lemma 1) that the principal will not deliberately promote the wrong agent in order to relax the truthtelling constraints. Thus, our maintained assumption throughout the paper is:

**Assumption 1** (1), (2) and (3) hold.

## 3 The Optimal Contract

There are two truthtelling or IC constraints for agent $i$, one for each signal $\sigma \in \{g, b\}$. (Recall that both agents see the *same* signal $\sigma$). Denote by $IC_i(\sigma)$ the constraint that agent $i$ should tell the truth after seeing $\sigma$. Following messages $m = (m_1 m_2)$, the project is implemented with probability $h(m)$. Let $w_i^y(m)$ denote agent $i$'s expected *wage* and $u_i^y(m)$ his expected *payoff* if the messages are $m$ and the outcome of the project is $y \in \{G, B, \emptyset\}$. The payoff is the sum of the wage and the value of being promoted times the probability that a promotion occurs. For agent 1:

$$u_1^y(m) = w_1^y(m) + \theta^y(m)R$$

and similarly for agent 2. The limited liability constraints specify that all wages are non-negative.

Suppose agent 2 always tells the truth. Agent 1's expected payoff when he sees $\sigma = g$ and truthfully announces $m_1 = g$ is:

$$h(gg)\left(p(g)u_1^G(gg) + (1-p(g))u_1^B(gg)\right) + (1-h(gg))u_1^{\emptyset}(gg) \tag{4}$$

His expected payoff when he sees $\sigma = g$ and untruthfully announces $m_1 = b$ is

$$h(bg)\left(p(g)u_1^G(bg) + (1-p(g))u_1^B(bg)\right) + (1-h(bg))u_1^{\emptyset}(bg) \tag{5}$$

Using (4), (5) and the definition of conditional probabilities, the $IC_1(g)$ constraint can be written as

$$\begin{aligned} & h(gg)\left(\lambda_1 q u_1^G(gg) + (1-\lambda_1)(1-q)u_1^B(gg)\right) + (1-h(gg))\left(\lambda_1 q + (1-\lambda_1)(1-q)\right)u_1^{\emptyset}(gg) \\ \geq\ & h(bg)\left(\lambda_1 q u_1^G(bg) + (1-\lambda_1)(1-q)u_1^B(bg)\right) + (1-h(bg))(\lambda_1 q + (1-\lambda_1)(1-q))u_1^{\emptyset}(bg) \end{aligned}$$

Similarly, the $IC_1(b)$ constraint is

$$\begin{aligned} & h(bb)\left(\lambda_1(1-q)u_1^G(bb) + (1-\lambda_1)q u_1^B(bb)\right) + (1-h(bb))(\lambda_1(1-q) + (1-\lambda_1)q)u_1^{\emptyset}(bb) \\ \geq\ & h(gb)\left(\lambda_1(1-q)u_1^G(gb) + (1-\lambda_1)q u_1^B(gb)\right) + (1-h(gb))(\lambda_1(1-q) + (1-\lambda_1)q)u_1^{\emptyset}(gb) \end{aligned}$$

Similarly, we obtain two IC constraints for agent 2. What happens in case of disagreement does not influence the principal's expected payoff directly (because disagreement only happens out of equilibrium). What happens in case of disagreement matters only through the right hand side of the IC constraints.

The following Lemma is proved in the appendix.

**Lemma 1** *(i) It is optimal to pay a zero wage to both agents whenever they disagree ($m_1 \neq m_2$). (ii) It is optimal to pay a zero wage to both agents whenever the project fails. (iii) It is optimal to implement the project whenever the agents disagree: $h(gb) = h(bg) = 1$. (iv) It is optimal for the principal to set $\theta^B(gg) = 0$ and $\theta^G(gg) = 1$. (v) It is optimal for the principal to set $h(gg) = 1$ and $h(bb) = 0$.*

Using Lemma 1 we can simplify the problem. Consider the principal's payoff. With probability $\lambda_1 q$ both the project and the signal is good. In this case, assuming the agents tell the truth, the project is successfully implemented (by Lemma 1 part (v)), agent 1 is promoted (by Lemma 1 part (iv)), and the principal's payoff is

$$G + \Delta - w_1^G(gg) - w_2^G(gg)$$

The principal's payoff for other cases is similarly computed from Lemma 1. Overall, the principal's expected payoff is

$$\begin{aligned} &\lambda_1 q \left(G + \Delta - w_1^G(gg) - w_2^G(gg)\right) + (1-\lambda_1)(1-q)\left(B + \lambda_2 \Delta\right) \\ &+\lambda_1(1-q)\left(\theta^{\emptyset}(bb) + (1-\theta^{\emptyset}(bb))\lambda_2\right)\Delta + (1-\lambda_1)q(1-\theta^{\emptyset}(bb))\lambda_2\Delta \\ &-(\lambda_1(1-q)+(1-\lambda_1)q)\left(w_1^{\emptyset}(bb) + w_2^{\emptyset}(bb)\right) \end{aligned} \tag{6}$$

She maximizes this expression subject to the IC constraints, which from Lemma 1 we can simplify [5] as follows:

$\mathrm{IC}_1(g)$ :

$$\lambda_1 q\ (w_1^G(gg) + R)\ \geq \lambda_1 q \theta^G(bg)R + (1-\lambda_1)(1-q)\theta^B(bg)R \tag{7}$$

$\mathrm{IC}_1(b)$ :

$$\begin{aligned} &(\lambda_1(1-q)+(1-\lambda_1)q)\left(w_1^{\emptyset}(bb) + \theta^{\emptyset}(bb)R\right) \\ \geq\ &\lambda_1(1-q)\theta^G(gb)R + (1-\lambda_1)q\theta^B(gb)R \end{aligned} \tag{8}$$

$\mathrm{IC}_2(g)$ :

$$\lambda_1 q w_2^G(gg) + (1-\lambda_1)(1-q)R \geq \lambda_1 q(1-\theta^G(gb))R + (1-\lambda_1)(1-q)(1-\theta^B(gb))R \tag{9}$$

$\mathrm{IC}_2(b)$ :

$$\begin{aligned} &(\lambda_1(1-q)+(1-\lambda_1)q)\left(w_2^{\emptyset}(bb) + (1-\theta^{\emptyset}(bb))R\right) \\ \geq\ &\lambda_1(1-q)(1-\theta^G(bg))R + (1-\lambda_1)q(1-\theta^B(bg))R \end{aligned} \tag{10}$$

The limited liability constraints are:

$$w_1^G(gg), w_2^G(gg), w_1^{\emptyset}(bb), w_2^{\emptyset}(bb) \geq 0 \tag{11}$$

To explain the left hand side of $\mathrm{IC}_1(g)$, for example, use Lemma 1 to set $h(gg) = 1$, $u_1^G(gg) = w_1^G(gg) + \theta^G(gg)R = w_1^G(gg) + R$, and $u_1^B(gg) = w_1^B(gg) + \theta^B(gg)R = 0$ in the left hand side of the $\mathrm{IC}_1(g)$ constraint stated before Lemma 1.

The details of the optimal contract depend on which incentive constraints are binding, and this in turn depends on the whether the inventor is a junior or senior worker.

[5] For $m_1 \neq m_2$: $u_1^G(bg) = \theta^G(bg)R$, $u_2^G(bg) = (1-\theta^G(bg))R$, $u_1^{\emptyset}(bg) = \theta^{\emptyset}(bg)R$ etc.

First, suppose the inventor is a *senior worker*: $p(b) > \lambda_2$. He is ahead in his career, but would not remain so after an unsuccessful project, which would be a very negative signal about talent. Thus, the inventor likes the status quo and has an incentive to *underestimate* the quality of his own project (playing it safe rather than suffering a costly failure, a.k.a. *false modesty*). [6] The peer on the other hand thinks he can only get promoted if the senior worker suffers an unsuccessful project (a bad signal is not enough), and a necessary condition for this is that a project is implemented! Thus, the peer is tempted to *flatter*, i.e. to *overestimate* the project's quality. The binding truth-telling constraints are $IC_1(g)$ (no *false modesty*), and $IC_2(b)$ (no *flattery*). We primarily have to worry about the promotion decision when the senior worker says his own project is bad while the peer report is good. If messages conflict in this way, the principal should relax the truth telling constraints by rewarding (promoting) the agent who is more likely to have told the truth. Thus, she promotes the inventor with a higher probability if the project is unsuccessful than if it is successful. However, this is the opposite of what she would like to do ex post, so as we will see in the next section renegotiation causes this policy to unravel. Together with Lemma 1, the following propositions summarize the salient features of the optimal contracts. Proofs are in the appendix.

**Proposition 2** *Suppose the inventor is a senior worker who is well ahead. Then, the following policy is optimal. Set $\theta^{\emptyset}(bb) = 1$. If $m = (bg)$ and the project fails, promote the inventor ($\theta^B(bg) = 1$). If $m = (bg)$ and the project succeeds, promote the inventor with probability*

$$\theta^G(bg) = \begin{cases} 0 & \text{if } \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} \geq 1 \\ 1 - \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} & \text{otherwise} \end{cases}$$

**Proposition 3** *Suppose the inventor is a senior worker but not well ahead. Then, the following policy is optimal. If $m = (bg)$ and the project fails, promote the inventor with probability*

$$\theta^B(bg) = \begin{cases} \frac{\lambda_1 q}{(1-\lambda_1)(1-q)} & \text{if } \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} \geq 1 \text{ and } p(b) - \lambda_2 - \frac{1-q}{q}\frac{R}{\Delta} < 0 \\ 1 & \text{otherwise} \end{cases}$$

*If $m = (bg)$ and the project succeeds, promote the inventor with probability*

$$\theta^G(bg) = \begin{cases} 0 & \text{if } \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} \geq 1 \\ 1 - \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} & \text{otherwise} \end{cases}$$

*Set $\theta^{\emptyset}(bb) = 1 - p(b)(1 - \theta^G(bg))$.*

[6] The generation of projects is treated as an exogenous process. It may be objected that if the inventor likes the status quo, he may refuse to develop a project in the first place. However, suppose there are three kinds of projects: Bad, Good, and Brilliant. Brilliant projects succeed for sure, and everyone can recognize them. If the payoff from completing a Brilliant project is very high, the senior worker will be willing to develop blueprints. The present analysis applies to the case where he just failed to develop a Brilliant one, and it is commonly known that the blueprint is either Good or Bad.

Now suppose the inventor is a *junior worker*: $p(b) < \lambda_2$. Then he will be tempted to *exaggerate* the quality of the project. This is intuitive, because the principal thinks the peer is the best candidate for promotion conditional on a bad signal. For the same reason, the peer has every reason to try to denigrate the project (the *NIH* effect). The binding truth telling constraints are $IC_1(b)$ (no *exaggeration*) and $IC_2(g)$ (avoiding the *NIH* effect). We particularly have to worry about the principal's decision when the inventor says his project is good and the peer says it is bad. If the messages conflict in this way, the principal should relax the truth telling constraints by implementing the project and rewarding (promoting) the agent who is more likely to have told the truth. Thus, she promotes the inventor if and only if the project succeeds. The principal has to compensate the inventor enough so he has no incentive to exaggerate, in effect by giving him a high salary even if he is not promoted. On the other hand, denigration does not increase the peer's probability of promotion with this policy, so the NIH effect is completely absent. This optimal policy is equivalent to a policy of self-assessment, and it is renegotiation proof because the right agent is always promoted. Proofs of the following propositions can be found in the appendix.

**Proposition 4** *Suppose the inventor is a junior worker and* $p(b) < \lambda_2 \leq p(b) + \frac{R}{\Delta}$. *Then, the following policy is optimal. Set* $\theta^{\emptyset}(bb) = p(b)$. *Set* $\theta^G(m) = 1$ *and* $\theta^B(m) = 0$ *if* $m$ *is such that* $m_1 \neq m_2$.

**Proposition 5** *Suppose the inventor is a junior worker and* $\lambda_2 > p(b) + \frac{R}{\Delta}$. *Then, the following policy is optimal. Set* $\theta^{\emptyset}(bb) = 0$. *Set* $\theta^G(m) = 1$ *and* $\theta^B(m) = 0$ *if* $m$ *is such that* $m_1 \neq m_2$.

Notice that if the inventor is a senior worker and $R \leq \Delta(p(b) - \lambda_2)$, or if the inventor is a junior worker and $R < \Delta(\lambda_2 - p(b))$, then the "right" worker is always promoted in equilibrium, even when no project was implemented ($\theta^{\emptyset}(bb) = 1$ in the first case, $\theta^{\emptyset}(bb) = 0$ in the second case). This agrees with intuition. In these cases $R$ is relatively small, and it is relatively cheap to pay sufficient wages so that the worker becomes indifferent towards promotion. The principal then prefers to induce truth-telling this way, rather than by distorting the promotion decision. If $R$ is relatively high, however, the principal prefers to distort the promotion decision by setting $0 < \theta^{\emptyset}(bb) < 1$.

# 4 Renegotiation

Suppose at any stage of the game the principal can propose a new contract to the agents. If the new contract is accepted by both agents, the new contract supersedes the old one. We now consider optimal *durable* or *renegotiation proof* contracts, where the principal never has an incentive to propose a new contract.

The only times where the principal can have any incentive to propose a new contract are times $t = 2$ and $t = 4$. Consider time $t = 2$. According to Lemma 1 part (v), in equilibrium the project is implemented iff the signal is good. Then, if the principal gets the instruction "don't implement the project" she thinks the signal is bad and, under our assumptions, she has no reason to try to implement the project. Similarly, if the instruction is "implement the project" she thinks the signal was good and has no reason not to implement. Therefore, no renegotiation takes place at time $t = 2$. [7]

At time $t = 4$ the issue of the principal's beliefs arises. Here, the analysis is simplified by two assumptions: (a) the principal always believes agent 2 is good with probability $\lambda_2$, independently of what has happened, because nothing that happens reveals any information about agent 2's type; (b) if the project is implemented, the principal learns agent 1's type *for sure.* The only remaining case is the principal's beliefs about agent 1 after she has received the instruction "don't implement". As long as the principal's observations are consistent with the equilibrium, beliefs are assigned by Bayes' rule. If the principal's observations are inconsistent with equilibrium, Bayes' rule is not applicable. Fortunately, the only thing we need to know about this case is that the principal thinks agent 1 is good with *at least* probability $p(b)$. This is a lower bound on this probability, because the worst possibility for agent 1 is that the signal was bad. None of our results will depend on a more sophisticated analysis of out-of-equilibrium beliefs. Using the terminology of Maskin and Tirole [8], the concepts of weak and strong renegotiation-proofness coincide in this model.

**Proposition 6** *The optimal contracts characterized by Lemma 1 and Propositions 2-5 are renegotiation proof if and only if the inventor is a junior worker.*

**Proof.** It suffices to consider time $t = 4$. First, suppose the events the principal has observed are consistent with the equilibrium. From Lemma 1 part (iv), if the project is implemented, the inventor is promoted if and only if his project succeeds. Thus, the right person is promoted and no renegotiation takes place.

Now suppose the project is cancelled along the equilibrium path. From Propositions 2-5, if the inventor is the senior worker and $R \leq \Delta(p(b) - \lambda_2)$, or if the inventor is a junior worker and $R < \Delta(\lambda_2 - p(b))$, then the "right" worker is always promoted, so there can be no renegotiation. In the remaining cases (when $R$ is relatively big) the principal sometimes promotes the wrong agent: $0 < \theta^{\emptyset}(bb) < 1$. If, for example, the inventor is a senior worker then the principal prefers to promote him even after the bad signal, yet $\theta^{\emptyset}(bb) < 1$. However, as long as $R > \Delta(p(b) - \lambda_2)$, it is still credible to promote the peer after the bad signal. Indeed, the peer will insist on a bribe of at least $R$ to give up the promotion, while the benefit from promoting the inventor instead of the peer is only $\Delta(p(b) - \lambda_2) < R$. Similarly, the promotion policy is renegotiation proof if the inventor is a junior worker and $R \geq \Delta(\lambda_2 - p(b))$, even though the wrong agent (the inventor) may be promoted after the bad signal. Thus, the contracts are always renegotiation proof along the equilibrium path.

Next, suppose the principal's observations are inconsistent with an equilibrium. There are two cases where it may happen. (i) After a disagreement among the agents

[7] The conclusion might be different if the principal could see the actual messages, for then we would have to worry about her response when $m_1 \neq m_2$. Unobservable messages help fight renegotiation.

the principal may receive the instruction to promote the inventor even though his project fails: $\theta^B(gb) \neq 0$ or $\theta^B(bg) \neq 0$. This situation is not renegotiation proof, because the principal knows the inventor is low quality after the unsuccessful project. The principal can convince agent 1 to decline the promotion by offering a bribe $R$. By (3) the principal gains at least

$$\lambda_2 \Delta - R > 0$$

(ii) The principal may receive the instruction not to promote the inventor even though his project succeeds: $\theta^G(gb) \neq 1$ or $\theta^G(bg) \neq 1$ Analogously with the previous case, the principal gains at least

$$(1 - \lambda_2)\Delta - R > 0$$

by renegotiating and promoting the inventor.

Thus, the contract is renegotiation proof off the equilibrium path if and only if $\theta^B(gb) = \theta^B(bg) = 0$ and $\theta^G(gb) = \theta^G(bg) = 1$. By inspection of Propositions 2-5, we find that renegotiation proofness is violated when the inventor is senior worker but satisfied if he is not. ■

## 4.1 Optimal Renegotiation Proof Contracts

The proof of Proposition 6 shows that renegotiation proofness fails *out of equilibrium* when the inventor is a senior worker because, in order to provide incentives to tell the truth, the peer is promoted if he was the only one who supported a successful project, and the inventor is promoted if he was the one who did *not* support an *unsuccessful* project. In these cases, the principal prefers to renegotiate the contract rather than promoting the wrong agent. We now consider the optimal renegotiation proof contract when the inventor is the senior worker. In this case the possibility of renegotiation strictly lowers the principal's expected payoff.

The proof of Proposition 6 established that renegotiation proofness imposes the constraint: for all $m$ (even *out-of- equilibrium* $m$),

$$\theta^G(m) = 1 \quad , \quad \theta^B(m) = 0 \tag{12}$$

Thus, if the project succeeds, the inventor must be promoted as he is known for sure to be good; if the project fails, the inventor must not be promoted as he is known to be bad. Now we can no longer argue, as in Lemma 1 parts (iii) and (v), that it is optimal for the principal to implement the project whenever the agents disagree or when both report it is good, because the proof of Lemma 1 parts (iii) and the first half of (v) does not go through if (12) is imposed. Because the principal cannot credibly use the promotion policy to reward the agent who was "more likely to have been right," it may be optimal not to implement the project when the agents disagree or even if both report it is of good quality. However, even when renegotiation proofness is imposed, it is optimal to impose $h(bb) = 0$ and indeed Lemma 1 part (v) concerned with $h(bb)$ goes through unchanged. Because lowering the probability of implementing the project also reduces the probability that we discover the inventor's type, the principal's incentive to reduce the probability of implementation is actually reinforced by renegotiation.

When the project is not implemented, the principal thinks agent 1 is good with probability *at least* $p(b)$. If the principal has been asked to promote agent 2, the gain from promoting 1 instead of 2 is at least

$$(p(b) - \lambda_2)\Delta$$

and the cost is never greater than a bribe $R$ paid to agent 2 (the principal can offer 2 the same salary as he would have received according to the original contract, plus the bribe to compensate for not being promoted). If the inventor is well ahead, $(p(b) - \lambda_2)\Delta > R$ and the contract is not renegotiation proof. In this case we must impose the constraint

$$\theta^{\emptyset}(m) = 1 \quad \text{for all } m \tag{13}$$

That is, agent 1 is promoted whenever the project is not implemented. If the inventor is a senior worker but not well ahead, the same argument does not go through and (13) can be violated.

To find the optimal renegotiation proof contract when the inventor is the senior worker, we first modify the program of Section 3 by *not* imposing $h(gg) = h(gb) = h(bg) = 1$, but instead imposing (12) and, if the inventor is well ahead, also (13). But to avoid a further multiplication of possible cases, we make an assumption which guarantees that at least $h(gg) = 1$. This assumption states that $R$ is small compared to the expected gain from implementing a project with a good signal.

**Assumption 2** $p(g)G + (1 - p(g))(B + \lambda_2\Delta) > R\max\{p(g), (1 - p(g))\}$.

**Lemma 7** *Suppose Assumption 2 holds and the inventor is the senior worker but not well ahead. The following is the solution if the program of Section 3 is modified by not imposing $h(gg) = h(gb) = h(bg) = 1$, but instead imposing (12). Set $h(gg) = h(gb) = 1$ and $h(bg) = 0$. All wages except $w_1^G(gg)$ are zero. If*

$$qp(b) + (1 - q)\,(\,\lambda_2 - p(b))\,p(g)\frac{\Delta}{R} < 0 \tag{14}$$

*then $\theta^{\emptyset}(bb) = \theta^{\emptyset}(bg) = 1$ and*

$$w_1^G(gg) = \frac{1 - p(g)}{p(g)}R$$

*If*

$$qp(b) + (1 - q)\,(\,\lambda_2 - p(b))\,p(g)\frac{\Delta}{R} \geq 0 \tag{15}$$

*then*

$$\theta^{\emptyset}(bb) = \theta^{\emptyset}(bg) = p(g) \tag{16}$$

*and $w_1^G(gg) = 0$.*

**Lemma 8** *Suppose Assumption 2 holds and the inventor is well ahead. When the program of Section 3 is modified by not imposing $h(gb) = h(bg) = 1$, but instead imposing (12) and (13), the solution is $h(gg) = h(gb) = 1$, $h(bg) = 0$. All wages are zero, except*

$$w_1^G(gg) = \frac{1 - p(g)}{p(g)} R$$

**Proof.** In the appendix.

**Proposition 9** *The contracts characterized in Lemmas 7 and 8 are optimal within the set of renegotiation-proof contracts (for the cases where the inventor is senior worker but not well ahead, or well ahead, respectively).*

**Proof.** Any renegotiation-proof contract must satisfy the constraints of the programs analyzed in Lemmas 7 and 8. Thus, it suffices to show that the contracts found in Lemmas 7 and 8 are renegotiation proof. This is certainly true in the case of Lemma 8 because the right agent is always promoted by construction. That is, agent 1 (who is well ahead) is promoted except when his project has failed.

In the case of Lemma 7 the only problematic aspect is (16). When the principal receives the instruction "don't implement", the only belief consistent with Bayes' rule is: the signal was bad and the inventor is good with probability $p(b)$. In this case, the principal prefers to promote agent 1 (by definition of senior worker). According to (16), agent 2 is nevertheless promoted with some probability. Notice that this happens in equilibrium because $0 < \theta^{\emptyset}(bb) < 1$, so Bayes' rule applies. By renegotiating and promoting agent 1 instead of agent 2, the principal would gain

$$\Delta\left(p(b) - \lambda_2\right) > 0$$

However, the principal would have to pay a bribe of $R$ dollars to agent 2 to make him willing to give up the promotion. This does not pay, because

$$\Delta\left(p(b) - \lambda_2\right) \leq R$$

when the inventor is not well ahead. Therefore, the mechanism is renegotiation proof. ■

Thus, when the inventor is a senior worker the optimal *renegotiation-proof* contract involves *not implementing* the project when only the peer supports it. This in effect gives the inventor veto power over the implementation of the project, so as we show in the next section this policy can be replicated by a self assessment mechanism where only one agent, the inventor, reports the quality of his project.

## 5 Self Assessment and Peer Review

We now show that the optimal renegotiation-proof contract can be replicated by a *self assessment* mechanism where *only* the inventor is asked for an opinion about his project. The peer, of course, always gets a zero wage. Implement the project if and only if the inventor says is *good*. Promote the inventor if it is successful, the peer if it is a failure. In addition:

(1) Suppose the inventor is a junior worker. If he says his project is bad, then if $\lambda_2 > p(b) + R/\Delta$, promote agent 2 and pay agent 1 $p(b)R$, otherwise promote agent 1 with probability $p(b)$ but pay him zero.

(2) Suppose the inventor is a senior worker. (a) Suppose he is not well ahead and (15) holds. If he says his project is bad, promote him with probability $p(g)$. (b) Otherwise: if he says his project is bad, promote him for sure. Pay him zero, except if the project is successfully implemented, then pay $\frac{1-p(g)}{p(g)}R$.

Except as mentioned, all wages are zero.

It is easy to check that the inventor will tell the truth, and the outcome mimics the optimal renegotiation-proof contract. Moreover, the binding constraint for a junior worker is that he should not say his project is *good* when he receives a *bad* signal: the *exaggeration* effect must be compensated for. The binding constraint for a senior workers is that he should not say his project is *bad* when he receives a *good* signal: the *false modesty* effect must be compensated for when the inventor is a senior worker.

Finally, the self-assessment procedure is renegotiation-proof. A project is implemented if and only if the inventor reports a good signal, and the principal does in fact want to go ahead with the project if and only if a good signal was received. When the project succeeds or fails, the correct agent is promoted. When the project is not implemented, the promotion policy is the same as the optimal renegotiation-proof contracts derived above, so by the same reasoning the self-assessment mechanism is renegotiation proof. Finally, the fact that the promotion policies and wages for a junior inventor are the same as under the optimal full commitment contract (from Propositions 4 and 5), and for a senior inventor the same as under the optimal renegotiation proof contract (from Proposition 9), means that the self assessment mechanism is always optimal under renegotiation constraints.

The other obvious candidate for a mechanism to elicit opinions is *peer review*: asking the agent who does not have a project to report on it. In fact, self assessment *strictly dominates* peer review. First, consider the case where the inventor is a junior worker. Consider the optimal contracts displayed in propositions 4 and 5. Suppose that only agent 2 reports his signal. If we were to replicate the optimal contract, the project must be implemented if and only if the peer supports it. Then by announcing $b$ the peer can guarantee himself a payoff of at least $(1 - p(b))R$. By announcing $g$ when he actually receives the signal $g$, he gets a lower payoff of $(1-p(g))R$. Therefore, the not invented here syndrome arises (i.e. the $\mathrm{IC}_2(g)$ constraint is violated), so the optimal contract cannot be replicated by peer review. Second, suppose the inventor is a senior worker. Consider the renegotiation-proof contract displayed above and suppose agent 2 reports his signal. If he announces $b$ when he actually receives the signal $b$ in that contract, then agent 1 gets promoted for certain and agent 2 gets a payoff of at most $(1 - p(g))R$. If he announces $g$, he can get a higher payoff of $(1 - p(b))R$ as he gets promoted when agent 1's project fails. Therefore, the flattery effect arises (i.e. the $\text{IC}_2(b)$ constraint is violated) and again the optimal renegotiation-proof contract cannot be replicated by peer review.

# 6 Appendix

## 6.1 Optimal Contracts

**Proof of Lemma 1**

(i) This follows from the fact that the disagreement payoffs $u_1^B(bg), u_1^G(bg)$ etc. only enter on the right hand side of the IC constraints.

(ii) The wages $w_1^G(gg)$ and $w_1^B(gg)$ enter in the principal's payoff and the $\text{IC}_1(g)$ constraints through the term

$$p(g)w_1^G(gg) + (1 - p(g))w_1^B(gg)$$

which is the expected wage to agent 1 when $\sigma = g$ and the project is implemented. Since both the principal and the agent only care about this expectation, it is without loss of generality to set $w_1^B(gg)$ as low as possible. A similar argument holds for $w_2^B(gg)$.

(iii) From (i) we can suppose all the disagreement wages are zero. Notice that $h(bg)$ only appears on the right-hand side of $\text{IC}_1(g)$ and $\text{IC}_2(b)$. It is intuitively clear that implementing the project after disagreement is optimal, as it conveys information about who was lying for free. Indeed, suppose a proposed contract has $h(bg) < 1$. Suppose the principal changes the contract in the following way: following the message $bg$, the project is implemented with probability one, and if the project turns out good, agent 1 is promoted with probability

$$h(bg)\theta^G(bg) + (1 - h(bg))\theta^\emptyset(bg)$$

(where $h(bg)$, $\theta^G(bg)$, $\theta^\emptyset(bg)$ are as specified in the original contract). If the project is bad, he promotes agent 1 with probability

$$h(bg)\theta^B(bg) + (1 - h(bg))\theta^\emptyset(bg).$$

This leaves the right-hand sides of $\text{IC}_1(g)$ and $\text{IC}_2(b)$ unchanged and does not affect the principal's welfare. Hence, we can assume without loss of generality that $h(bg) = 1$ and by a similar argument, $h(gb) = 1$.

(iv) Suppose $\theta^B(gg) > 0$. Consider changing the contract by reducing $\theta^B(gg)$ by $\epsilon$. Maintain the same expected payoffs (conditional on messages, outcomes and promotion decisions) for both agents, except that $u_2^B(gg)$ may have to be increased to respect the limited liability constraints (agent 2 is more often promoted if $\theta^B(gg)$ is reduced). Clearly, though, it will not be necessary to increase $u_2^B(gg)$ by more than $\epsilon R$. In the new contract the IC constraints are obviously still satisfied. The increase in expected wages is no greater than

$$\Pr(\sigma = g)(1 - p(g))\, h(gg)\epsilon R$$

while the principal gains

$$\Pr(\sigma = g)(1 - p(g))\, h(gg)\epsilon\lambda_2\Delta$$

because under the new contract he promotes agent 2 (who is good with probability $\lambda_2$) more often when agent 1 is *known* to be bad (after the outcome of the project was $B$). By (3), this improves the principal's payoff. The argument for $\theta^G(gg) = 1$ is similar.

(v) Consider $h(gg)$. By implementing the project when the signal is good, the principal gets more information because she can observe the outcome of the project. Since she can always disregard this information if she wants (cf. part (iii) of this Lemma), she can design a policy with $h(gg) = 1$ which implies no greater wage payments than a policy with $h(gg) < 1$. As messages $(gg)$ are received in equilibrium whenever $\sigma = g$, there is also a direct effect on the principal's revenue from increasing $h(gg)$. But this is positive, because $Gp(g)+B(1-p(g)) > 0$ by assumption. Therefore, $h(gg) = 1$ is optimal.

Consider $h(bb)$. Suppose a contract has $h(bb) = h^* > 0$. By an argument similar to part (iv), we can set $\theta^B(bb) = 0$ and $\theta^G(bb) = 1$. Consider a new contract where the project is never implemented following the message $(bb)$. Now the principal implements fewer unsuccessful projects and her expected income increases by

$$-\Pr(\sigma = b)h^*\left(Gp(b) + B(1 - p(b))\right) > 0 \tag{17}$$

In the old contract agent 1 got promoted with probability $\theta^\emptyset(bb)$ when the project was not implemented and messages were $bb$. In the new contract replace $\theta^\emptyset(bb)$ by $\hat{\theta}^\emptyset(bb)$, where $\hat{\theta}^\emptyset(bb)$ is chosen so that after $m = (bb)$ agent 1 has the same chance of being promoted as in the old contract (that is, $\hat{\theta}^\emptyset(bb) = h^*p(b) + (1 - h^*)\theta^\emptyset(bb)$). Pay the agents the same (conditional on promotion or no promotion) as under the old contract. As the probability of promotion and the wages are the same, the expected payoffs are the same as under the old contract, so the IC constraints still hold, and so do the limited liability constraints. The principal does lose something from not being able to find out the true quality of the agent when $\sigma = b$: this loss is

$$-\ \Pr(\sigma = b)h^*\left(p(b)(1 - \hat{\theta}^\emptyset(bb))(1 - \lambda_2) + (1 - p(b))\hat{\theta}^\emptyset(bb)\lambda_2\right)\Delta \tag{18}$$

To see this, consider what happens under the old contract when $\sigma = b$, $m = (bb)$ and the principal implements the project. With probability $p(b)$ the inventor is a good type, and the principal finds it out and promotes him. On the other hand, in the new contract, the principal will promote a bad agent 2 with probability $(1 - \hat{\theta}^\emptyset(bb))(1 - \lambda_2)$ instead. With probability $1 - p(b)$, the inventor is a bad type, and under the old contract the principal finds it out and promotes agent 2 who is good with probability $\lambda_2$. In the new contract, the principal will promote the bad agent 1 instead with probability $\hat{\theta}^\emptyset(bb)$, thus reducing the probability of promoting a good agent by $\hat{\theta}^\emptyset(bb)\lambda_2$. Now (2) makes sure that the sum of (18) and (17) is positive, so the new contract dominates. ■

We shall use the results from Lemma 1 in the following propositions.
**Proof of Proposition 2.**
Suppose the inventor is well ahead, that is,

$$\lambda_2 \leq p(b) - \frac{R}{\Delta} \tag{19}$$

Then, we claim the following is optimal:

$$\theta^{\emptyset}(bb) = \theta^G(gb) = \theta^B(bg) = 1$$

$$\theta^B(gb) = 0$$

$$\theta^G(bg) = \max\left\{0, 1 - \frac{(1-\lambda_1)(1-q)}{\lambda_1 q}\right\}$$

Each agent is paid a zero wage, *except* that $w_2^{\emptyset}(bb) = p(b)(1-\theta^G(bg))R$, and if $(1-\lambda_1)(1-q) \geq \lambda_1 q$ then

$$w_1^G(gg) = \left(\frac{(1-\lambda_1)(1-q)}{\lambda_1 q} - 1\right) R.$$

To show this, first consider increasing $\theta^{\emptyset}(bb)$ by $\epsilon > 0$ and $w_2^{\emptyset}(bb)$ by $R\epsilon$, thus compensating agent 2 for the reduced probability of promotion (recall that $h(bb) = 0$). By (19), this changes the principal's payoff by

$$\begin{aligned} & (\lambda_1(1-q)(1-\lambda_2) - (1-\lambda_1)q\lambda_2)\,\epsilon\Delta \quad - (\lambda_1(1-q) + (1-\lambda_1)q)\,R\epsilon \\ = \quad & (\lambda_1(1-q) + (1-\lambda_1)q)\,[(p(b) - \lambda_2)\,\epsilon\Delta \quad - R\epsilon] \geq 0 \end{aligned}$$

without violating any of the other constraints. Thus, set $\theta^{\emptyset}(bb) = 1$ from now on.

The $bg$ - variables only appear on the right hand side of $\mathrm{IC}_1(g)$ and $\mathrm{IC}_2(b)$ constraints. $\mathrm{IC}_2(b)$ will hold with equality, otherwise $w_2^{\emptyset}(bb)$ can be reduced ($w_2^{\emptyset}(bb) > 0$ as $\theta^{\emptyset}(bb) = 1$). We claim also $\mathrm{IC}_1(g)$ holds with equality. If not, then $w_1^G(gg) = 0$, and the principal will set the $bg-$ variables to minimize the right hand side of $\mathrm{IC}_2(b)$ as it is the only binding constraint involving the $bg$-variables. This implies:

$$1 - \theta^G(bg) = 1 - \theta^B(bg) = 0 \tag{20}$$

But, now $\mathrm{IC}_1(g)$ is

$$\lambda_1 q\; R \geq \lambda_1 q R + (1-\lambda_1)(1-q)R$$

which is violated. Thus, $\mathrm{IC}_1(g)$ holds with equality. By inspection of the principal's expected wage payments, we see that she cares about the *sum* of the left hand side of the $\mathrm{IC}_1(g)$ and $\mathrm{IC}_2(b)$ constraints. As both these constraints are satisfied with equality, she should set the $bg$- variables to minimize the sum of the right hand side of the $\mathrm{IC}_1(g)$ and $\mathrm{IC}_2(b)$ constraints, with the restriction that the right hand side of $\mathrm{IC}_1(g)$ must exceed $\lambda_1 q R$ for otherwise equality in $\mathrm{IC}_1(g)$ is incompatible with (11).

We claim $\theta^B(bg) = 1$ is optimal. In other words, promote agent 1 when he is "more likely to have told the truth". For if $\theta^B(bg) < 1$ then raising $\theta^B(bg)$ lowers the sum of expected wage payments as the right hand side of $\mathrm{IC}_1(g)$ increases more slowly than the right hand side of $\mathrm{IC}_2(b)$ falls by $q > 1-q$. Also, by a similar argument, the principal should set $\theta^G(bg)$ as low as possible. However, the right hand side of $\mathrm{IC}_1(g)$ must exceed $\lambda_1 qR$ . This yields two cases: (a) if $(1-\lambda_1)(1-q) \geq \lambda_1 q$ then set $\theta^G(bg) = 0$; (b) if $(1-\lambda_1)(1-q) < \lambda_1 q$, then set $\theta^G(bg) = 1 - \frac{(1-\lambda_1)(1-q)}{\lambda_1 q}$. In case (a), $w_1^G(gg) + R = \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} R \geq R$ and in case (b) $w_1^G(gg) = 0$, as there is equality in $\mathrm{IC}_1(g)$. Finally, $w_2^\emptyset(bb) = \frac{\lambda_1(1-q)}{\lambda_1(1-q)+(1-\lambda_1)q}(1-\theta^G(bg))R$, as there is equality in $\mathrm{IC}_2(b)$.

Finally, by setting $\theta^G(gb) = 1$, $\theta^B(gb) = 0$, $\mathrm{IC}_1(b)$ and $\mathrm{IC}_2(g)$ are satisfied with $w_1^\emptyset(bb) = w_2^G(gg) = 0$, and this is clearly optimal. ■

**Proof of Proposition 3**

Suppose the inventor is the senior worker but not well ahead, that is,

$$p(b) - \frac{R}{\Delta} < \lambda_2 \leq p(b) \tag{21}$$

Then, we claim the following is optimal:

$$\theta^\emptyset(bb) = 1 - p(b)(1-\theta^G(bg))$$

$$\begin{aligned} \theta^G(gb) &= 1 \\ \theta^B(gb) &= 0 \end{aligned}$$

$$\theta^G(bg) = \begin{cases} 0 & \text{if } \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} \geq 1 \\ 1 - \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} & \text{otherwise} \end{cases}$$

$$\theta^B(bg) = \begin{cases} \frac{\lambda_1 q}{(1-\lambda_1)(1-q)} & \text{if } \frac{(1-\lambda_1)(1-q)}{\lambda_1 q} \geq 1 \text{ and } p(b) - \lambda_2 - \frac{1-q}{q}\frac{R}{\Delta} < 0 \\ 1 & \text{otherwise} \end{cases}$$

$$\begin{aligned} w_2^\emptyset(bb) &= 0 \\ w_1^\emptyset(bb) &= 0 \\ w_2^G(gg) &= 0 \end{aligned}$$

$$w_1^G(gg) = \begin{cases} \left(\frac{(1-\lambda_1)(1-q)}{\lambda_1 q} - 1\right) R & \text{if } \frac{(1-\lambda_1(1-q)}{\lambda_1 q} \geq 1 \text{ and } p(b) - \lambda_2 - \frac{1-q}{q}\frac{R}{\Delta} \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

*Claim 1:* It is optimal to set $w_1^\emptyset(bb) = 0$.

*Proof :* Suppose $w_1^\emptyset(bb) > 0$. Then if $\theta^\emptyset(bb) < 1$ the principal can increase $\theta^\emptyset(bb)$ by $\epsilon > 0$, reduce $w_1^\emptyset(bb)$ by $\epsilon R$ and increase $w_2^\emptyset(bb)$ by $\epsilon R$. By (21), this increases her payoff by

$$\Delta\left(\lambda_1(1-q) + (1-\lambda_1)q\right)\left(p(b) - \lambda_2\right)\epsilon > 0 \tag{22}$$

without violating any incentive or limited liability constraints. Thus we can set $\theta^{\emptyset}(bb) = 1$. But then $\mathrm{IC}_1(b)$ is also slack, and $w_1^{\emptyset}(bb)$ can be lowered without violating any constraint.

*Claim 2:* $\mathrm{IC}_2(b)$ binds at the optimum.

*Proof :* Suppose not. Then $w_2^{\emptyset}(bb) = 0$ (or else the principal can lower $w_2^{\emptyset}(bb)$ without violating any constraints) and if $\mathrm{IC}_2(b)$ is not binding then $\theta^{\emptyset}(bb) < 1$. But we can raise $\theta^{\emptyset}(bb)$ by $\epsilon > 0$ which raises the principal's welfare by (22), which is positive by (21).

*Claim 3:* $\mathrm{IC}_1(g)$ binds at the optimum.

*Proof:* Suppose not. Then $w_1^G(gg) = 0$ (or else profit can be increased by reducing $w_1^G(gg)$) and $\theta^G(bg) < 1$. Hence, $\theta^G(bg)$ can be increased without violating $\mathrm{IC}_1(g)$ while relaxing $\mathrm{IC}_2(b)$. But when $\mathrm{IC}_2(b)$ is relaxed the principal can be made better off as shown in claim 2.

*Assume from now on that $IC_1(b)$ and $IC_2(g)$ do not bind.* (We will show later that this is indeed the case.) Under this assumption, it is clearly optimal to set $w_2^G(gg) = w_1^{\emptyset}(bb) = 0$

*Claim 4:* It is optimal to set $w_2^{\emptyset}(bb) = 0$.

*Proof :* Suppose $w_2^{\emptyset}(bb) > 0$. As $\mathrm{IC}_2(b)$ binds from Claim 2, $w_2^{\emptyset}(bb) + (1 - \theta^{\emptyset}(bb))R \leq R$, hence $\theta^{\emptyset}(bb) > 0$. Now $\theta^{\emptyset}(bb)$ can be decreased by $\epsilon$ and $w_2^{\emptyset}(bb)$ decresed by $\epsilon R$. (Recall we are neglecting $\mathrm{IC}_1(b)$ and $\mathrm{IC}_2(g)$). This increases the principal's payoff by

$$\epsilon\Delta\left(\lambda_1(1-q) + (1-\lambda_1)q\right)\left(\lambda_2 - p(b) + \frac{R}{\Delta}\right)$$

which is positive by (21).

*Claim 5:* Either $\theta^G(bg) = 0$ or $\theta^B(bg) = 1$.

*Proof :* Increasing $\theta^B(bg)$ and decreasing $\theta^G(bg)$ in such a way that the right hand side of $\mathrm{IC}_1(g)$ is constant, relaxes $\mathrm{IC}_2(b)$ while leaving all other constraints unchanged. This proves the claim.

Now we know that

$$w_2^G(gg) = w_1^{\emptyset}(bb) = w_2^{\emptyset}(bb) = 0 \tag{23}$$

and

$$(1-\theta^{\emptyset}(bb))R = p(b)(1-\theta^G(bg))R + (1-p(b))\,(1-\theta^B(bg))R \tag{24}$$

from $\mathrm{IC}_2(b)$ and

$$w_1^G(gg) + R = \theta^G(bg)R + \frac{(1-\lambda_1)(1-q)}{\lambda_1 q}\theta^B(bg)R \tag{25}$$

from $\mathrm{IC}_1(g)$. Using these expressions we can write the principal's payoff as a function of only $\theta^B(bg)$ and $\theta^G(bg)$. Changing $\theta^G(bg)$ by $\epsilon$ changes profits by

$$\Delta\lambda_1(1-q)\left(p(b) - \lambda_2 - \frac{q}{1-q}\frac{R}{\Delta}\right)\epsilon$$

and the expression in parenthesis is negative by (21). Hence, it is optimal to lower $\theta^G(bg)$ as much as possible subject to (25) and $w_1^G(gg) \geq 0$. There are two cases.

Case a: $\frac{(1-\lambda_1(1-q)}{\lambda_1 q} < 1$. Then claim 3 together with $w_1^G(gg) \geq 0$ implies $\theta^G(bg) > 0$ and hence $\theta^B(bg) = 1$ from claim 5. The lowest $\theta^G(bg)$ we can set is $\theta^G(bg) = \frac{\lambda_1 q-(1-\lambda_1)(1-q)}{\lambda_1 q}$, and then $w_1^G(gg) = 0$.

Case b: $\frac{(1-\lambda_1)(1-q)}{\lambda_1 q} \geq 1$. Then we can lower $\theta^G(bg)$ to zero without violating $w_1^G(gg) \geq 0$, so $\theta^G(bg) = 0$ is optimal. For $\theta^B(bg)$ there are two possibilities. If $p(b) - \lambda_2 - \frac{1-q}{q}\frac{R}{\Delta} \geq 0$ then an increase in $\theta^B(bg)$ by $\epsilon > 0$ increases the principal's profit by

$$(1-\lambda_1)q\Delta\left[p(b) - \lambda_2 - \frac{1-q}{q}\frac{R}{\Delta}\right]\epsilon$$

so $\theta^B(bg) = 1$ is optimal, with

$$w_1^G(gg) = \left(\frac{(1-\lambda_1)(1-q)}{\lambda_1 q} - 1\right)R$$

from (25). If $p(b) - \lambda_2 - \frac{1-q}{q}\frac{R}{\Delta} < 0$ then the principal's profit is decreasing in $\theta^B(bg)$ and the optimal $\theta^B(bg)$ is the lowest possible, subject to $w_1^G(gg) \geq 0$. Using (25) this gives $\theta^B(bg) = \frac{\lambda_1 q}{(1-\lambda_1)(1-q)}$ and $w_1^G(gg) = 0$ .

Finally, it can be checked that by setting $\theta^G(gb) = 1$ and $\theta^B(gb) = 0$, the omitted constraints are automatically satisfied. In fact, $\mathrm{IC}_2(g)$ is trivial and $\mathrm{IC}_1(b)$ becomes $\theta^\emptyset(bb) \geq p(b)$. Using (24), this requires

$$\theta^\emptyset(bb) = p(b)\theta^G(bg) + (1-p(b))\,\theta^B(bg) \geq p(b) \tag{26}$$

and it is easy to check that $q > 1-q$ implies that (26) is satisfied in both case *a* and case *b* above. ■

**Proof of Proposition 4**

Suppose

$$p(b) < \lambda_2 \leq p(b) + \frac{R}{\Delta} \tag{27}$$

We claim the following is optimal: set all wages equal to zero and

$$\begin{aligned} \theta^G(gb) &= \theta^G(bg) = 1 \\ \theta^B(gb) &= \theta^B(bg) = 0 \\ \theta^\emptyset(bb) &= p(b) \end{aligned}$$

We prove the proposition via a series of claims.

*Claim 1:* At the optimum, it must be the case that $w_2^\emptyset(bb) = 0$.

*Proof:* Suppose $w_2^\emptyset(bb) > 0$. If $\theta^\emptyset(bb) = 0$ then $\mathrm{IC}_2(b)$ is not binding and $w_2^\emptyset(bb)$ should be reduced to zero. If $\theta^\emptyset(bb) > 0$, then the principal can reduce $w_2^\emptyset(bb)$ by $\epsilon R$, increase $w_1^\emptyset(bb)$ by $\epsilon R$ and reduce $\theta^\emptyset(bb)$ by $\epsilon$. This increases her payoff (by (27)) without violating any incentive constraints.

*Claim 2:* $IC_1(b)$ binds at the optimum.

*Proof:* Suppose not. Then $w_1^\emptyset(bb) = 0$, or else the principal can lower $w_1^\emptyset(bb)$ without violating any constraints. Thus, $\theta^\emptyset(bb) > 0$ if $IC_1(b)$ does not bind. But lowering $\theta^\emptyset(bb)$ raises the principal's profit by (27) without violating any incentive constraints.

*Claim 3:* $IC_2(g)$ binds at the optimum.

*Proof:* Suppose not. Then we must have $w_2^G(gg) = 0$, and either $1 - \theta^G(gb)$ or $1 - \theta^B(gb)$ is strictly less than one. Hence, one of these variables can be increased without altering the principal's payoff and not violate $IC_2(g)$. This relaxes $IC_1(b)$, but then profit can be increased as in the proof of claim 2.

*Claim 4:* $\theta^B(gb) = 0$, $\theta^G(gb) = 1$ and $w_2^G(gg) = 0$.

*Proof:* By claims 2 and 3, $IC_1(b)$ and $IC_2(g)$ bind at the optimum. Therefore, at the optimum, the principal minimizes the sum of the right hand sides of $IC_1(b)$ and $IC_2(g)$ subject to the constraint that the right hand side of $IC_2(g)$ must be at least $(1-\lambda_1)(1-q)R$. Then, as $q > 1-q$, $1 - \theta^G(gb) = 0$ and $1 - \theta^B(gb) = 1$. Finally, $w_2^G(gg) = 0$ from $IC_2(g)$.

Assume $IC_1(g)$ and $IC_2(b)$ are not binding (we will verify this later). Then, clearly $w_1^G(gg) = w_2^\emptyset(bb) = 0$ is optimal.

*Claim 5:* $w_1^\emptyset(bb) = 0$.

Suppose $w_1^\emptyset(bb) > 0$. $IC_1(b)$ binding means $\theta^\emptyset(bb) < 1$. Lower $w_1^\emptyset(bb)$ by $\epsilon R$ and increase $\theta^\emptyset(bb)$ by $\epsilon$. This raises the principal's profit by

$$\Pr(\sigma = b)\epsilon\left(R - \Delta(\lambda_2 - p(b))\right) \geq 0$$

by (27) without violating any constraints. This proves the claim.

Claims 2 and 5 imply $\theta^\emptyset(bb) = p(b)$.

Finally, we can make sure $IC_1(g)$ and $IC_2(b)$ are satisfied by setting $\theta^B(bg) = 0$ and $\theta^G(bg) = 1$. ■

**Proof of Proposition 5**

Suppose

$$\lambda_2 > p(b) + \frac{R}{\Delta}. \tag{28}$$

We claim it is optimal to set all wages equal to zero except $w_1^\emptyset(bb) = p(b)R$, and

$$\begin{aligned} \theta^\emptyset(bb) &= \theta^B(bg) = \theta^B(gb) = 0 \\ \theta^G(gb) &= \theta^G(bg) = 1 \end{aligned}$$

Suppose $\theta^\emptyset(bb) > 0$. Then lower $\theta^\emptyset(bb)$ by $\epsilon$ and raise $w_1^\emptyset(bb)$ by $R\epsilon$. This changes the principal's payoff by

$$\Pr(\sigma = b)\left((\lambda_2 - p(b))\Delta - R\right)\epsilon > 0 \tag{29}$$

using (28), without violating any incentive constraints. Therefore, we must have $\theta^\emptyset(bb) = 0$ so agent 2 is always promoted if $m = (bb)$.

The $gb$-variables only appear in the $IC_2(g)$ and $IC_1(b)$ constraints. Notice that $IC_1(b)$ must hold with equality: otherwise just lower $w_1^{\emptyset}(bb)$. Therefore, as $q > 1-q$, it is optimal to set $\theta^B(gb) = 0$ as it reduces total expected wage payments. Then $IC_2(g)$ binds at the optimum: otherwise it must be the case that $w_2^G(gg) > 0$ but then $w_2^G(gg)$ can be reduced. Therefore, as $q > 1-q$, it is optimal to set $\theta^G(gb) = 1$ as it minimizes expected wage payments (the principal cares about the sum of the right hand sides of $IC_1(b)$ and $IC_2(g)$). But then, $IC_2(g)$ is satisfied with $w_2^G(gg) = 0$ so this is optimal. From $IC_1(b)$ we obtain $w_1^{\emptyset}(bb) = p(b)R$.

The $bg$-variables only appear on the right hand side of $IC_2(b)$ and $IC_1(g)$. This constraints are satisfied at minimum cost if $w_2^{\emptyset}(bb) = w_1^G(gg) = 0$, $\theta^B(bg) = 0$ and $\theta^G(bg) = 1$. ■

## 6.2 Optimal Renegotiation-Proof Contracts

First, even when contracts are required to be renegotiation proof, an argument along the lines of Lemma 1 shows that $h(bb) = 0$. Suppose the program in Section 3 is modified by not imposing $h(gg) = h(gb) = h(bg) = 1$, but instead imposing (12).

$$\begin{aligned}
&h(gg)\left(\lambda_1 q\left(G+\Delta-w_1^G(gg)-w_2^G(gg)\right)+\ (1-\lambda_1)(1-q)\left(B+\lambda_2\Delta\right)\right) \quad (30)\\
&+(1-h(gg))\left(\lambda_1 q\left(\theta^{\emptyset}(gg)\Delta+(1-\theta^{\emptyset}(gg))\lambda_2\Delta-w_1^{\emptyset}(gg)-w_2^{\emptyset}(gg)\right)\right)\\
&+(1-h(gg))\left(\ (1-\lambda_1)(1-q)\left((1-\theta^{\emptyset}(gg))\lambda_2\Delta-w_1^{\emptyset}(gg)-w_2^{\emptyset}(gg)\right)\right)\\
&\qquad+\left(\lambda_1(1-q)\left(\theta^{\emptyset}(bb)\Delta+(1-\theta^{\emptyset}(bb))\lambda_2\Delta-w_1^{\emptyset}(bb)-w_2^{\emptyset}(bb)\right)\right)\\
&\qquad+\left(\ (1-\lambda_1)q\left((1-\theta^{\emptyset}(bb))\lambda_2\Delta-w_1^{\emptyset}(bb)-w_2^{\emptyset}(bb)\right)\right)
\end{aligned}$$

subject to

$IC_1(g)$ :

$$\begin{aligned}
&h(gg)\ \lambda_1 q\left(w_1^G(gg)+R\right) \quad (31)\\
&+(1-h(gg))\left(\lambda_1 q+(1-\lambda_1)(1-q)\right)\left(w_1^{\emptyset}(gg)+\theta^{\emptyset}(gg)R\right)\\
\geq\ &h(bg)\lambda_1 qR+(1-h(bg))\left(\lambda_1 q+(1-\lambda_1)(1-q)\right)\theta^{\emptyset}(bg)R
\end{aligned}$$

$IC_1(b)$ :

$$\begin{aligned}
&(\lambda_1(1-q)+(1-\lambda_1)q)\left(w_1^{\emptyset}(bb)+\theta^{\emptyset}(bb)R\right)\\
\geq\ &h(gb)\lambda_1(1-q)R+(1-h(gb))\left(\lambda_1(1-q)+(1-\lambda_1)q\right)\theta^{\emptyset}(gb)R \quad (32)
\end{aligned}$$

$IC_2(g)$ :

$$\begin{aligned}
&h(gg)\left(\lambda_1 q w_2^G(gg)+(1-\lambda_1)(1-q)R\right)\\
&+(1-h(gg))\left(\lambda_1 q+(1-\lambda_1)(1-q)\right)\left(w_2^{\emptyset}(gg)+R(1-\theta^{\emptyset}(gg))\right) \quad (33)\\
\geq\ &h(gb)(1-\lambda_1)(1-q)R+(1-h(gb))\left(\lambda_1 q+(1-\lambda_1)(1-q)\right)R(1-\theta^{\emptyset}(gb))
\end{aligned}$$

$\mathrm{IC}_2(b)$ :

$$\begin{aligned}
&(\lambda_1(1-q)+(1-\lambda_1)q)\left(w_2^{\emptyset}(bb)+(1-\theta^{\emptyset}(bb))R\right) \\
\geq\ & h(bg)(1-\lambda_1)qR+(1-h(bg))\left(\lambda_1(1-q)+q(1-\lambda_1)\right)(1-\theta^{\emptyset}(bg))R
\end{aligned} \tag{34}$$

and the limited liability constraints:

$$w_1^G(gg), w_2^G(gg), w_1^{\emptyset}(bb), w_2^{\emptyset}(bb) \geq 0 \tag{35}$$

**Proof of Lemma 7**

We need to show that if the inventor is senior worker but not well ahead, then maximizing (30) subject to the IC constraints (31)-(34) and limited liability results in: $h(bg)=0$, $h(gg)=h(gb)=1$. If (14) holds then $\theta^{\emptyset}(bb)=\theta^{\emptyset}(bg)=1$ and

$$w_1^G(gg)=\frac{1-p(g)}{p(g)}R$$

Otherwise, $\theta^{\emptyset}(bb)=\theta^{\emptyset}(bg)=p(g)$ and $w_1^G(gg)=0$. All other wages are zero.

*Claim 1.* $h(gg)=1$.

*Proof.* Increase $h(gg)$ by $\epsilon$ and, if needed, increase $w_1^G(gg)$ and $w_2^G(gg)$ to keep the left hand sides of $\mathrm{IC}_1(g)$ and $\mathrm{IC}_2(g)$ constant. If either $w_1^G(gg)$ or $w_2^G(gg)$ is equal to zero and the limited liability constraint binds, then this change in $h(gg)$ increases either the left hand side of $\mathrm{IC}_1(g)$ by at most $\epsilon\lambda_1 qR$ or the left hand side of $\mathrm{IC}_2(g)$ by at most $\epsilon(1-\lambda_1)(1-q)R$. Notice though that it cannot be the case that both increase. Therefore, using the fact that the inventor is a senior worker so $p(g)>p(b)>\lambda_2$, the principal's payoff changes by at least

$$\epsilon\left(\lambda_1 q(G+\Delta)+\ (1-\lambda_1)(1-q)\left(B+\lambda_2\Delta\right)\right)-\epsilon\lambda_1 q\Delta-\epsilon\max\{\lambda_1 q,(1-\lambda_1)(1-q)\}R$$

which is strictly positive by Assumption 2. Hence, it is optimal to set $h(gg)=1$ as claimed.

*Claim 2.* $\mathrm{IC}_1(g)$ and $\mathrm{IC}_2(b)$ binds. Either $\theta^{\emptyset}(bb)=1$ or $w_1^{\emptyset}(bb)=0$.

*Proof.* Suppose $\mathrm{IC}_2(b)$ does not bind. Then $w_2^{\emptyset}(bb)=0$ or else $w_2^{\emptyset}(bb)$ could be lowered, and hence $(1-\theta^{\emptyset}(bb))R>0$. Now raise $\theta^{\emptyset}(bb)$ by $\varepsilon>0$. This respects all constraints and increases the principal's payoff by

$$\varepsilon\Delta\left(\lambda_1(1-q)\left(1-\lambda_2\right)-\ (1-\lambda_1)q\lambda_2\right)=\ \left(\lambda_1(1-q)+(1-\lambda_1)q\right)\ \varepsilon\Delta\left(p(b)-\ \lambda_2\right)>0 \tag{36}$$

as the inventor is a senior worker. Therefore, $\mathrm{IC}_2(b)$ must bind.

Suppose $\mathrm{IC}_1(g)$ does not bind and recall from Claim 1 that $h(gg)=1$. Then, $w_1^G(gg)=0$. Except for the slack constraint $\mathrm{IC}_1(g)$, $h(bg)$ and $\theta^{\emptyset}(bg)$ only enter $\mathrm{IC}_2$(b) which binds. Reducing the right hand side of $\mathrm{IC}_2(b)$ is advantageous because the principal can either lower $w_2^{\emptyset}(bb)$ or raise $\theta^{\emptyset}(bb)$ (the latter is strictly advantageous from (36)). Therefore, if $\mathrm{IC}_1(g)$ is slack the right hand side of $\mathrm{IC}_2(b)$ must be zero, which implies $\theta^{\emptyset}(bg)=1$ and $h(bg)=0$. However, together with $w_1^G(gg)=0$ this violates $\mathrm{IC}_1(g)$. Therefore $\mathrm{IC}_1(g)$ must bind.

Finally, suppose $\theta^{\emptyset}(bb) < 1$ and $w_1^{\emptyset}(bb) > 0$. Then, by raising $\theta(bb)$ by $\varepsilon$, reducing $w_1^{\emptyset}(bb)$ by $\epsilon R$ and increasing $w_2^{\emptyset}(bb)$ by $\epsilon R$, the sum of the wages is constant, all constraints are respected, and the principal payoff goes up by (36). This proves the claim.

We shall temporarily omit $\mathrm{IC}_1(b)$ and $\mathrm{IC}_2(g)$ from the program and show later that they are satisfied. In this case $w_1^{\emptyset}(bb) = w_2^{G}(gg) = w_2^{\emptyset}(gg) = 0$.

*Claim 3.* At the optimum, $\theta^{\emptyset}(bb) > 0$ and $w_2^{\emptyset}(bb) = 0$.

*Proof:* If $\theta^{\emptyset}(bb) = 0$, then as $\mathrm{IC}_2(b)$ binds we must have $h(bg) = \theta^{\emptyset}(bg) = 0$. Then the right hand side of $\mathrm{IC}_1(g)$ is zero, but this contradicts the fact that $\mathrm{IC}_1(g)$ is binding and $h(gg) = 1$. Thus, $\theta^{\emptyset}(bb) > 0$.

Now suppose $w_2^{\emptyset}(bb) > 0$. As $\theta^{\emptyset}(bb) > 0$ we can lower $\theta^{\emptyset}(bb)$ by $\varepsilon$ and $w_2^{\emptyset}(bb)$ by $\epsilon R$ without violating any constraints (recall we are omitting $\mathrm{IC}_1(b)$ from the program). The principal's expected payoff goes up by

$$\varepsilon\Delta\left(\lambda_1(1-q) + (1-\lambda_1)q\right)\left(-p(b) + \lambda_2 + \frac{R}{\Delta}\right) > 0$$

by not well aheadness. This proves the claim.

From $\mathrm{IC}_2(b)$ we now have

$$1 - \theta^{\emptyset}(bb) = h(bg)(1-p(b)) + (1-h(bg))(1-\theta^{\emptyset}(bg)) \tag{37}$$

and from $\mathrm{IC}_1(g)$ as $h(gg) = 1$

$$w_1^{G}(gg) = (1-h(bg))\left[\frac{\theta^{\emptyset}(bg)}{p(g)} - 1\right] R \geq 0 \tag{38}$$

Omitting constants in the principal's maximization problem, setting $w_1^{\emptyset}(bb) = w_2^{G}(gg) = w_2^{\emptyset}(bb) = 0$ and adding the constant term $-\lambda_1(1-q)\Delta$ we obtain

$$\begin{aligned}
& -\lambda_1 q w_1^{G}(gg) + \lambda_1(1-q)(1-\theta^{\emptyset}(bb))(\lambda_2 - 1)\Delta + (1-\lambda_1)q(1-\theta^{\emptyset}(bb))\lambda_2\Delta \\
= \; & -\lambda_1 q w_1^{G}(gg) + (1-\theta^{\emptyset}(bb))\Delta\left(\lambda_1(1-q)(\lambda_2-1) + (1-\lambda_1)q\lambda_2\right)
\end{aligned}$$

Next, using (37), the maximization problem is

$$\begin{aligned}
& -\lambda_1 q w_1^{G}(gg) + \left(h(bg)(1-p(b))\right. \\
& \left. +(1-h(bg))(1-\theta^{\emptyset}(bg))\right)\left(\lambda_1(1-q)(\lambda_2-1) + (1-\lambda_1)q\lambda_2\right)\Delta
\end{aligned}$$

and up to constants and using (38) this the same as

$$\begin{aligned}
& -\lambda_1 q(1-h(bg))\left[\frac{\theta^{\emptyset}(bg)}{p(g)} - 1\right] R \\
& \quad +(1-h(bg))(p(b) - \theta^{\emptyset}(bg))\left(\lambda_1(1-q)(\lambda_2-1) + (1-\lambda_1)q\lambda_2\right)\Delta \\
= \; & -(1-h(bg))\lambda_1\left[q\left[\frac{\theta^{\emptyset}(bg)}{p(g)} - 1\right] R + (1-q)\left(\lambda_2 - p(b)\right)\left[\frac{\theta^{\emptyset}(bg)}{p(b)} - 1\right]\Delta\right]
\end{aligned}$$

The derivative w.r.t. $\theta^{\emptyset}(bg)$ is positive if (14) holds, so in this case $\theta^{\emptyset}(bg) = 1$. Then, the derivative with respect to $h(bg)$ is omitting constants equal to

$$\begin{aligned} & \left[q\left[\frac{1}{p(g)} - 1\right] R + (1-q)\left(\lambda_2 - p(b)\right)\left[\frac{1}{p(b)} - 1\right]\Delta\right] \\ < & \left[q\left[\frac{1}{p(g)} - \frac{p(b)}{p(g)}\right] R + (1-q)\left(\lambda_2 - p(b)\right)\left[\frac{1}{p(b)} - 1\right]\Delta\right] \\ = & \ (1-p(b))\left[q\frac{1}{p(g)} R + (1-q)\left(\lambda_2 - p(b)\right)\frac{1}{p(b)}\Delta\right] \end{aligned}$$

which is negative by (14), so $h(bg) = 0$.

If (14) does not hold then $\theta^{\emptyset}(bg) = p(g)$ (the minimum $\theta^{\emptyset}(bg)$, from (38)) and again $h(bg) = 0$.

As $h(bg) = 0$, (37) implies $\theta^{\emptyset}(bg) = \theta^{\emptyset}(bb)$.

Finally, $\mathrm{IC}_1(b)$ and $\mathrm{IC}_2(g)$ are satisfied at zero cost by setting $h(gb) = 1$. ■

**Proof of Lemma 8**

Suppose the inventor is well ahead. We need to show that the program given by (30)-(35) and with the extra constraint $\theta^{\emptyset}(m) = 1$ for all $m$, is solved by $h(gb) = 1$, $h(bg) = 0$. All wages are zero, *except* that

$$w_1^G(gg) = \frac{1-p(g)}{p(g)} R$$

We shall omit $\mathrm{IC}_1(b)$ and $\mathrm{IC}_2(g)$ from the program, and later show they are satisfied. As in the proof of Lemma 7 one can show that $\mathrm{IC}_1(g)$ and $\mathrm{IC}_2(b)$ must bind. Then $w_1^{\emptyset}(bb) = w_2^G(gg) = 0$ and

$$w_1^G(gg) = (1-h(bg))\frac{1-p(g)}{p(g)} R$$

$$w_2^{\emptyset}(bb) = h(bg)\,(1-p(b))\,R \tag{39}$$

As $\theta^{\emptyset}(m) = 1$ for all $m$, the principal's payoff is, omitting constants:

$$\begin{aligned} & -\lambda_1 q w_1^G(gg) - \left(\lambda_1(1-q) + (1-\lambda_1)q\right) w_2^{\emptyset}(bb) \\ = & \ -(1-\lambda_1)\left((1-h(bg))(1-q) + h(bg)q\right) R \end{aligned} \tag{40}$$

so that $h(bg) = 0$ is optimal. Moreover, by setting $h(gb) = 1$ we guarantee that $\mathrm{IC}_1(b)$ and $\mathrm{IC}_2(g)$ hold. ■

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