# Launching a Thousand Ships: Incentives for Parallel Innovation

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**Abstract**

A crucial aspect of the innovation process is the exchange of ideas when several workers or teams explore new work methods in parallel. In such a setting, under-exploration may result as workers attempt to free-ride on the new ideas generated by co-workers. This paper studies optimal incentive schemes for innovation and shows that when workers can learn from each other's experience, incentives for innovation fundamentally differ from incentives for routine activities. Optimal incentives for routine activities take the form of standard pay-for-performance where only individual success determines compensation. In contrast, the optimal incentive scheme for parallel innovation tolerates early failure and provides workers with long-term group incentives for joint success. This result is in line with the empirical regularity that profit sharing, employee ownership, and broad-based stock option plans are positively associated with innovative activity. When subjects in a controlled laboratory experiment are asked to perform a task that requires creativity and exploration, they attempt to free-ride on exploration if given standard pay-for-performance contracts. Innovation success and performance is highest when subjects receive a group incentive scheme that rewards long-term joint success.

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# 1 Introduction

Innovation and creativity are crucially important for the success and survival of organizations. As a result, "stimulating innovation, creativity and enabling entrepreneurship" is a top priority for management and widely regarded as the "greatest human resource challenge" facing organizations according to CEO surveys.[1] Moreover, innovation activities are rarely, if ever, undertaken in isolation by a single individual. The traditional view of innovation as an activity performed by a lone R&D scientist working in isolation is not relevant anymore in today's organizations where several workers freely share ideas (Harden, Kruse and Blasi, 2008).

One of the difficulties with innovation is that there are often many different ways to innovate.[2] As a result, it would take too much time for organizations to try different approaches sequentially. Instead, firms may initially need to explore many different new work methods at once before settling on the most promising option. Many companies including Apple, AT&T, Black & Decker, Ford, General Electric, Sun Microsystems and Xerox have successfully used parallel innovation where several new approaches are explored simultaneously, in the development of new products (Zahra and Ellor, 1993; Stefik and Stefik, 2004). In such a setting, the advantage of parallel innovation is social learning: Innovators can learn from each other's results. The disadvantage, however, is free-riding: Given a mandate to innovate, individual innovators may decide either to shirk or to produce using tried-and-true methods, rather than to experiment with new ideas, planning to free-ride on successful innovations by their co-workers. The importance of both aspects of this trade-off has been documented in the literature. Henderson and Cockburn (1994) and Cano and Cano (2006) provide evidence that maintaining an extensive flow of information and encouraging the sharing of experiences between R&D workers has a positive effect on innovation performance in firms. On the other hand, Williams, Harkins and Lattane (1981) and Karau and Williams (1993) show that employees may resist exploring new approaches for fear of colleagues free-riding on their best ideas.

The central contribution of this paper is the theoretical and experimental analysis of incentive schemes for innovation for multiple agents. On the theoretical side, I show that when workers freely exchange ideas and can learn from each other's experience, incentives for innovation fundamentally differ from incentives for routine activities. Optimal incentives for routine activities take the form of standard pay-for-performance where only individual success determines compensation. However, when workers are to be motivated to innovate and to try new, untested work methods, standard pay-for-performance incentive schemes undermine workers' motivation to innovate. Instead, they encourage the use of conventional work methods as well as imitative free-riding on the successful ideas of other members of the organization. In contrast, the optimal incentive scheme for innovating and exploring new work methods tolerates early failure and provides workers with long-term *group* incentives for *joint* success.

My theoretical findings resonate with empirical studies documenting that within organizations,

[1]CEO Challenge 2004: Perspectives and Analysis, The Conference Board, Report 1353.

[2]For example, in response to the idea that he had failed after 10,000 experiments to develop a storage battery, Thomas Edison quipped, "I have not failed, I've just found 10,000 ways that won't work."

innovative activities go hand in hand with compensation schemes that reward long-term joint group success, such as profit/gainsharing, employee ownership, and broad-based stock option plans. However, these studies only document a positive correlation between long-term group incentives and innovation activity and performance. I therefore test the causal relationship between incentives and innovation activity in a controlled economic laboratory experiment. When subjects are asked to perform a task that requires creativity and exploration yet receive standard pay-for-performance compensation, the subjects significantly reduce their own individual exploration activities and instead rely on the innovating efforts of other subjects. Innovation success and performance are highest when subjects receive a group incentive scheme that rewards long-term joint success.

Previous empirical and experimental research in economics shows that paying the agent based on his performance induces the agent to exert more effort, improving productivity in simple routine tasks such as the installation of windshields, tree planting or letter typing (Lazear, 2000; Shearer, 2004; Dickinson, 1999) In contrast, a substantial body of experimental and field research in psychology provides evidence that, in tasks that require exploration and creativity, pay-for-performance may actually undermine performance. McGraw (1978), McCullers (1978), Kohn (1993) and Amabile (1996) summarize the findings of this line of research by stating that pay-for-performance encourages the repetition of what has worked in the past, but not the exploration of new, untested approaches. These studies thus conclude that, in tasks that involve creativity and innovation, standard monetary incentives should not be used to motivate agents.

There seems, however, to be a developing consensus that group incentives that reward agents for long-term joint success are particularly important in knowledge-intensive organizations, such as in firms that heavily rely on research and development. First, incentives for innovation should have a clear time structure which rewards long-term success. Using compensation data from 237 firms in the high-technology industry, Yanadori and Marler (2006) find that greater emphasis on innovation activities is positively associated with a greater reliance on long-term incentives and longer stock option vesting period lengths. Lerner and Wulf (2007) also document that long-term incentives are positively associated with several measures of innovation. Second, incentives for innovation should and do indeed have a clear group component. Harden, Kruse and Blasi (2008) find that shared compensation systems such as profit sharing, employee ownership, and broad-based stock option plans, are consistently positive predictors of both an innovation culture and a willingness to engage in innovative activity. Similarly, Tushman and O'Reilly (1997) argue that " individual-based awards may be less effective in promoting innovation than group-based recognition and rewards". Thus, various financial incentives that reward a large group of people for their long-term group performance are shown to go hand in hand with innovation.

I model the process of innovation by using a standard bandit problem which captures the tension between the exploration of new untested approaches and the exploitation of well-known conventional work methods. An informational externality arises naturally in innovation settings with multiple agents. After having chosen his preferred action each agent can learn from both his own and the past success of other agents about the success probability of different work methods. As a result, information and scientific discovery is a public good, and a free-rider problem in experimentation with new work methods arises. When solely compensated for their own performance, agents are biased towards choosing conventional work methods ("exploiting" actions with high expected value and well-known success probabilities) rather than new work methods ("explorative" actions with low expected value but less well-known success probabilities) and learning ex post from the performance of other agents. In equilibrium, there is too little exploration relative to the first best. In this setting, optimally designed incentives schemes that reward long term joint success can internalize this informational externality by allowing agents who explore low payoff tasks to benefit directly from the beneficial spillover effects of the exploration of new work methods. To study optimal incentives for innovation I embed this multi-agent bandit problem into a principal-agent framework where employing conventional and new work methods is costly but shirking is costless. In such a setting, the principal must weigh the benefits of group compensation against its disincentive effects that make shirking and free-riding more attractive.

When an agent is required to carry out routine tasks the optimal incentive scheme rewards the agent for individual success from the very beginning. The wages the agent receives are similar to standard pay-for-performance contracts. They are independent of the performance of other agents and pay the agent for individual success in each period. In contrast, the incentives for innovative tasks that require an agent to explore new work methods are radically different. The optimal contract that motivates parallel innovation consists of both individual and group incentives. In particular, it gives long-term incentives for joint success.

I proceed to test key aspects of my theoretical model in a laboratory experiment in which subjects are asked to perform a creative real effort task that involves innovation through exploration. The subjects are able to observe and learn from the actions of other subjects. To test the causal effect of incentive schemes on innovation, the subjects are exogenously administered different incentive contracts that share some of the key features of the optimal incentive contracts. I first show that social learning, the possibility of observing the choices of other players, improves innovation performance. Thus, the mutual exchange of information is beneficial for innovation. In addition, for a given learning environment, contracts that tolerate early failure and reward subjects for long-term success are shown to be more effective in promoting innovation than standard pay-for-performance contracts. However, social learning also reduces the incentives for individual exploration when subjects are rewarded for success from the beginning. I show that when subjects are given standard pay-for-performance incentives that do not tolerate early failure they free-ride on the exploration activities of other subjects by reducing individual exploration which entails an opportunity cost in such settings. Finally, I show that when subjects receive incentive contracts that tolerate early failure and reward long-term *group* success innovation performance is higher than it is when subjects are given incentives that are exclusively based on individual performance. This improvement in innovation performance is primarily due to subjects increasing their individual exploration over and above the level elicited by contracts that only reward long-term individual performance.

**Related Literature** By analyzing optimal incentives for innovation for multiple agents in a formal theoretical model, this paper brings together several different strands of literature. There are a number of papers that study optimal incentives when multiple agents use conventional work methods that do not involve exploration and learning. Holmstrom (1982) shows that relative performance evaluation can be helpful in reducing moral hazard costs, because it provides for better risk sharing. In contrast, Itoh (1991) focuses on moral hazard problems in multi-agent situations where cooperation is an issue. In such a setting, group compensation is optimal if the benefits of cooperation are sufficiently strong. However, in Itoh's model, group compensation is the result of the interaction dependencies of the agents' cost function rather than the result of informational spillovers that are a key aspect of innovation activities.

Another strand of the literature on incentive design focuses on compensation schemes that motivate innovation for a single agent. In Holmstrom (1989), optimal incentive schemes that motivate innovation exhibit a greater tolerance for failure since performance measures for innovation activities are noisier than measures for conventional work methods. In a similar vein, Aghion and Tirole (1994) argue that the difficulty of contracting on the unpredictable outcomes of innovation activities leads to muted incentives. The paper that is most closely related to the present analysis is Manso (2008) who explicitly models the trade-off between the exploitation of conventional work methods and the exploration of new approaches. He shows that the optimal innovation incentives for a single agent tolerate early failure and reward the agent for long-term success.

Bolton and Harris (1999) and Keller, Rady and Cripps (2005) study strategic experimentation with multiple agents and exogenous payoffs. As in my setting, information is a public good and there is under-exploration in equilibrium. In contrast to these papers, I endogenize the payoffs the agents receive to analyze optimal incentive schemes for multi-agent innovation.

A common approach to the study of incentives using laboratory experiments is either to give subjects a cost function and require them to choose an effort level (Bull, Schotter and Weigelt, 1987; Fehr, Gachter and Kirchsteiger, 1997; Nalbantian and Schotter, 1997) or to have subjects perform routine tasks such as typing letters (Dickinson, 1999), decoding a number from a grid of letters (Sillamaa, 1999), cracking walnuts (Fahr and Irlenbusch, 2000), solving two-variable optimization problems (van Dijk, Sonnemans and van Winden, 2001), and stuffing letters into envelopes (Falk and Ichino, 2006). These tasks, however, are inadequate to study incentives for innovation. My experimental analysis builds on Ederer and Manso (2008) who experimentally study incentives for innovation for single agents. In this paper I use the same task as in Ederer and Manso (2008), which involves real effort and also incorporates the trade-off between exploration and exploitation, essential in innovation activities. In addition, I allow for observational learning and informational spillovers so that subjects can learn from their own experience as well as from the exploration of other agents. This, in turn, allows me to study the effects of different multi-agent incentive schemes.

The paper is organized as follows. Section 2 develops the multi-agent bandit problem and illustrates the free-riding effect that arises naturally in innovation settings. Section 3 discusses the setup of the principal-agent model, Section 4 studies optimal incentives for several forms of exploitation and exploration. Section 5 presents the results of a laboratory experiment of multi-agent incentives for innovation. Section 6 concludes. Omitted proofs are contained in the Appendix.

# 2 The Multi-Agent Bandit Problem

In this section I review the two-agent, two-armed bandit problem with one known arm. This model illustrates the tension between exploitation and exploration as well as the informational externalities that naturally arise in such settings.

There are two identical risk-neutral agents, $A$ and $B$, who live for two periods and have a discount factor normalized to one. In each period, the two agents simultaneously take an action $i$, each producing output $S$ ("success") with probability $p_i$ or output $F$ ("failure") with probability $1 - p_i$. Without loss of generality, I normalize the payoffs of a success and a failure to 1 and 0. I let $E(p_i)$ denote the unconditional expectation of $p_i$, while $E(p_i|S_j)$ and $E(p_i|F_j)$ denote the conditional expectations of $p_i$ given a success or a failure of action $j$. When the agent chooses action $i$, he only learns about the probability $p_i$, so that

$$E(p_j) = E(p_j|S_i) = E(p_j|F_i) \text{ for } j \neq i.$$

Action 1 is the conventional work method. It has a known probability of success $p_1$ such that

$$p_1 = E(p_1) = E(p_1|S_1) = E(p_1|F_1).$$

On the other hand, actions 2 and 3 are the new work methods, which are independently identically distributed. They have the same unknown probability of success such that

$$E(p_j|F_j, F_j) < E(p_j|F_j) < E(p_j) < E(p_j|S_j) < E(p_j|S_j, S_j) \text{ for } j = 2, 3. \tag{1}$$

The new work methods are of exploratory nature and hence their success probability is initially lower than the success probability of the conventional work method. This relationship is captured by

$$E(p_j) < p_1 < E(p_j|S_j) \text{ for } j = 2, 3. \tag{2}$$

Finally, I assume that

$$p_1 < E(p_j|S_j, F_j) \text{ for } j = 2, 3. \tag{3}$$

This restriction implies that if exploration by both agents is chosen, it is socially optimal to explore two different new work methods in the first period rather than a single new work method twice in the first period.

Note that the success probabilities of the different work methods are independent. Thus, the performance of agents is uncorrelated when they employ different work methods. Furthermore, because the success probability of the conventional work method is known with certainty, the performance of both agents working on the conventional work method is also uncorrelated. However, the performance of two agents working on the same new work method is positively correlated since there is learning about the new work methods.

Each agent observes his own action choices and outcomes. In addition, at the beginning of the second period, each agent observes the outcome of the first-period choice of the other agent. This means that each agent can learn both from his own experience as well as the experience of the other agent.

## 2.1 Social Optimum

There are three distinct action paths which are primarily distinguished by whether zero, one or two agents explore in the first period. I call these three action plans pure exploitation, single innovation, and parallel innovation.

First, consider the case of pure exploitation, where both agents choose the conventional work method in the first period as well as in the second period. The payoff of this action plan is $4p_1$. Next, consider the case of single innovation, where one agent explores a new work method (either 2 or 3) in the first period, while the other agent chooses the conventional work approach. If the exploring agent is successful in the first period, both agents switch to the new work method, otherwise they both choose the conventional work method in the second period. The resulting payoff is

$$p_1 + E(p_2) + 2p_1\left(1 - E(p_2)\right) + 2E(p_2|S_2)E(p_2).$$

Finally, under parallel innovation both agents explore the new work methods 2 and 3 in the first period. If at least one of the new work methods is successful, then both agents switch to the new work method that was found to be successful in the first period. If neither work method is successful, the agents switch to action 1, the conventional work method. The payoff of this action plan is

$$2E(p_2) + 2E(p_2|S_2)\left[1 - \left(1 - E(p_2)\right)^2\right] + 2p_1\left(1 - E(p_2)\right)^2$$

where I used the fact that the two new work methods follow the same distribution.

Therefore, pure exploitation is optimal if

$$p_1 \geq E(p_2)\frac{1 + 2E(p_2|S_2)}{1 + 2E(p_2)} \tag{4}$$

while single innovation is optimal if

$$E(p_2)\frac{1 + 2E(p_2|S_2)}{1 + 2E(p_2)} \geq p_1 \geq E(p_2)\frac{1 + 2\left(1 - E(p_2)\right)E(p_2|S_2)}{1 + 2\left(1 - E(p_2)\right)E(p_2)} \tag{5}$$

and parallel innovation is optimal if

$$p_1 \leq E(p_2)\frac{1 + 2\left(1 - E(p_2)\right)E(p_2|S_2)}{1 + 2\left(1 - E(p_2)\right)E(p_2)}. \tag{6}$$

To summarize, if the success probability of the exploitative task $p_1$ is sufficiently high, pure exploitation is optimal, while parallel innovation is optimal if $p_1$ is sufficiently low. Single innovation is preferred for intermediate values of $p_1$. This relationship captures the tension between exploiting conventional work methods and exploring new approaches that arises in bandit problems. Even though the initial success probabilities $E(p_2) = E(p_3)$ are lower than the success probability of the conventional work approach, $p_1$, both agents are still willing to explore a new work method when $p_1$ is sufficiently low. Both agents choose to incur the opportunity cost of exploration because exploration of the new work method offers a learning benefit and has an option value. However, exploration of new work methods also exhibits diminishing returns. The exploration of a second additional new work method offers learning benefits over the conventional work method that are smaller than the learning benefits of exploring a single new work method. These diminishing returns are the result of "duplication" since the agents only require one of the new work methods to be better than the conventional approach. When both agents are successful in exploring the different work methods, they are indifferent which of the two is chosen in the second period. As a result of this duplication, as the success probability of the conventional work method increases (and the opportunity costs of exploration rise), it is efficient to let only one agent explore a new work method. Finally, when $p_1$ is large enough the opportunity costs of exploration are too large and no exploration is efficient.

## 2.2 Non-cooperative Interaction

Now consider the subgame perfect Nash equilibrium of the game between the two agents. I solve the game by backwards induction. Throughout the analysis I focus on pure-strategy equilibria so that in equilibrium each agent knows which actions the other agent chooses.

### 2.2.1 Second Period

After finding that the use of a new work method was successful in the first period, each agent strictly prefers to choose a successful new work approach rather than the conventional work approach in the second period. This is because the probability of success of a new work method after it was found to be successful in the first period is higher than the success probability of a conventional work method, $E(p_j|S_j) > p_1$ for $j = 2, 3$. On the other hand, if neither of the two new work methods was successful in the first period, each agent strictly prefers to use the conventional work method in the second period since $E(p_j|S_j) < p_1$. Finally, if neither of the new work methods was explored in the first period, each agent also strictly prefers to choose the conventional work method in the second period since $E(p_j) < p_1$. Thus, in the second period, each agent either chooses the new work method that was found successful in the first period or chooses the conventional work method if the new work method proved unsuccessful or if no exploration was undertaken.

### 2.2.2 First Period

If the other agent uses the conventional approach, action 1, in the first period, then the agent's payoff from exploring the new work methods, actions 2 or 3, in the first period is

$$E(p_2) + E(p_2|S_2)E(p_2) + p_1(1 - E(p_2))$$

while the payoff from using the conventional approach 1 in the first period is $2p_1$. If the other agent uses the other new work method, action 3, in the first period, then the agent's payoff from exploring the new work method, action 2, in the first period is

$$E(p_2) + E(p_2|S_2)\left[1 - (1 - E(p_2))^2\right] + p_1(1 - E(p_2))^2$$

while the payoff from using the conventional approach 1 in the first period is

$$p_1 + E(p_2|S_2)\left[1 - (1 - E(p_2))\right] + p_1(1 - E(p_2)).$$

Thus, there is a unique pure-strategy subgame perfect Nash equilibrium where both agents use the conventional work method in the first period (pure exploitation) if

$$p_1 \geq E(p_2)\frac{1 + E(p_2|S_2)}{1 + E(p_2)}. \tag{7}$$

If the conventional work method has a lower probability of success the parallel innovation equilibrium no longer exists. Instead, there is a unique pure-strategy subgame perfect Nash equilibrium where one agent explores a new work method and the other agent uses the conventional work method (single innovation) if

$$E(p_2)\frac{1 + E(p_2|S_2)}{1 + E(p_2)} \geq p_1 \geq E(p_2)\frac{1 + (1 - E(p_2))E(p_2|S_2)}{1 + (1 - E(p_2))E(p_2)} \tag{8}$$

Finally, there is a unique pure-strategy subgame perfect Nash equilibrium where both agents explore new work methods in the first period (parallel innovation) if

$$p_1 \leq E(p_2)\frac{1 + (1 - E(p_2))E(p_2|S_2)}{1 + (1 - E(p_2))E(p_2)}. \tag{9}$$

Thus, there is a parallel innovation equilibrium for low values of $p_1$, a single innovation equilibrium for intermediate values of $p_1$, and an exploitation equilibrium for high values of $p_1$.

## 2.3 Comparison

Comparing the equilibrium outcomes of the social optimum and the non-cooperative interaction between the agent immediately reveals that there is inefficient underexploration.

**Proposition 1** *There is inefficient underexploration if*

$$E(p_2)\frac{1+2\,(1-E(p_2))\,E(p_2|S_2)}{1+2\,(1-E(p_2))\,E(p_2)} \geq p_1 \geq E(p_2)\frac{1+(1-E(p_2))E(p_2|S_2)}{1+(1-E(p_2))E(p_2)}$$

*and if*

$$E(p_2)\frac{1+2E(p_2|S_2)}{1+2E(p_2)} \geq p_1 \geq E(p_2)\frac{1+E(p_2|S_2)}{1+E(p_2)}.$$

**Proof.** Direct comparisons of the thresholds for the social optimum and the non-cooperative equilibria from equations (4), (5), (6), (7), (8), and (9) immediately establish the relationships above. ■

Relative to the social optimum there is underexploration as the agents free-ride on each other's exploration activities in the subgame perfect Nash equilibrium. This occurs since exploration creates a positive informational externality which is not internalized in the non-cooperative interaction between the two agents. The exploration of new work methods allows the agents to learn, but it also entails an opportunity cost of foregoing the higher success probability of employing conventional work methods in the first period. In contrast, learning from the experience of other agents is costless. In a non-cooperative setting with exogenous payoffs, an agent may therefore elect not to explore a new work method even if it is socially desirable for him to do so.

A simple way to solve this imitative free-riding problem is to have the agents share the surplus between them evenly. This allows agents to capture fully the social benefit of their exploration activities and essentially reduces the non-cooperative problem to the social optimum problem yielding efficient exploration choices. However, as I show in the next section, such a simple compensation scheme is not optimal, when this multi-agent decision problem is embedded in a principal-agent framework.

## 3 The Principal-Multi-Agent Problem

To embed the multi-agent decision problem into a principal-agent framework I follow the approach of Manso (2008). Consider the setting where a principal employs two agents to perform the tasks described in the previous section. The agents privately choose actions, but the agents' outcomes are public information. Each agent incurs private costs $c_1 \geq 0$ if he chooses the conventional work method, action 1, private costs $c_2 = c_3 \geq 0$ if he chooses one of the two new work methods, actions 2 or 3, and he incurs no costs if he shirks, action 0. Shirking has a lower success probability than the conventional and the new work methods, so that

$$p_0 < E(p_i) \text{ for } i = 1, 2, 3. \tag{10}$$

To motivate the agents to employ the productive work methods the principal publicly offers each agent $h = A, B$ a wage contract $\overrightarrow{w}^h = \{\overrightarrow{w}_1^h, \overrightarrow{w}_{SS}^h, \overrightarrow{w}_{SF}^h, \overrightarrow{w}_{FS}^h, \overrightarrow{w}_{FF}^h\}$, which specifies agent $h$'s wages in the first and the second period. In the first period the wage vector is $\overrightarrow{w}_1^h$. In the

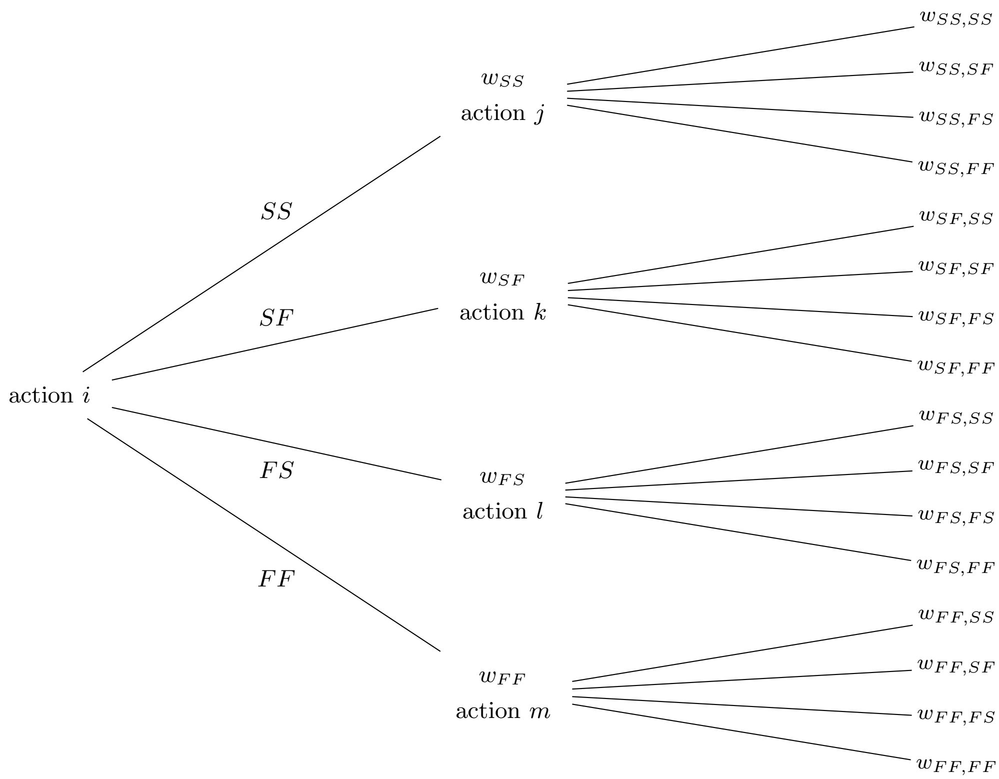


**Figure 1:** Actions taken and wages paid to agent $h$ in the first and second period given the outcomes of both agents.

second period following successes of both agents it is $\overrightarrow{w}^h_{SS}$ while following a success of agent $A$ and a failure of agent $B$ it is $\overrightarrow{w}^h_{SF}$. Similarly, following a failure of agent $A$ and a success of agent $B$ the wage vector is $\overrightarrow{w}^h_{FS}$, and following failures of both agents it is $\overrightarrow{w}^h_{FF}$. The 20 wages offered to agent $h$ are

$$\begin{aligned}
\overrightarrow{w}^h_1 &= \left\{w^h_{SS}, w^h_{SF}, w^h_{FS}, w^h_{FF}\right\} \\
\overrightarrow{w}^h_{SS} &= \left\{w^h_{SS,SS}, w^h_{SS,SF}, w^h_{SS,FS}, w^h_{SS,FF}\right\} \\
\overrightarrow{w}^h_{SF} &= \left\{w^h_{SF,SS}, w^h_{SF,SF}, w^h_{SF,FS}, w^h_{SF,FF}\right\} \\
\overrightarrow{w}^h_{FS} &= \left\{w^h_{FS,SS}, w^h_{FS,SF}, w^h_{FS,FS}, w^h_{FS,FF}\right\} \\
\overrightarrow{w}^h_{FF} &= \left\{w^h_{FF,SS}, w^h_{FF,SF}, w^h_{FF,FS}, w^h_{FF,FF}\right\}.
\end{aligned}$$

That is, the wage $w^h_{SF}$ specifies the wage given to agent $h$ in the first period if agent $A$ has a success and agent $B$ has a failure in the first period. The wage $w^h_{FS,SF}$ is the wage given to agent $h$ in the second period if agent $A$ has a failure and agent $B$ has a success in the first period and agent $A$ has a success and agent $B$ has a failure in the second period. Figure 1 depicts the wages paid to each agent $h$ in graphical form. Each agent has limited liability and therefore the wages cannot be negative.

Each agent $h$ thus chooses an action plan $\langle i {}^{j\ k}_{l\ m} \rangle$ to maximize his total expected payments $W^h(\overrightarrow{w}^h, \langle i {}^{j\ k}_{l\ m} \rangle)$ where $i$ is the first-period action, $j$ is the second-period action in case of a success of both agents in the first period, $k$ is the second-period action in case of a success of agent $A$ and a failure of agent $B$ in the first period, $l$ is the second-period action in case of a failure of agent $A$ and a success of agent $B$ in the first period, and $m$ is the second-period action in case of a failure of both agents in the first period. The total private expected costs that the agent incurs from choosing the action plan $\langle i {}^{j\ k}_{l\ m} \rangle$ is $C(\langle i {}^{j\ k}_{l\ m} \rangle)$.

An optimal contract that implements the desired action plan $\langle i {}^{j\ k}_{l\ m} \rangle$ for agent $h$ is a contract that minimizes the total expected wage payments $W^A + W^B$ subject to the incentive compatibility constraint $\text{IC}_{\langle n {}^{o\ p}_{q\ r} \rangle}$ of each agent $h$

$$W^h(\overrightarrow{w}^h, \langle i {}^{j\ k}_{l\ m} \rangle) - C(\langle i {}^{j\ k}_{l\ m} \rangle) \geq W^h(\overrightarrow{w}^h, \langle n {}^{o\ p}_{q\ r} \rangle) - C(\langle n {}^{o\ p}_{q\ r} \rangle) \text{ for } h = A, B. \tag{11}$$

Formally, this is a linear programming problem with 20 unknowns (wages) and 1024 incentive compatibility constraints. When there is more than one program that solves this program I focus on the contract that pays the agent earlier and that involves wages that solely depend on individual performance. These two assumptions are important since they allow me to focus on both the time structure as well as the group features of incentives for innovation. The assumptions mean that unless it is strictly cheaper for the principal to use delayed incentives or to condition the wages of a worker on the performance of other agent, the optimal contract pays the agent earlier and solely rewards him for individual success. Furthermore, the first assumption can be justified by assuming that the agent is slightly impatient and therefore prefers to be paid earlier. Similarly, the latter assumption can be justified by assuming a very small degree of risk aversion on behalf of the agent. If the agent is only slightly risk-averse it is cheaper not to make an agent's wage vary with the performance of another agent since this only imposes additional risk. To indicate that a wage only depends on individual performance I write, for example,

$$w_{A\cdot} \equiv w_{AS} = w_{AF}$$
$$w_{AB,S\cdot} \equiv w_{AB,SS} = w_{AB,SF}.$$

for $A = \{S, F\}$, $B = \{S, F\}$. Finally, to simplify notation I omit writing the superscript $h$ when it is clear which agent receives the compensation.

# 4 Optimal Incentive Schemes

In this section I analyze optimal contracts that implement pure exploitation, single innovation and parallel innovation. This paper is concerned with identifying what type of contracts will be used when a firm wants its workers to employ conventional work methods as opposed to when it wants them to innovate. Therefore, I do not study which of the three action schemes yields higher revenues and profits for the principal. In other words, I focus on the relationship between optimal incentive schemes and different work activities. Because the choice of action plan that is to be implemented is the sole determinant of which incentives will be used, considerations of profits and revenue are not the main interest.

### 4.1 Incentives for Pure Exploitation

I first turn my attention to analyzing the optimal incentive scheme for pure exploitation. The principal wishes to implement the action plan $\langle {\scriptstyle 1} \,{}^{1}_{1}\,{}^{1}_{1} \rangle$ for both agents. The following expressions will be helpful in stating the proposition regarding optimal incentives for pure exploitation

$$\begin{aligned} \alpha_1 &= \frac{c_1}{p_1 - p_0} \\ \beta_1 &= \frac{E(p_2) - p_0 + E(p_2)(E(p_2|S_2) - p_0)}{(1 + E(p_2))(p_1 - p_0)} \\ (x)^+ &\equiv \max\{x, 0\}. \end{aligned}$$

Furthermore, I write $w_{F\cdot} = w_{FS} = w_{FF}$ if the agent's wage is based only on individual performance and does not depend on whether agent B has a success or a failure.

**Proposition 2** *The optimal contract to implement exploitation for both agents is such that for agent A the first-period wages are*

$$w_{S\cdot} = \alpha_1 + \frac{c_1(1 + E(p_2))}{p_1 - E(p_2)} \left( \beta_1 - \frac{c_2}{c_1} \right)^+ \ \textit{and} \ w_{F\cdot} = 0$$

*and the second-period wages are*

$$w_{S\cdot,S\cdot} = w_{F\cdot,S\cdot} = \alpha_1 \ \textit{and} \ w_{S\cdot,F\cdot} = w_{F\cdot,F\cdot} = 0.$$

*The analogous contract is optimal for agent B.*

**Proof.** See appendix. ∎

To implement pure exploitation the principal must structure wages in such a way as to deter shirking and exploring. In particular, the optimal contract that implements pure exploitation has two prominent features.

First, incentives are entirely based on individual performance. This means that in every period, each agent receives the same wages regardless of how the other agent performed. The intuition for this result is the following. Both agents choose to use the conventional work method and therefore the first-period performance of the other agent does not convey any new information to the agent when he decides which work method to adopt in the second period. Furthermore, the absence of learning implies that the agents' performances are independent and thus individual performance is a sufficient statistic. Hence, the principal does not benefit from using an incentive scheme that conditions an agent's wage on the performance of both agents. The principal can therefore restrict attention to a completely individual incentive contract.

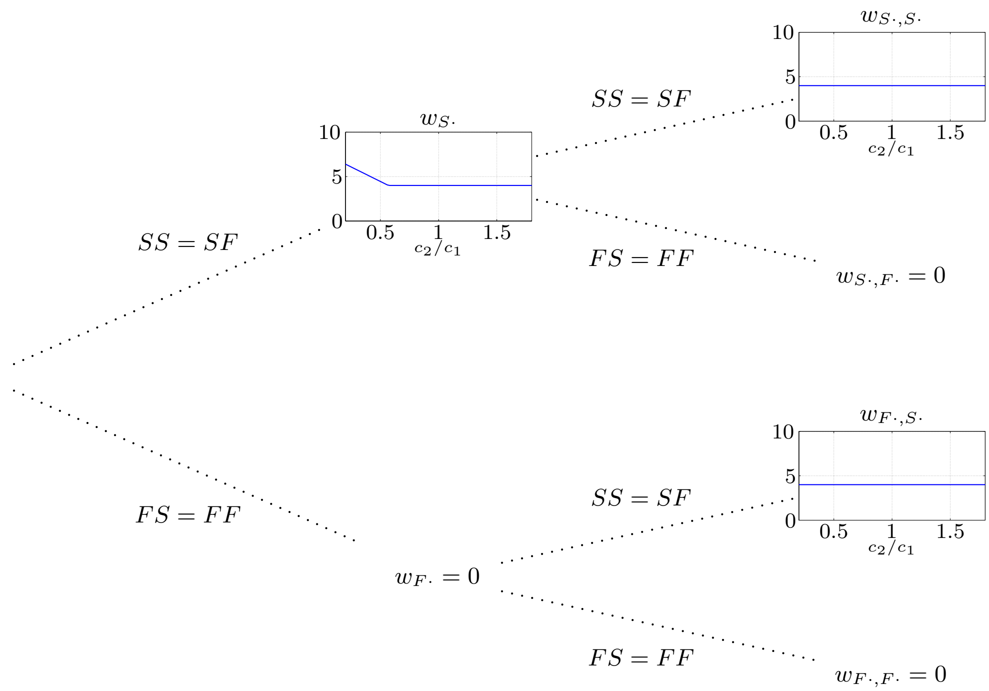


**Figure 2:** Wages in the first and second period for agent $A$ under the optimal contract that implements pure exploitation.

Second, incentives for pure exploitation reward each agent for success in the first and in the second period and no wages are paid whenever an agent fails. If $\frac{c_2}{c_1} \geq \beta_1$, then the exploration constraint $\text{IC}_{\langle 2\,{}^{2}_{1}\,{}^{2}_{1}\rangle}$ is not binding and the contract takes the same form as a standard repeated moral hazard contract. Throughout, the principal pays the agent the same wage for success, so that $w_{S\cdot} = w_{S\cdot,S\cdot} = w_{F\cdot,S\cdot} = \alpha_1$. However, if $\frac{c_2}{c_1} < \beta_1$ the exploration constraint is binding since the new work method is very cheap to use relative to the conventional work method. In this case, the principal must pay each agent an extra premium for success in the first period, so that $w_{S\cdot} \geq w_{S\cdot,S\cdot} = w_{F\cdot,S\cdot} = \alpha_1$. Naturally, this premium is decreasing in the relative private costs of the new work method.

Figure 2 shows the wages in the first and second period for agent $A$ of the optimal contract that implements pure exploitation for different values of $\frac{c_2}{c_1}$ under the base case parameters.[3] The agent is rewarded only for individual success and his wages do not depend on the performance of the other agent.

## 4.2 Incentives for Single Innovation

I now focus on the optimal contract that implements single innovation. The principal wishes to implement the action plan $\langle 2\,{}^{2}_{1}\,{}^{2}_{1}\rangle$ for agent $A$ (explorer) and the action plan $\langle 1\,{}^{2}_{1}\,{}^{2}_{1}\rangle$ for agent $B$

[3] The base case parameters used in all the figures are $p_0 = 0.25$, $E(p_2) = 0.3$, $p_1 = 0.5$, $E(p_2|S_2) = 0.7$, $E(p_2|S_2, F_2) = 0.55$ and $c_1 = 1$. From Bayes' rule it follows that $E(p_2|F_2) = 0.1286$, $E(p_2|S_2, S_2) = 0.7643$ and $E(p_2|F_2, F_2) = 0.0664$.

(exploiter). The optimal contracts for the two agents are structured differently so that agent $B$ uses the conventional work method in the first period while agent $A$ explores the new work method. I begin with characterizing the optimal incentive scheme for the exploiting agent $B$ as it is similar to the optimal contract given to agents under pure exploitation.

### 4.2.1 Incentives for Exploiting Agent

It is useful to define the following expressions for the next proposition which states the optimal contract for the agent working on the conventional work method in the first period

$$
\begin{aligned}
\alpha_2 &= \frac{1}{E(p_2|S_2)} \max_{j=0,1} \frac{c_2 - c_j}{E(p_2|S_2, S_2) - p_j} \\
\beta_2 &= \frac{E(p_2) - p_0 + E(p_2)(1 - E(p_2))(E(p_2|S_2) - p_0)}{[1 + E(p_2)(1 - E(p_2))]\,(p_1 - p_0)}
\end{aligned}
$$

**Proposition 3** *The optimal contract to implement single innovation is such that for the exploiting agent (agent $B$) the first-period wages are*

$$
w_{\cdot S} = \alpha_1 + \frac{c_1 [1 + E(p_2)(1 - E(p_2))]}{p_1 - E(p_2)} \left(\beta_2 - \frac{c_2}{c_1}\right)^+ \quad \textit{and } w_{\cdot F} = 0
$$

*and the second-period wages are*

$$
\begin{aligned}
&w_{S\cdot,SS} = \alpha_2 \ \textit{ and } w_{S\cdot,SF} = w_{S\cdot,FS} = w_{S\cdot,FF} = 0 \\
&w_{F\cdot,\cdot S} = \alpha_1 \ \textit{ and } w_{F\cdot,\cdot F} = 0.
\end{aligned}
$$

**Proof.** See appendix. ■

The optimal contract for the exploiting agent when the principal wishes to implement single innovation is similar to the optimal contract in the pure exploitation case, with a few important exceptions.

First, as in the pure exploitation case, wages only depend on individual performance in the first period and in the second period following a failure of the exploring agent in the first period. In the first period, the two agents use different work methods and hence their performances are independent, allowing the principal to structure incentives on a purely individual basis. When the exploring agent is unsuccessful with the new work method in the first period, both agents use the conventional work method in the second period. Since there is no learning about this established work method, the success and failure outcomes of the two agents are again uncorrelated and individual incentives for success are optimal.

Second, the exploiting agent receives rewards for success in the first and the second period and the principal does not make payments for a failure. If $\frac{c_2}{c_1} \geq \beta_2$, then the exploration constraint $\text{IC}_{\langle 3 \, {}^{2}_{3} \, {}^{2}_{1} \rangle}$ is not binding. Note that this exploration constraint is similar to the exploration constraint in the pure exploitation case. The exploiting agent always strictly prefers to explore a new work method (action 3) that is different from the new work method that the exploring agent uses (action 2). The contract takes the same form as a standard repeated moral hazard contract. The principal pays the agent the same wage for success in the first period and in the second period following a failure of the exploring agent, so that $w_{\cdot S} = w_{\cdot F, \cdot S} = \alpha_1$. On the other hand, if $\frac{c_2}{c_1} < \beta_2$ the exploration constraint is binding since the new work method is very cheap to use relative to the conventional work method. In this case, the principal must pay each agent an extra premium for success in the first period, so that $w_{\cdot S} \geq w_{\cdot F, \cdot S} = \alpha_1$. As before, this premium is decreasing in the relative costs of the new work method. At the same time, this premium is lower and paid less often than in the pure exploitation case, since $\beta_1 > \beta_2$. The reason for this lower bonus is that in the pure exploitation case, when an agent deviates to exploring a new work method, he fully benefits from his exploration in the case of a success. In contrast, under single innovation, the other agent is already exploring a new work method and so the exploiting agent only benefits from a success of the new work method when the exploring agent is unsuccessful with a new work method in the first period. In other words, since the other agent is already exploring a new work method, further exploration is less attractive and thus the principal needs to pay a smaller premium to deter such a deviation. Furthermore, the decrease in the beneficial effects of exploration is also a direct result of the free-riding effect identified in Proposition 1 where agents found it less appealing to explore once another agent undertook exploration activities. However, in the present case such free-riding allows a reduction in the wage bill of the principal who needs to deter exploration for the exploiting agent.

Finally, when the exploring agent is successful, the exploiting agent receives a standard moral hazard payment $\alpha_2$ in the second period if he is successful, which serves to deter him from shirking or choosing the conventional work method. Because the agents still learn about the new work method even after a success, i.e. $E(p_2|S_2, S_2) > E(p_2|S_2)$, the performances of the two agents are positively correlated when the agents both choose the new work method. Thus, it is cheaper for the principal to reward the exploiting agent only when both agents are successful rather than to base compensation on individual success only.

Figure 3 depicts the optimal contract for the exploiting agent $B$ graphically. The agent is rewarded for individual success in the first period and in the second period if the exploring agent was unsuccessful in the first period. If the exploring agent was successful in the first period, the agent is only rewarded for joint success in the second period.

In summary, the structure of the optimal contract involves a mix of individual and team compensation. For the exploiting agent, the optimal contract rewards the agent for success from the first period in order to deter the agent from shirking and exploring. While first-period incentives and second-period incentives following a failure do not depend on the other agent's performance, the exploiting agent is compensated for joint success in the second period following a success of the exploring agent in the first period.

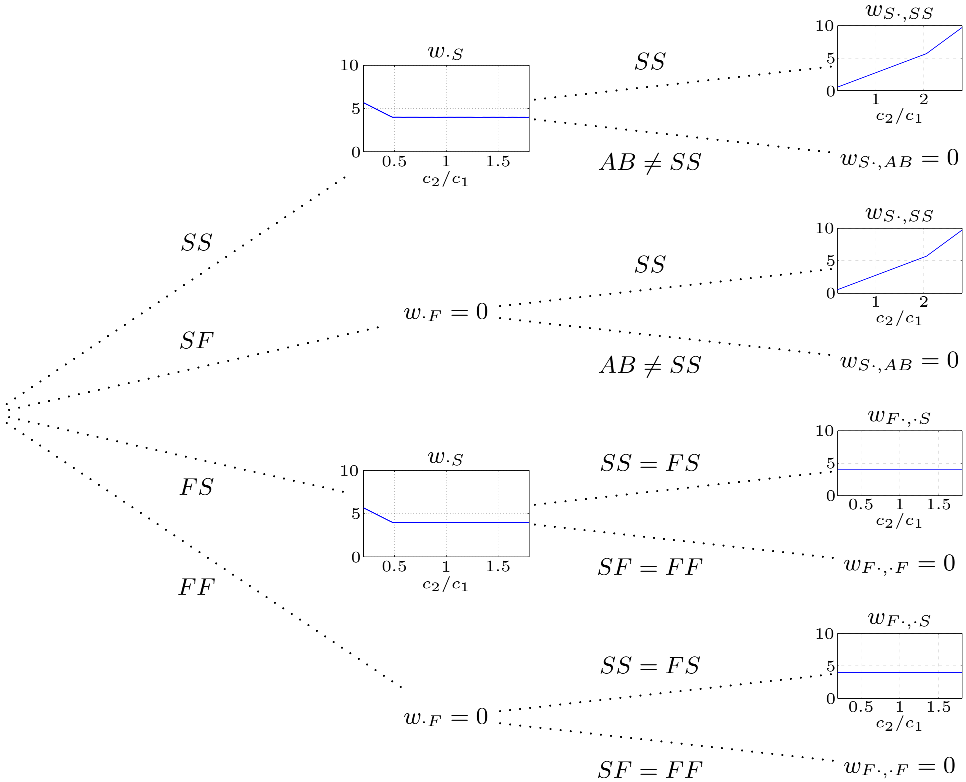


**Figure 3:** Wages in the first and second period for the exploiting agent $B$ under the optimal contract that implements single innovation.

### 4.2.2 Incentives for Exploring Agent

I now turn my attention to optimal contract for the exploring agent (agent $A$). It is helpful to distinguish two cases. I say that exploration is very radical if

$$\frac{1 - E(p_2)}{1 - p_1} \geq \frac{E(p_2|S_2)E(p_2|S_2, S_2)}{p_1 p_1}.$$

Define the following expressions:

$$\alpha_3 = \max_{j=0,1,2} \frac{(1 + E(p_2))c_2 - p_0 c_j + (E(p_2) - p_0)p_0\alpha_1}{E(p_2)\left[E(p_2|S_2)E(p_2|S_2, S_2) - p_0 E(p_j|S_2)\right]}$$

$$\beta_3 = \frac{E(p_2|S_2)E(p_2|S_2, S_2) - p_0 p_1 + p_1(E(p_2|S_2)E(p_2|S_2, S_2) - E(p_2)p_0))}{(1 + E(p_2))(p_1 - p_0)p_1}$$

$$\gamma_1 = \frac{p_1(p_1 - p_0)(1 + E(p_2))c_1}{E(p_2)\left[E(p_2|S_2)E(p_2|S_2, S_2) - p_1 p_1\right]\left[E(p_2|S_2)E(p_2|S_2, S_2) - p_0 p_1\right]}$$

$$\gamma_2 = \frac{p_1(1 + E(p_2))c_1}{E(p_2|S_2)E(p_2|S_2, S_2) - p_1 E(p_2)}$$

$$\gamma_3 = \frac{p_1(E(p_2) - p_0)(1 + E(p_2))c_1}{E(p_2)\left[E(p_2|S_2)E(p_2|S_2, S_2) - p_0 p_1\right]\left[E(p_2|S_2)E(p_2|S_2, S_2) - p_1 E(p_2)\right]}$$

The optimal contract for the exploring agent for single innovation is given by the following proposition.

**Proposition 4** *If exploration is not very radical the optimal contract to implement single innovation is such that for the exploring agent (agent A), the first-period wages are*

$$w_{S\cdot} = 0 \text{ and } w_{F\cdot} = 0$$

*and the second-period wages are*

$$w_{S\cdot,SS} = \alpha_3 + \gamma_1 \left(\frac{c_2}{c_1} - \beta_3\right)^+ \text{ and } w_{S\cdot,SF} = w_{S\cdot,FS} = w_{S\cdot,FF} = 0$$
$$w_{F\cdot,S\cdot} = \alpha_1 \text{ and } w_{F\cdot,F\cdot} = 0.$$

*On the other hand if exploration is very radical*

$$w_{F\cdot} = \gamma_2 \left(\frac{c_2}{c_1} - \beta_3\right)^+$$
$$w_{S\cdot,SS} = \alpha_3 + \gamma_3 \left(\frac{c_2}{c_1} - \beta_3\right)^+.$$

**Proof.** See appendix. ■

The optimal contract for the exploring agent deters the agent from shirking or exploiting. While the contract shares some similarities with the previously analyzed contracts that implement the use of conventional work methods in the first period, it differs in several important aspects.

First, as in the previous cases, wages depend only on individual performance in the first period and in the second period following a failure of the exploring agent in the first period. This occurs for precisely the same reasons as under parallel innovation since the agents either choose different work methods or both choose conventional work methods. Performance in both of these cases is uncorrelated and individual rewards for success are therefore optimal. After a failure of the exploring agent in the first period, the principal pays the agent $\alpha_1$ in case of a success tn the second period to prevent him from shirking. The principal gives no rewards in case of a failure.

Second, the principal does not make payments for success in the first period, both because rewarding first-period performance gives the exploring agent incentives to employ the conventional work method, and because additional information about the first-period action is provided by second-period performance. Delaying compensation is therefore optimal. The principal may even reward the agent for his failure in the first period. Loosely speaking, this is useful when a failure in the first period is a stronger signal that the agent has chosen the new work method than a success in the first period followed by successes of both agents in the second period.

Finally, when the exploring agent is successful in the first period, the principal makes a payment only if both agents are successful in the second period. Since there is still learning about the new

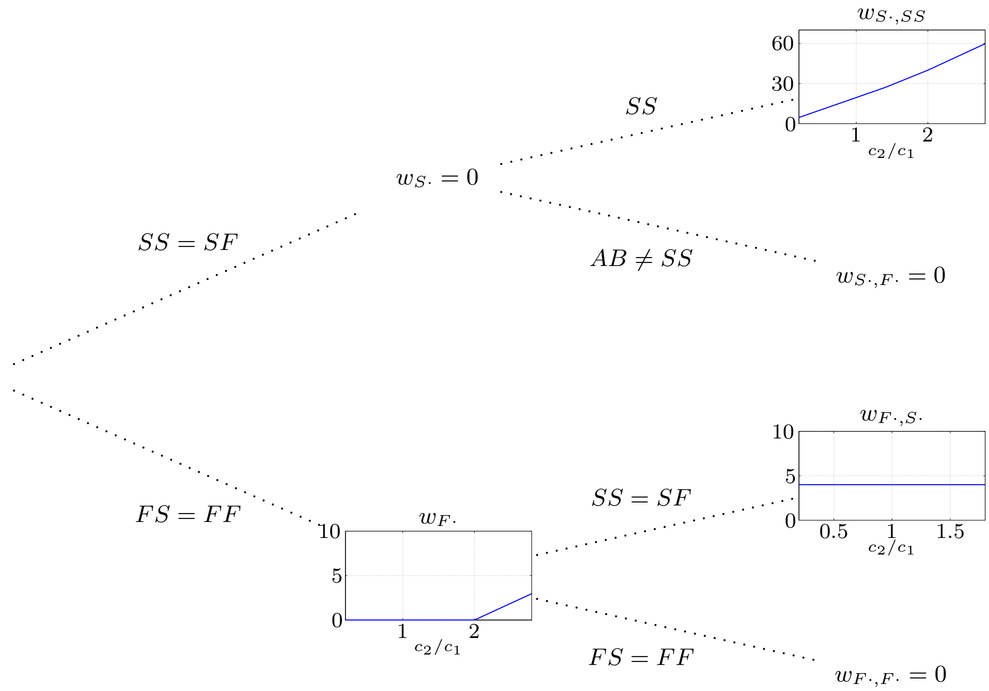


**Figure 4:** Wages in the first and second period for the exploring agent $A$ under the optimal contract that implements single innovation.

work method, the performance of the agents is correlated when they both employ the new work method, and thus it is cheaper to reward joint success. If $\frac{c_2}{c_1} < \beta_3$, then the new work method is relatively cheap compared to the conventional work method and therefore the exploitation constraint $\text{IC}_{\langle 1 \frac{1}{1} \frac{1}{1} \rangle}$ is not binding and the principal only needs to deter the exploring agent from shirking. To do so, the principal pays the agent $w_{S\cdot,SS} = \alpha_3$, which just deters the agent from shirking in the first period and in the second period after a success in the first period. If $\frac{c_2}{c_1} \geq \beta_3$, then the new work method is relatively costly compared to the conventional work method and hence the exploitation constraint is binding. To deter the agent from employing the conventional work method in the first period the principal uses the wages $w_{S\cdot,SS}$ and/or $w_{F\cdot}$ where the choice of these instruments depends on whether or not exploration is very radical. In both cases, the principal is forced to pay a premium over and above $\alpha_3$ to deter the agent from exploiting. Relative to the case of incentives for exploration in the single-agent model of Manso (2008), the exploring agent receives a strictly positive wage $w_{F\cdot}$ for failure in the first period for a smaller range of parameter values. The presence of two rather than just one agent employing the new work method implies that there is more additional information that is obtained in the later stages of the multi-agent model, and thus compensation for joint success in the second period after a success of the exploring agent in the first period is likely to be cheaper than compensation for failure in the first period. Figure 4 graphically shows the wages offered to the exploring agent.

In summary, the structure of the optimal contract for the exploring agent involves a mix of individual and team compensation. In contrast to the incentives for the exploiting agent, the exploring agent does not receive any compensation for success in the first period and may even be rewarded for failure. Compensation is biased towards paying the agent for joint success in the second period if he was successful in the first period. This is less costly for the principal than paying the agent for situations where the two agents have different second-period outcomes and when they both fail. If the agent is unsuccessful in the first period incentives in the second period again are identical to those obtained in a standard repeated moral-hazard model. The principal only has to ensure that the agent would rather choose the conventional work method than shirk.

### 4.3 Parallel Innovation

Consider now the setting where the principal wants both of his agents to explore in the first period. This means that the principal wants to implement the action plan $\langle 2\, {}^{2}_{3}\, {}^{2}_{1} \rangle$ for agent $A$ and the action plan $\langle 3\, {}^{3}_{3}\, {}^{2}_{1} \rangle$ for agent $B$. Note that these are symmetric action plans where the agents choose to explore different new work methods in the first period. If both agents are successful, they each continue to employ the new work methods (action 2 and action 3) they used in the first period. If only one agent is successful in the first period, both agents employ the new work method (action 2 or action 3) that proved successful in the first period. Finally, if neither agent is successful in the first period, they both employ the conventional work method in the second period.

I focus on optimal symmetric contracts for the two agents. The following proposition again shows that the optimal contract involves a mix of individual and team incentives. As before, I can distinguish between two cases that determine whether $w_{F\cdot}$ is equal or greater to zero. This depends on whether the following inequality is satisfied:

$$\frac{1 - E(p_2)}{1 - p_1} \geq \frac{E(p_2|S_2, S_2)}{p_1}.$$

More importantly, I say that free-riding is cheap if

$$\frac{c_3}{c_1} \leq \frac{E(p_3|S_3) - p_0}{p_1 - p_0}$$

while free-riding is costly otherwise. I define the following expression,

$$\alpha_4 = \max_{j=0,1} \frac{c_2 - c_j}{E(p_2|S_2) - p_j},$$

and $\beta_4, \beta_5 > 0$ as well as $\gamma_4, \gamma_5, \gamma_6, \gamma_7, \gamma_8, \gamma_9 > 0$. The exact expressions used in the following proposition can be found in the appendix.

**Proposition 5** *The optimal contract to implement parallel innovation is such that for agent A* *(and conversely for agent $B$) the wages are*

$$\begin{aligned}
w_{S\cdot} = w_{SS,FS} = w_{SS,FF} = w_{SF,SF} = w_{SF,FS} = w_{SF,FF} = 0 \\
w_{FS,SF} = w_{FS,FS} = w_{FS,FF} = w_{FF,FS} = w_{FF,FF} = 0 \\
w_{FF,S\cdot} = \alpha_1 \\
w_{FS,SS} = \alpha_3.
\end{aligned}$$

*If free-riding is cheap*

$$\begin{aligned}
w_{SS,SS} &= \alpha_4 - \gamma_4 \left( \frac{c_3}{c_1} - \beta_4 \right) \\
w_{SS,SF} &= \begin{cases} \alpha_4 + \gamma_5 \frac{c_3}{c_1} & \text{if } \frac{c_3}{c_1} \leq \beta_4 \\ \alpha_4 + \gamma_6 \left( \beta_4 - \frac{c_3}{c_1} \right) & \text{if } \frac{c_3}{c_1} > \beta_4 \end{cases}
\end{aligned}$$

*while if free-riding is costly*

$$w_{SS,SS} = w_{SS,SF} = \alpha_4.$$

*If $\frac{1-E(p_2)}{1-p_1} < \frac{E(p_2|S_2,S_2)}{p_1}$ then*

$$\begin{aligned}
w_{F\cdot} &= 0 \\
w_{SF,SS} &= \alpha_5 + \gamma_7 \left( \frac{c_2}{c_1} - \beta_5 \right)^+,
\end{aligned}$$

*otherwise*

$$\begin{aligned}
w_{F\cdot} &= \gamma_8 \left( \frac{c_2}{c_1} - \beta_5 \right)^+ \\
w_{SF,SS} &= \alpha_5 + \gamma_9 \left( \frac{c_2}{c_1} - \beta_5 \right)^+.
\end{aligned}$$

**Proof.** See appendix. ■

The optimal contract that implements parallel innovation provides incentives to the agents that are similar to the incentives given to the exploring agent under single innovation. The wages paid to the agents again deter them from shirking and exploiting. In addition, the optimal contract needs to deter each agent free-riding on the exploration activities of the other agent. This is only a concern in the parallel innovation case since both agents are exploring a new work method in the first period.

Figure 5 graphically shows the wages for the optimal contract that implements parallel innovation for agent $A$ under the base case parameters for different values of $\frac{c_2}{c_1}$.

First, wages in the first period and in the second period after failures of both agents in the first period are based on individual performance only, since in these situations the agents use different new work methods or the conventional work method.

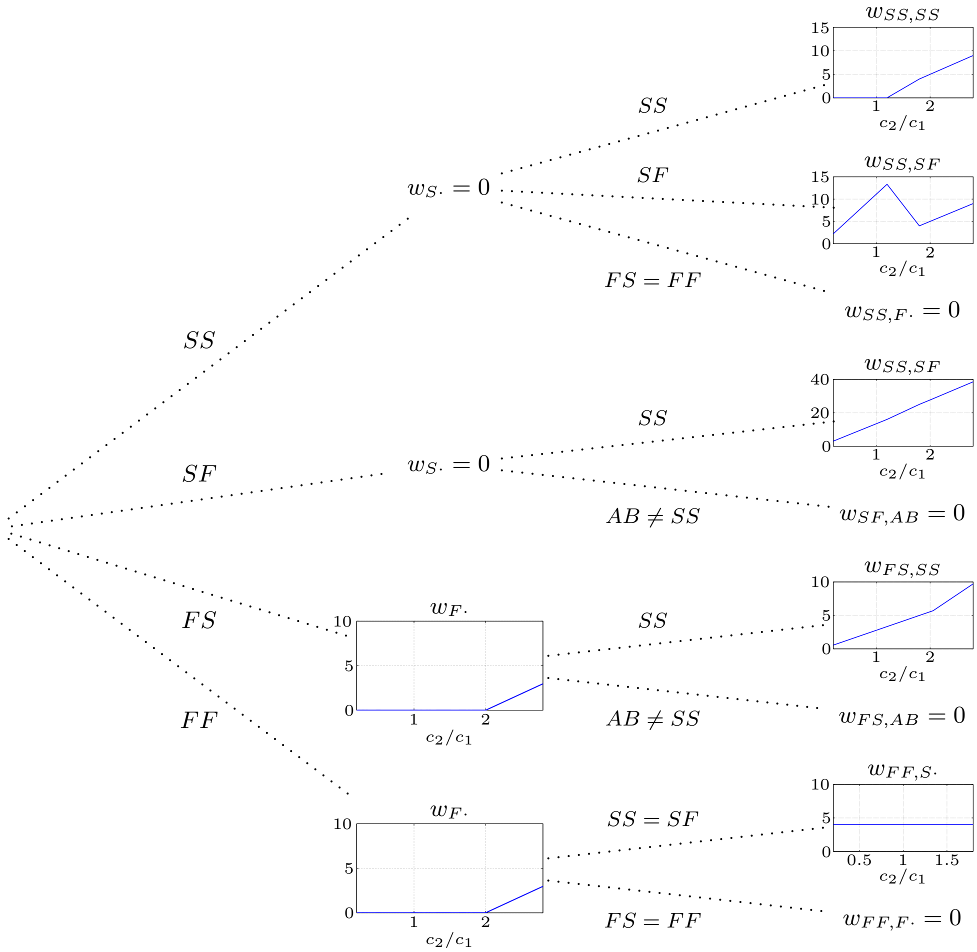


**Figure 5:** Wages in the first and second period for agent $A$ under the optimal contract that implements parallel innovation.

Second, the agents receive no rewards for success in the first period since $w_{S\cdot} = 0$. As before, the principal is better off delaying payments for success to the second period in order to deter the use of the conventional work method in the first period and to take advantage of the additional information available in the second period. The principal may, however, provide rewards for failure in the first period through the use of $w_{F\cdot}$ depending on how strong of a signal failure in the first period is for the use of the new work method.

Third, the agents again receive rewards $w_{SF,SS}$ and $w_{FS,SS}$ for joint success in the second period if only one of them was successful in that period. In such a situation, both agents either take action 2 (if only agent $A$ was successful in the first period) or action 3 (if only agent $B$ was successful) in the second period. Since there is still learning about the new work methods it is cheaper for the principal to reward agents for joint success only. Note, however, that these wages are not equal. If agent $A$ had a failure in the first period, then the wage $w_{FS,SS}$ he can receive in the second period merely deters him from shirking or using the conventional work method in the second period and gives him no additional premium. If agent $A$ instead had a success in the first period, the wage $w_{SF,SS}$ he can receive in the second period deters him from deviating from the equilibrium action plan in both the first and the second period. That is to say, an agent who is successful in the first period still receives a greater reward later on if he continues to be successful. While in the former case the initially successful agent uses different new work methods in both periods (action 2 in the first period and action 3 in the second period), the agent uses the same new work method (action 2) in both periods. Note that this difference in wages occurs for the same reasons as the difference in second-period wages for success for the exploring agent under single innovation after a success or a failure in the first period. If $\frac{c_2}{c_1} < \beta_5$ then the new work approach is relatively cheap and the exploitation constraint $\text{IC}_{\langle 1 \, {}^{1}_{3} \, {}^{1}_{1} \rangle}$ is not binding. The principal pays $w_{SF,SS} = \alpha_5$ in this case, while he has to pay a premium if $\frac{c_2}{c_1} \geq \beta_5$. This is similar to the bonus the principal has to pay in the single innovation case.

Finally, when both agents are successful in the first period, it may be optimal for the principal to induce competition between the agents. In particular, after two successes in the first period the principal may only make a payment $w_{SS,SF}$ to agent $A$ if agent $A$ has a success in the second period and agent $B$ has a failure. The reason for inducing competition is that it serves as an effective deterrent against imitative free-riding on exploration, which occurs when an agent shirks in the first period and then takes advantage of the new work method which the other agent found to be successful in the first period.

If $\frac{c_3}{c_1} \geq \frac{E(p_3|S_3)-p_0}{p_1-p_0}$, imitative free-riding is too costly and the principal can give individual compensation for success, that is $w_{SS,SS} = w_{SS,SF} = \alpha_4$, when both agents are successful in the first period. This is a standard moral hazard payment which simply deters the agent from shirking or employing the conventional work method in the second period. Since the agents work on different new work methods, there is no correlation in performance and the principal can rely on purely individual rewards.

On the other hand, if $\frac{c_3}{c_1} < \frac{E(p_3|S_3)-p_0}{p_1-p_0}$, then free-riding is cheap and the constraint $\text{IC}_{\langle 0 \, {}^{3}_{3} \, {}^{1}_{1} \rangle}$ is binding. This means that agent $A$ is tempted to shirk in the first period and then to use the new work method (action 3) in the second period which was found to be successful by the other agent. There are several features of note here. First, to prevent an agent from free-riding on the exploration activities of the other agent, the principal prefers to induce competition between the two agents by paying a higher wage $w_{SS,SF}$, if agent $A$ performs better than agent $B$ in the second period than if both agents are successful. In this case the principal pays $w_{SS,SS}$, where $w_{SS,SS} < \alpha_4 < w_{SS,SF}$. The reason for driving a wedge between the two wages is that when an agent tries to free-ride on the previous innovation activity of the other agent, the two agents choose the same new work method (action 3 here) in the second period. This, in turn, makes a joint success more likely than if the agent were to choose a different new work method (action 2) in the second period. To deter such behavior, it is optimal for the principal to use this form of relative performance evaluation. Second, the expected equilibrium wage bill paid in the second period following successes of both agents in the first period exceeds the expected value of the standard moral hazard payment $\alpha_4$. In particular,

$$E(p_2|S_2)\left[E(p_3|S_3)w_{SS,SS} + (1 - E(p_3|S_3))w_{SS,SF}\right] > E(p_2|S_2)\alpha_4.$$

This bonus for success over and above the standard moral hazard payment $\alpha_4$ is the result of using wages to deter the first-period deviation to shirking which occurs in the action plan $\langle 0 {}^{3}_{3} {}^{1}_{1} \rangle$. Finally, this bonus is increasing in the difference between $E(p_3|S_3, S_3)$ and $E(p_3|S_3)$. Intuitively, if $E(p_3|S_3, S_3)$ is larger relative to $E(p_3|S_3)$, then the outcomes of the two agents when both use action 3 are more positively correlated. Since, the principal wants both agents to choose different new work methods he can give incentives that feature a strong relative performance evaluation component. When there is a lot of learning about the success probability of the risky bandit from a second pull, then the difference between $E(p_3|S_3, S_3) - E(p_3|S_3)$ is large. The principal takes advantage of this correlation, raises $w_{SS,SF}$ and lowers $w_{SS,SS}$ accordingly. By contrast, when there is little or no learning in the second period so that $E(p_3|S_3, S_3)$ is close to $E(p_3|S_3)$, the bonus is small because the positive correlation in performance when both agents choose the same new work method is also rather small. In the limiting case of no learning, that is $E(p_3|S_3, S_3) = E(p_3|S_3)$, the principal only pays $w_{SS,SS} = w_{SS,SF} = \alpha_4$ throughout and relies exclusively on $w_{SF,SS}$ to deter shirking in the first period and free-riding in the second period when both agents were previously successful. Thus, if there is little additional information gained when a new work approach that proved successful on the first attempt is used for a second time, the principal exclusively uses $w_{SF,SS}$ to deter equilibrium deviations.

In summary, the optimal contract that implements parallel innovation tolerates early failure. If both agents are successful in the first period, the principal may either give individual incentives or pay agents if they perform better than their colleague. In contrast, if only one agent is successful in the first period the optimal contract rewards joint success in the second period. To deter shirking in the first period an agent receives a higher wage for joint success in the second period if he was also successful in the first period. If neither agent is successful in the first period, both agents receive compensation based on individual performance that merely deters them from shirking.

## 5 Experimental Application

I now proceed to test the central aspects of the theoretical model in an environment in which I can measure the effects of different incentive schemes on innovation and performance under individual and social learning. For this purpose I conduct experiments in which each participant has to solve a real effort task that involves a trade-off between exploration and exploitation. The exogenous variation in the learning environment and incentives allows me to identify some of the causal relationships between incentives and innovation analyzed in the theoretical model. In particular, I am interested in whether standard pay-for-performance contracts discourage individuals from undertaking exploration as postulated by the theoretical model. Furthermore, following the predictions of the theoretical model I investigate how contracts that tolerate early failure and that provide group rewards for joint success alleviate these free-riding problems that are present in settings with social learning.

## 5.1 Design

I use the experimental setup pioneered in Ederer and Manso (2008) to analyze the performance of subjects carrying out a creative, open-ended task when given different incentive contracts. For more details the reader is referred to that paper.

### 5.1.1 Procedures and Subject Pool

The experiments were programmed and conducted with the software z-Tree (Fischbacher 2007) at the Harvard Business School Computer Laboratory for Economic Research (HBS CLER). Participants were recruited from the HBS subject pool which predominantly consists of undergraduate students using an online recruitment system. A total of 275 subjects participated in the experiments. After subjects completed the experiment, I elicited their degree of risk aversion. I describe the exact procedures, which are standard, in the appendix. Subjects were then privately paid. A session lasted, on average, 60 minutes. During the experiment, experimental currency units called francs were used to keep track of monetary earnings. The exchange rate was set at 100 francs = $1 and the show-up fee was $10. Subjects on average earned $24.

In the experiment subjects take the role of an individual operating a lemonade stand. The experiment lasts 20 periods. In each period, subjects make decisions on how to run the lemonade stand. These decisions involve the location of the stand, the sugar and the lemon content, the lemonade color and the price. The choices available to the subjects as well as the parameters of the game are given in the appendix. At the end of each period, subjects learn the profits they obtained during that period. They also learn customer reactions that contain information about their choices. Customer feedback is implemented by having the computer randomly select one choice variable to provide a binary feedback to the subject. In treatments where there is social learning, each subject also receives the information about the strategy choices, profits and customer feedback of another player paired with him during the 20 periods of the experiment. This allows subjects to learn both from their own experience and that of their group member.

Subjects do not know the profits associated with each of the available choices. Attached to the instructions, however, there is a letter from the previous manager which is reproduced in the appendix. The letter gives hints to the subjects about a strategy that has worked for this manager. The strategy suggested by the previous manager involves setting the stand in the business district, choosing a high lemon content, a low sugar content, a high price, and green lemonade. The manager's letter also states that the manager has tried several combinations of variables in the business district location, but has never experimented setting up the stand in a different location. It further suggests that different locations may require a very different strategy. The participants in the experiment thus face the choice between fine-tuning the product choice decisions given to them by the previous manager (exploitation) or choosing a different location and radically altering the product mix to discover a more profitable strategy (exploration). The strategy of the previous managers is not the most profitable strategy. The most profitable strategy is to set the lemonade stand in the school district, and to choose a low lemon content, a high sugar content, a low price, and pink lemonade.

The payoffs in the game were chosen in such a way that, without changing the default location, the additional profits earned from improving the strategy in the business district are relatively small. On the other hand, changing the location to the school required large changes in at least two other variables to attain an equally high profit as suggested by the default strategy.

In addition to the previous manager's letter, the instructions contain a table in which subjects can input their choices, profits, and feedback in each period. Subjects are told that they can use this table to keep track of their choices and outcomes as well as those of the other subject they can observe. I use the information subjects record in this table as one measure of their effort during the experiment.

#### 5.1.2 Treatment Groups and Predictions

I initially implement four treatment conditions in order to examine how different incentive schemes affect innovation success, exploration behavior, time allocation, and effort choices. Each subject participated in one treatment only. The treatment groups are differentiated along two dimensions. First, the treatment groups differ in how subjects are compensated. This allows me to test for the differences in responses to financial incentives. Second, I differentiate between environments where social learning (SL) is possible and environments where only individual learning (IL) is available to subjects. In the treatment groups that allow for social learning, in addition to obtaining information about action choices, profits and customer feedback about their own lemonade profits, subjects also receive the same information from another subject. In the other treatments, there is no social learning and only individual learning. Subjects can only learn from their own exploration activities. This distinction allows me to analyze the effects that social learning has under different compensation schemes. The compensation language used in the different treatment groups is as follows:

**Pay-for-Performance Contract (IL and SL):** *You will be paid 50% of the profits you make during the 20 periods of the experiment.*

**Exploration Contract (IL and SL):** *You will be paid 50% of the profits you make during the last 10 periods of the experiment.*

While the pay-for-performance contract is motivated by previous research in economics and psychology, the exploration contract is motivated by the theoretical findings which stress the importance of the tolerance of early failure and reward for long-term success when motivating innovation. The resulting four treatment groups allow me to examine the impact of social learning in the presence of different incentive schemes. My main hypothesis concerns the extent to which social learning affects the exploration activity of subjects and whether it leads to imitative free-riding under the different payment schemes considered in the treatment groups. In particular, the first hypothesis is that for a given compensation scheme subjects in a social learning treatment find the optimal business strategy more often than subjects in a treatment without social learning.

**Learning Hypothesis**: *Subjects under the pay-for-performance contract and the exploration contract get closer to the optimal business strategy when there is social learning.*

The learning hypothesis focuses on the beneficial effects of additional information on performance. Holding their own exploration and learning fixed, subjects receive more information in a social learning environment than under individual learning. As a result, they are more likely to find the best business strategy. Since nothing prevents the subjects from conducting the same amount of exploration in a social learning environment as they do in an environment where they can only learn from their own experience, the subjects should not perform worse when they have access to the information of another subject. On the other hand, it is possible that when subjects attempt to free-ride on costly exploration activities they may perform worse than in a setting where free-riding on exploration is not possible.

This last observation leads to the next hypothesis which addresses free-riding on exploration in settings with free information exchange. In particular, I hypothesize that subjects under the pay-for-performance contract are more likely to free-ride on the information generated by the other subject they can observe since exploration of new business strategies carries a higher opportunity cost under a pay-for-performance contract than under an exploration contract.

**Free-riding Hypothesis:** *Relative to individual learning under social learning subjects who are given the pay-for-performance contract reduce their exploration activities in the first 10 periods by more than subjects who are given the exploration contract.*

The incentive schemes I have focused on so far only reward an agent for his individual performance. However, the results of the theoretical analysis suggest that the optimal incentive scheme when several agents are to be motivated to innovate tolerates early failure and rewards long-term *joint group* success of both subjects. The main question of interest whether such an incentive scheme can lead to even better innovation and performance than an incentive scheme that only tolerates early failure and rewards performance on an individual basis. The particular incentive scheme I consider is as follows:

**Team Exploration Contract (SL):** *You will be paid 25% of the profits you make and 25% of the profits your partner makes during the last 10 periods of the experiment.*

The team exploration contract is motivated by the theoretical results. The theoretical findings suggest that when information is exchanged freely between agents, the optimal incentive scheme not only tolerates early failure, but also rewards long-term group success. Subjects are not penalized for early failure and are able to capture the full surplus of their exploration activities through delayed team incentives.

**Team Exploration Hypothesis:** *When there is social learning, subjects under the team exploration contract get closer to the optimal business strategy than subjects who receive pay-for-performance contracts or exploration contracts.*

Under social learning, exploration also benefits the other subject since it reveals important information about the success of different business strategies. Because each subject is rewarded for the good performance of his partner through the team structure of the compensation scheme, subjects have even stronger incentives to innovate than when they are given standard pay-for-performance or exploration contracts.

## 5.2 Results

In this section I present the results obtained in the experiments comparing outcomes across the five different treatments.

### 5.2.1 Learning Hypothesis

I first focus on the beneficial aspects of additional information that the free exchange of information between agents brings about. The first result shows that the prediction that social learning leads to more innovation for a given incentive scheme is, indeed, borne out by the data.

**Result 1 (Learning):** *Subjects under the pay-for-performance contract are significantly more likely to choose to sell at the school (highest profit location) in the final period of the experiment and come closer to the optimal business strategy if there is social learning. There is also a positive (though statistically insignificant) effect of social learning on innovation for subjects under the exploration contract. For a given learning setting, subjects who are given an exploration contract are significantly more likely to choose the highest profit location and come closer to the optimal business strategy than subjects who are given a pay-for-performance contract.*

Initial supporting evidence for Result 1 comes from Figure 6 which shows the proportion of subjects under the pay-for-performance and exploration contracts for individual and social learning conditions choosing to sell lemonade in a particular location in the final period. Consistent with the learning hypothesis, subjects who are also able to learn from one of their peers are more likely to sell at the school (the location with the highest profits) in the final period of the experiment than subjects who can only learn from individual experience. Whereas in the pay-for-performance condition with individual learning only 40% of subjects choose to sell lemonade at the school, almost 60% choose to do so under social learning. Using Wilcoxon tests for independent samples, I can show that this difference is significant ($p$-value 0.0463).[4] In contrast, the improvement in innovation for subjects under exploration contract is much smaller, as 82% of subjects choose the best final location under individual learning and 83% choose it under social learning. This difference is not statistically significant ($p$-value 0.8745).

I also examine how close subjects come to finding the optimal strategy over the course of the experiment. This can easily be measured by examining the maximum per period profit achieved

[4] In the treatments with individual learning, the independent unit of observation is a subject. In the treatments with social learning, the independent unit of observation is a pair of subjects who can observe each other.

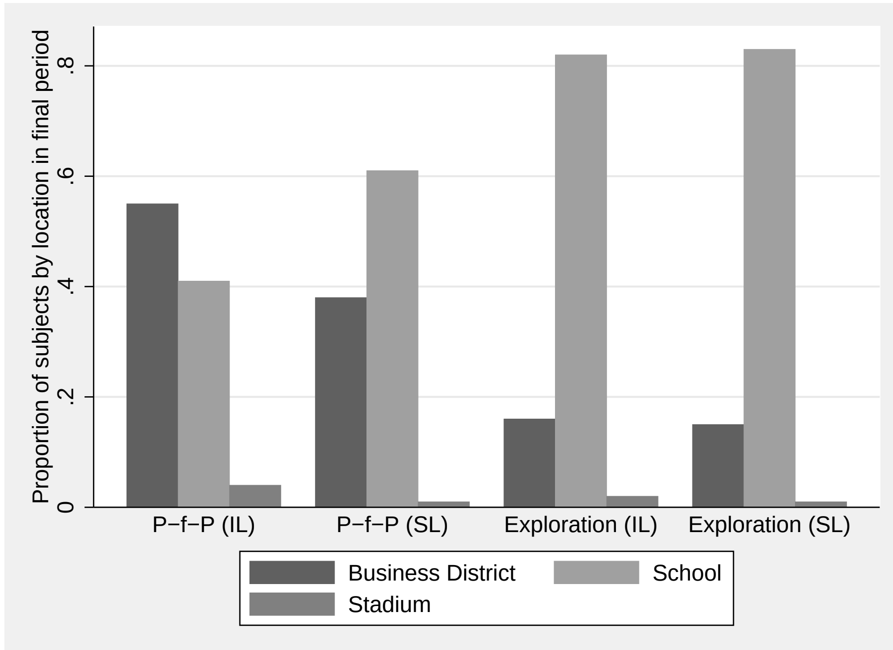


**Figure 6:** Proportion of subjects by location in the final period of the experiment for the pay-for-performance and exploration contracts under individual and social learning.

by subjects throughout the course of the experiment, as in Figure 7. Again, there is a clear learning effect in the pay-for-performance treatment, in which, on average, maximum per period profits rise from 117 francs (individual learning) to 130 francs (social learning). The same pattern holds for final period profit which increases from 111 francs to 128 francs. Both of these differences are statistically significant ($p$-value 0.0257 for maximum profit, $p$-value 0.0326 for final period profit). The corresponding increases under the exploration contract are much smaller and not statistically significant. The reason for this small increase is that even under individual learning subjects who receive an exploration contract already undertake a sizeable amount of exploration and the additional information obtained from another subject is not sufficient to significantly increase their innovation performance.

Finally, note that, as in Ederer and Manso (2008), the delay in compensation that the exploration contract brings about is equally beneficial in a multi-agent setting with social learning. For a given information setting, subjects are significantly more likely to find the best business location ($p$-value 0.0357) and come closer to the optimal business strategy in terms of maximum and final period profits ($p$-values of 0.0178 and 0.0266) when they are given an exploration contract rather than a pay-for-performance contract.

In addition, as in the single-agent experiments of Ederer and Manso (2008), I investigate the effect of risk aversion on final location choice and profits. I measure risk aversion with a separate experiment where subjects are asked to choose between different risky gambles. In the pay-for-performance treatment with social learning, subjects with a higher degree of risk aversion are significantly less likely to choose the optimal location in the final period ($p$-value 0.0578) and have

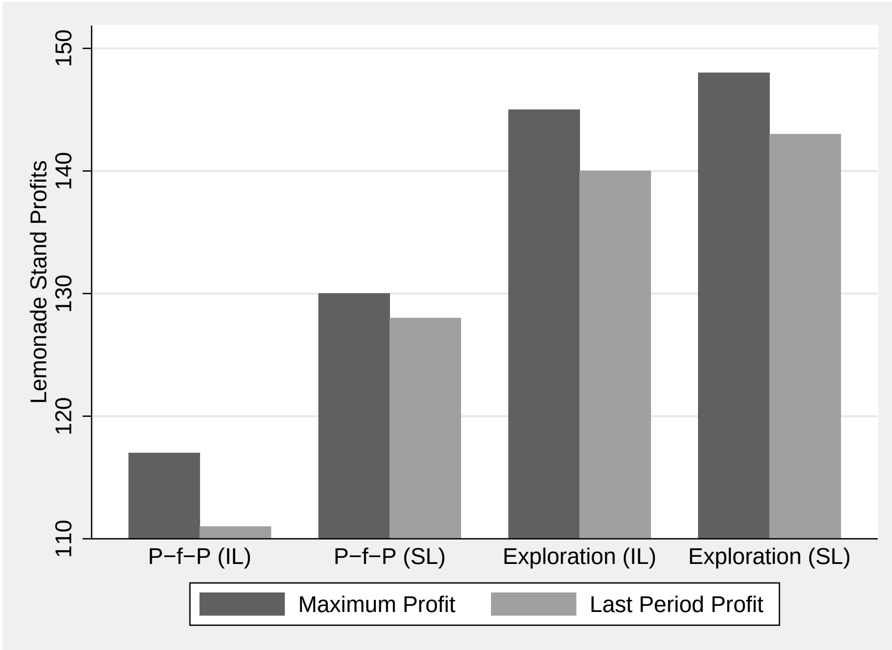


**Figure 7:** Average maximum and final period profits for the pay-for-performance and exploration contracts under individual and social learning.

lower maximum and final period profits ($p$-values 0.0563 and 0.0432) than subjects with lower risk aversion. This decrease is particularly pronounced when comparing groups in which both subjects are less risk-averse and groups in which both subjects are more risk-averse ($p$-values 0.0129, 0.0342 and 0.0374). In fact, a group of two more risk-averse subjects does not perform any better than a risk-averse subject with a pay-for-performance contract and individual learning. In contrast, the innovation- and performance-reducing effects of risk aversion are of much smaller magnitude and not statistically significant when subjects are given exploration contracts.

### 5.2.2 Free-riding Hypothesis

I now turn to how the presence of social learning changes individual exploration behavior. In particular, I am interested in whether social learning is a cheap substitute for individual learning and thus leads to a reduction of exploration when exploration has an opportunity cost as it does in the pay-for-performance treatments.

**Result 2 (Free-riding):** *Subjects under the pay-for-performance contract explore significantly less on their own in the social learning treatment than in the individual learning treatment in the first 10 periods of the experiment. There is a small, statistically insignificant reduction in individual exploration activity in the exploration contract treatment. The exploration activity of a pair of subjects is still significantly larger than the individual exploration activity in the pay-for-performance treatment with individual learning.*

Using the different choice variables available to the agents, I can construct several measures of exploration activity. I first analyze location choice behavior. In the first 10 periods of the experiment, subjects in the pay-for-performance condition explore locations other than the default location (business district) less often under social learning than under individual learning. Subjects under the pay-for-performance contract choose a location other than the default location 51% of the time under individual learning, but only 42% of the time under social learning and this difference is statistically significant ($p$-value 0.0261). There is no clearly discernible reduction in exploration activity due to social learning under the exploration contract under which this percentage is only slightly lower when information is freely exchanged (81% and 78% respectively, $p$-value 0.7532). In addition, as in Ederer and Manso (2008), there is a significant increase in exploration activity under social learning when subjects are given an exploration contract rather than a standard pay-for-performance contract ($p$-value 0.0038). This means that the tolerance of early failure also increases individual exploration in a setting where information is freely exchanged.

This reduction of individual exploration activity is also reflected in Figure 8 which shows the average subject-specific standard deviation in strategy choices for the three continuous choice variables (sugar content, lemon content and price) during the first and last 10 periods of the experiment. Most importantly, there is a statistically significant reduction in the variability of action choices in the pay-for-performance treatment in the first 10 periods when there is social learning in addition to individual learning ($p$-value 0.0021). This reduction is again indicative of how social learning provides a cheap substitute for individual exploration. Because, in order to undertake the exploration of new business strategies, subjects has to sacrifice the immediate benefits of exploiting well-known default business strategies, they are tempted to use the information that is costlessly generated for them by their respective partners. In contrast, individual exploration activities do not significantly decline in the presence of social learning under an exploration contract.

Note also, that in all four treatments, the variability of action choices significantly declines over the course of the experiment in the pay-for-performance ($p$-values 0.0005 and 0.0012) and the exploration contracts ($p$-values 0.0001 and 0.0004). This occurs because in periods 11 to 20 the beneficial learning effects of exploration relative to exploitation are no longer as large as they are at the beginning of the experiment since the time horizon is shorter. Finally, there is also a noticeable decrease in action choice variability resulting from social learning in the last 10 periods of the experiment, but these decreases are not significantly different.

While the analysis shows that there is a decrease in individual exploration activity on average the benefits of social learning still outweigh the costs of free-riding in the pay-for-performance treatment. Indeed, the standard deviation of action choices taken by a pair of subjects under social learning in the first 10 periods is still significantly higher than the standard deviation of action choices of a single subject under individual learning ($p$-value 0.0361). Similarly, while it is true that only 42% of the time subjects choose a location other than the business district, the proportion of periods in which at least one subject in a pair of subjects chooses a location other than the default location is 65%. Under individual learning, a subject on average only obtained information about a location other than the default location only 51% of the time. This further explains the

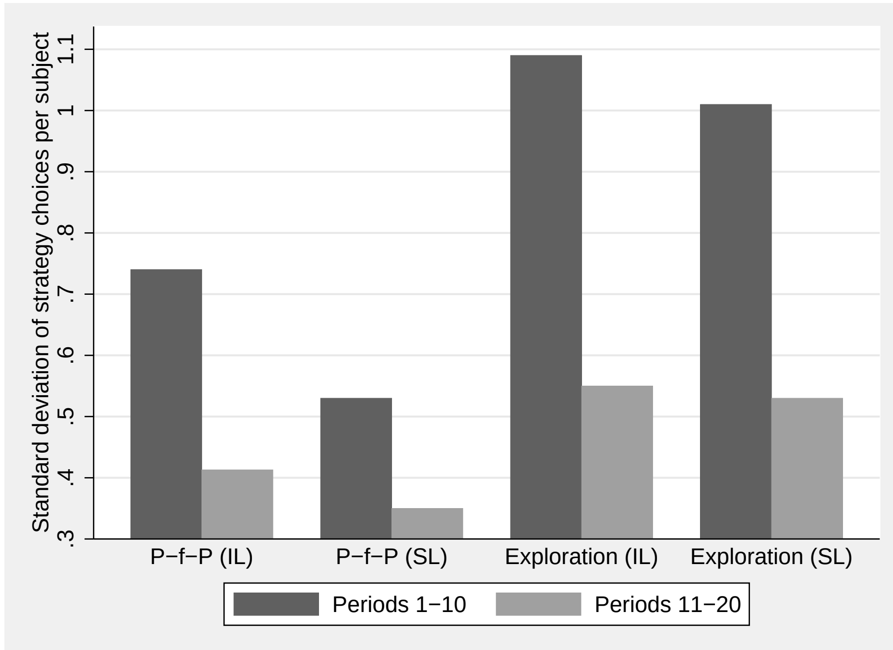


**Figure 8:** Average subject-specific standard deviation of strategy choices for the three continuous variables (sugar content, lemon content, price) in periods 1-10 and 11-20 of the experiment for pay-for-performance and exploration contracts under individual and social learning.

improved innovation performance of subjects under the pay-for-performance contract resulting from observational learning.

The free-riding effect is particularly pronounced when subjects receive a pay-for-performance contract and both subjects of a group are risk-averse. Here, the exploration activity of a pair of two subjects under social learning is as low as the exploration activity of a single risk-averse subject under individual learning. This explains the particularly low innovation performance of pairs of risk-averse subjects I documented in the previous section.

#### 5.2.3 Team Exploration Hypothesis

I focus, finally, on the team exploration hypothesis. The central question here is whether contracts that specifically reward subjects for team, rather than individual, performance can be even more successful in motivating innovation when information is exchanged freely than contracts that only reward individual performance. This is, indeed, the case as the next result shows.

**Result 3 (Team Exploration):** *If there is social learning, subjects under the team exploration contract are more likely to choose to sell at the school (highest profit location) in the final period of the experiment and come significantly closer to the optimal business strategy than subjects under the exploration contract.*

First, Figure 9 provides suggestive evidence that the team exploration contract leads to better final period location choice than the exploration contract. The improvement, however, is relatively

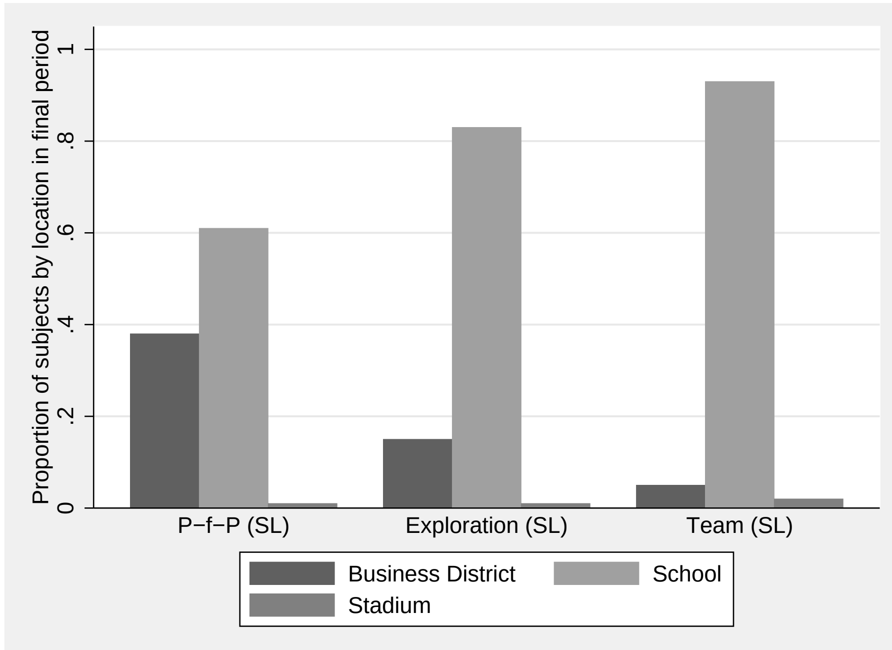


**Figure 9:** Proportion of subjects by location in the final period of the experiment for the pay-for-performance, exploration and team exploration contracts under social learning.

small and is not statistically significant ($p$-value 0.1732). The reason for this relatively small improvement is that when subjects are given an exploration contract and are able to profit from observational learning, more than 80% of them already choose to sell in the optimal location in the final period. Even though this proportion rises to 91% under team compensation, this difference is not large enough to be statistically significant given my sample size.

In contrast, the other measures of innovation success, maximum per period profit and final period profit, are significantly higher when subjects are given team compensation contracts as shown in Figure 10. Subjects under the exploration contract on average have maximum and final period profits of 148 and 143 francs while these figures rise to 162 and 159 francs ($p$-values 0.013 and 0.009) for subjects with team exploration contracts.

The reason for this improved innovation performance under the team exploration contract seems to come primarily from a higher variability of action choices and better coordination between the subjects of a group. Rather than following each other's choices, subjects are willing to explore more since they realize that their own exploration benefits their partner and, consequently, themselves through the team component of the contract. When asked in the post-experimental questionnaire about how the compensation scheme influenced their strategy, subjects spontaneously argued that the team component of compensation encouraged them "to explore more to help [their] partner". Indeed, the variability of action choices in the first 10 periods is higher under the team exploration contract than it is under the exploration contract as shown in Figure 11, and this difference is statistically significant ($p$-value 0.0435).

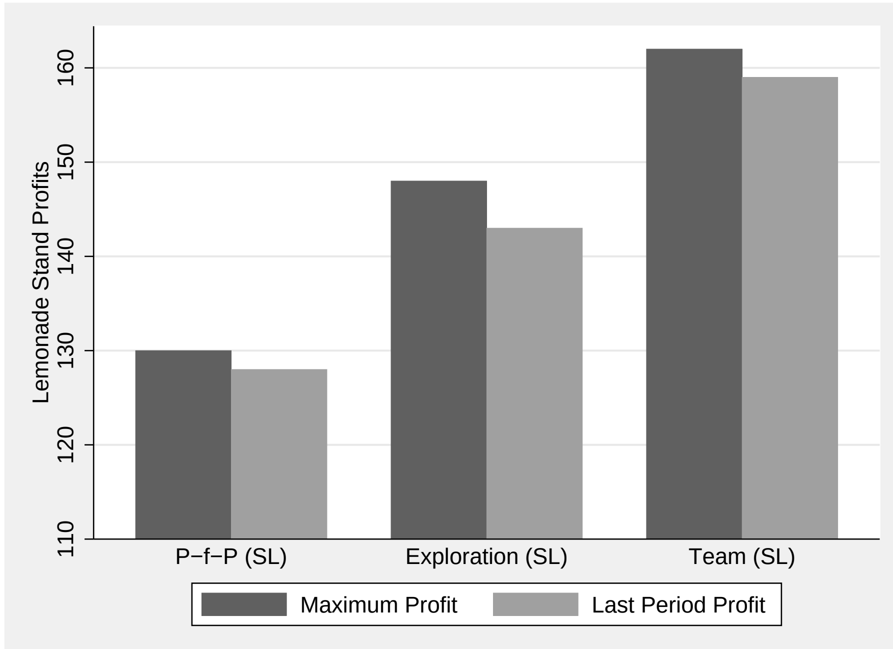


**Figure 10:** Average maximum and final period profits for the pay-for-performance, exploration and team contracts under social learning.

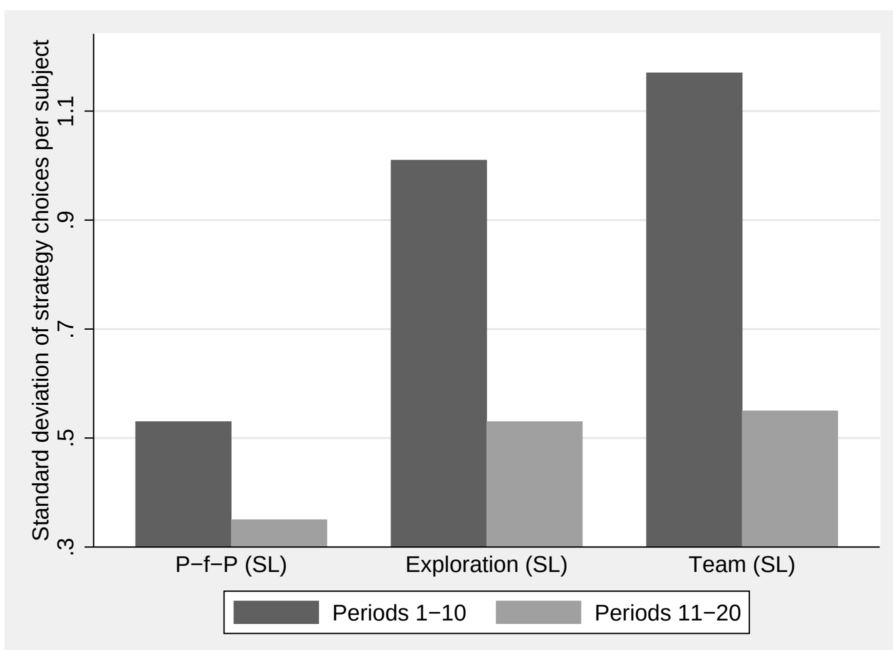


**Figure 11:** Average subject-specific standard deviation of strategy choices for the three continuous variables (sugar content, lemon content, price) in periods 1-10 and 11-20 of the experiment for pay-for-performance, exploration and team exploration contracts under social learning.

# 6 Conclusion

This paper asked what incentives are optimal to motivate innovation in an organization where workers freely exchange ideas and are able to learn from each other's experience. I showed that workers' incentives for innovation fundamentally differ from incentives for routine activities. Optimal incentives for routine activities take the form of standard pay-for-performance contracts where only individual success determines compensation. However, when workers must be motivated to innovate and try new, untested work methods, standard pay-for-performance incentive schemes may actually undermine workers' motivation to innovate by encouraging imitative free-riding on successful ideas found by other members of the organization. This means that the optimal incentive scheme for innovating and exploring new work methods tolerates early failure and provides workers with long-term incentives for joint success.

My theoretical findings mesh with findings in the human resource management literature as well as an emerging empirical economics literature, which documents that within organizations innovative activities go hand in hand with compensation schemes that reward long-term joint success, such as profit sharing, employee ownership, and broad-based stock option plans. My theoretical results are also given further credence by behavior observed in a controlled economic laboratory experiment. When subjects are asked to perform a task that requires creativity and exploration, yet receive standard pay-for-performance compensation, the subjects significantly reduce their own individual exploration activities and instead rely on the innovating efforts of other subjects. An incentive scheme that tolerates early failure and rewards both agents in a group for their joint, long-term performance yields the best result in terms of innovation success.

# A Omitted Proofs

The following definitions will be useful in stating the incentive compatibility constraints. I write

$$\begin{aligned}
\Delta W_1 &= W_1(\langle n,o,p,q,r\rangle) - W_1(\langle i,j,k,l,m\rangle)\\
\Delta W_{SS} &= W_{SS}(\langle n,o,p,q,r\rangle) - W_{SS}(\langle i,j,k,l,m\rangle)\\
\Delta W_{SF} &= W_{SF}(\langle n,o,p,q,r\rangle) - W_{SF}(\langle i,j,k,l,m\rangle)\\
\Delta W_{FS} &= W_{FS}(\langle n,o,p,q,r\rangle) - W_{FS}(\langle i,j,k,l,m\rangle)\\
\Delta W_{FF} &= W_{FF}(\langle n,o,p,q,r\rangle) - W_{FF}(\langle i,j,k,l,m\rangle)
\end{aligned}$$

where $\langle n,o,p,q,r\rangle$ denotes the desired equilibrium action plan and $\langle i,j,k,l,m\rangle$ denotes the deviations. These expressions denote the differences in wages obtained by an agent in the first period ($\Delta W_1$) and in the second period after successes of both agents ($\Delta W_{SS}$), after a success of only either agent $A$ ($\Delta W_{SF}$) or agent $B$ ($\Delta W_{FS}$), and after failures of both agents ($\Delta W_{FF}$) that result from deviations from the equilibrium actions. Similarly, I denote the differences in private costs by

$$\Delta C = C(\langle i,j,k,l,m\rangle) - C(\langle n,o,p,q,r\rangle).$$

In what follows I will define the equilibrium action plan and write the deviations as $\langle i,j,k,l,m\rangle$.

**Proof of Proposition 2.** The optimal contract that implements the action plan $\langle 1,1,1,1,1\rangle$ for both agents satisfies the following incentive compatibility constraints for agent $A$, which I denote by $\langle i,j,k,l,m\rangle$:

$$\Delta W_1 + \Delta W_{SS} + \Delta W_{SF} + \Delta W_{FS} + \Delta W_{FF} \geq \Delta C$$

where

$$\Delta W_1 = (p_1 - E(p_i))\,(p_1 w_{SS} + (1-p_1)w_{SF}) - (p_1 - E(p_i))\,(p_1 w_{FS} + (1-p_1)w_{FF})$$

$$\begin{aligned}
\Delta W_{SS} = {}& \left(p_1^2 - E(p_i)E(p_j|S_i)\right) p_1\left[p_1 w_{SS,SS} + (1-p_1)w_{SS,SF}\right]\\
&+ \left[(1-p_1)p_1 - E(p_i)(1-E(p_j|S_i))\right] p_1\left[p_1 w_{SS,FS} + (1-p_1)w_{SS,FF}\right]
\end{aligned}$$

$$\begin{aligned}
\Delta W_{SF} = {}& \left(p_1^2 - E(p_i)E(p_k|S_i)\right)(1-p_1)\left[p_1 w_{SF,SS} + (1-p_1)w_{SF,SF}\right]\\
&+ \left[p_1(1-p_1) - E(p_i)(1-E(p_k|S_i))\right](1-p_1)\left[p_1 w_{SF,FS} + (1-p_1)w_{SF,FF}\right]
\end{aligned}$$

$$\begin{aligned}
\Delta W_{FS} = {}& \left[(1-p_1)p_1 - (1-E(p_i))E(p_l|F_i)\right] p_1\left[p_1 w_{FS,SS} + (1-p_1)w_{FS,SF}\right]\\
&+ \left[(1-p_1)^2 - (1-E(p_i))(1-E(p_l|F_i))\right] p_1\left[p_1 w_{FS,FS} + (1-p_1)w_{FS,FF}\right]
\end{aligned}$$

$$\begin{aligned}
\Delta W_{FF} = {}& \left[(1-p_1)p_1 - (1-E(p_i))E(p_m|F_i)\right](1-p_1)\left[p_1 w_{FF,SS} + (1-p_1)w_{FF,SF}\right]\\
&+ \left[(1-p_1)^2 - (1-E(p_i))(1-E(p_m|F_i))\right](1-p_1)\left[p_1 w_{FF,FS} + (1-p_1)w_{FF,FF}\right].
\end{aligned}$$

and

$$\begin{aligned}
\Delta C = {}& c_1 - c_i + p_1\left(p_1 c_1 - E(p_i)c_j\right) + (1-p_1)\left(p_1 c_1 - E(p_i)c_k\right)\\
&+ p_1\left[(1-p_1)c_1 - (1-E(p_i))c_l\right] + (1-p_1)\left[(1-p_1)c_1 - (1-E(p_i))c_m\right].
\end{aligned}$$

First, I can set

$$w_{S\cdot} \equiv w_{SS} = w_{SF} \text{ and } w_{F\cdot} \equiv w_{FS} = w_{FF}$$

as well as

$$w_{AB,S\cdot} \equiv w_{AB,SS} = w_{AB,SF} \text{ and } w_{AB,F\cdot} \equiv w_{AB,FS} = w_{AB,FF} \text{ for } A = \{S,F\} \text{ and } B = \{S,F\}$$

since this contract pays agent $A$ the same wage independent of the performance of agent $B$, it satisfies all incentive compatibility constraints and it has the same wage bill for the principal.

Next, I argue that

$$w_{F\cdot} = w_{FS,F\cdot} = w_{FF,F\cdot} = 0$$

and

$$w_{SS,F\cdot} = w_{SF,F\cdot} = 0.$$

Suppose that $w_{F\cdot} > 0$ or $w_{FS,F\cdot} > 0$ or $w_{FF,F\cdot} > 0$. A contract $\overrightarrow{w}'$ that is the same as $\overrightarrow{w}$ but has $w'_{F\cdot} = w'_{FS,F\cdot} = w'_{FF,F\cdot} = 0$ satisfies all incentive compatibility constraints and has a strictly lower wage bill for the principal. Suppose now that $w_{SS,F\cdot} > 0$ or $w_{SF,F\cdot} > 0$. Let the contract $\overrightarrow{w}'$ be the same as $\overrightarrow{w}$ except that $w'_{SS,F\cdot} = 0$, $w'_{SS,S\cdot} = w_{SS,S\cdot} - w_{SS,F\cdot}$ and $w'_{S\cdot} = w_{S\cdot} + p_1 w_{SS,F\cdot}$. The contract $\overrightarrow{w}'$ satisfies all incentive compatibility constraints and has the same wage bill, but the contract $\overrightarrow{w}'$ pays the agent earlier than $\overrightarrow{w}$. Let the contract $\overrightarrow{w}'$ be the same as $\overrightarrow{w}$ except that $w'_{SF,F\cdot} = 0$, $w'_{SF,S\cdot} = w_{SF,S\cdot} - w_{SF,F\cdot}$ and $w'_{S\cdot} = w_{S\cdot} + (1-p_1) w_{SF,F\cdot}$. The contract $\overrightarrow{w}'$ satisfies all incentive compatibility constraints and has the same wage bill, but the contract $\overrightarrow{w}'$ pays the agent earlier than $\overrightarrow{w}$.

I now show that some incentive compatibility constraints are redundant. It is important to note that the actions $j$ and $k$ taken after outcomes $SS$ and $SF$ and the actions $l$ and $m$ taken after outcomes $FS$ and $FF$ are strategically equivalent for each agent since the other agent's first period performance. If $(i,j,k,l) \neq (1,1,1,1)$ then it follows from $\langle 1,1,1,1,0\rangle$ and $\langle i,j,k,l,1\rangle$ that $\langle i,j,k,l,0\rangle$ are redundant. If $(i,j,k,m) \neq (1,1,1,1)$ then it follows from $\langle 1,1,1,0,1\rangle$ and $\langle i,j,k,1,m\rangle$ that $\langle i,j,k,0,m\rangle$ are redundant. If $(i,j,l,m) \neq (1,1,1,1)$ then it follows from $\langle 1,1,0,1,1\rangle$ and $\langle i,j,1,l,m\rangle$ that $\langle i,j,0,l,m\rangle$ are redundant. If $(i,k,l,m) \neq (1,1,1,1)$ then it follows from $\langle 1,0,1,1,1\rangle$ and $\langle i,1,k,l,m\rangle$ that $\langle i,0,k,l,m\rangle$ are redundant. If $(i,j,k,l,m) \neq (2,2,2,1,1)$ and either $i=2$, $j=2$, $k=2$, $l=2$, or $m=2$, then it follows from

$$\frac{c_2}{c_1} \geq \frac{E(p_2) - p_0}{p_1 - p_0}$$

that $\langle i,j,k,l,m\rangle$ are redundant. The incentive compatibility constraints that are not redundant are

$$(p_1 - p_0)\, w_{SS,S\cdot} \geq c_1 \text{ and } (p_1 - p_0)\, w_{SF,S\cdot} \geq c_1$$
$$(p_1 - p_0)\, w_{FS,S\cdot} \geq c_1 \text{ and } (p_1 - p_0)\, w_{FF,S\cdot} \geq c_1$$

$$(p_1 - p_0)\, w_{S\cdot} + p_1(p_1 - p_0)\left[p_1(w_{SS,S\cdot} - w_{FS,S\cdot}) + (1-p_1)(w_{SF,S\cdot} - w_{FF,S\cdot})\right] \geq c_1$$

$$\begin{aligned}(p_1 - E(p_2))w_{S\cdot} &+ (p_1^2 - E(p_2)E(p_2|S_2))\left[p_1 w_{SS,S\cdot} + (1-p_1)w_{SF,S\cdot}\right] \\ &- (p_1^2 - E(p_2)p_1)\left[p_1 w_{FS,S\cdot} + (1-p_1)w_{FS,S\cdot}\right] \geq c_1 - c_2 + E(p_2)(c_1 - c_2)\end{aligned}$$

The first four constraints are binding. If that is not the case, then I have on or more the following inequalities

$$\delta_1 \equiv w_{SS,S\cdot} - \frac{c_1}{p_1 - p_0} > 0 \text{ and } \delta_2 \equiv w_{SF,S\cdot} - \frac{c_1}{p_1 - p_0} > 0$$
$$\delta_3 \equiv w_{FS,S\cdot} - \frac{c_1}{p_1 - p_0} > 0 \text{ and } \delta_4 \equiv w_{FF,S\cdot} - \frac{c_1}{p_1 - p_0} > 0$$

Let the contract $\overrightarrow{w}'$ be the same contract as $\overrightarrow{w}$ except that

$$w'_{SS,S\cdot} = w_{SS,S\cdot} - \delta_1 \text{ and } w'_{SF,S\cdot} = w_{SF,S\cdot} - \delta_2$$
$$w'_{FS,S\cdot} = w_{FS,S\cdot} - \delta_3 \text{ and } w'_{FF,S\cdot} = w_{FF,S\cdot} - \delta_4$$

and

$$w'_{S\cdot} = w_{S\cdot} + p_1 \left[ p_1 \delta_1 + (1-p_1)\delta_2 \right]$$
$$w'_{F\cdot} = w_{F\cdot} + p_1 \left[ p_1 \delta_3 + (1-p_1)\delta_4 \right].$$

The contract $\overrightarrow{w}'$ satisfies the remaining incentive compatibility constraints, it has the same wage bill for the principal and it pays the agent earlier than the contract $\overrightarrow{w}$. Hence I have

$$w_{S\cdot,S\cdot} \equiv w_{SS,S\cdot} = w_{SF,S\cdot} = \frac{c_1}{p_1 - p_0}$$
$$w_{F\cdot,S\cdot} \equiv w_{FS,S\cdot} = w_{FF,S\cdot} = \frac{c_1}{p_1 - p_0}.$$

The remaining incentive compatibility constraints are $\langle 0,1,1,1,1\rangle$ and $\langle 3,3,3,1,1\rangle$ and they become

$$(p_1 - p_0)\, w_{S\cdot} \geq c_1$$

$$(p_1 - E(p_2))w_{S\cdot} + E(p_2)(p_1 - E(p_2|S_2))\frac{c_1}{p_1 - p_0} \geq c_1 - c_2 + E(p_2)(c_1 - c_2).$$

If $\frac{c_2}{c_1} \geq \beta_1$ then the first constraint is binding, otherwise the second constraint is binding. ■

**Proof of Proposition 3.** The principal wishes to implement the action plan $\langle 1,2,2,1,1\rangle$ for agent $A$ (exploiter) and the action plan $\langle 2,2,2,1,1\rangle$ for agent $B$ (explorer). Assume for the moment that action 2 is not available to the exploiting agent $B$ in the first period. I later show that all incentive compatibility constraints that involve such a deviation in the first period are redundant. The optimal contract for agent $B$ that implements these action plans then satisfies the following incentive compatibility constraints which I denote by $\langle i,j,k,l,m\rangle$:

$$\Delta W_1 + \Delta W_{SS} + \Delta W_{SF} + \Delta W_{FS} + \Delta W_{FF} \geq \Delta C$$

where

$$\Delta W_1 = (p_1 - E(p_i)) \left[ E(p_2) w_{SS} + (1 - E(p_2)) w_{FS} \right] - (p_1 - E(p_i)) \left[ E(p_2) w_{SF} + (1 - E(p_2)) w_{FF} \right]$$

$$\begin{aligned}
\Delta W_{SS} = & \left[ p_1 E(p_2|S_2,S_2) - E(p_i)E(p_j|S_2,S_i,S_2) \right] E(p_2)E(p_2|S_2) w_{SS,SS} \\
& + \left[ p_1(1 - E(p_2|S_2,S_2)) - E(p_i)(1 - E(p_j|S_2,S_i,S_2)) \right] E(p_2)E(p_2|S_2) w_{SS,SF} \\
& + \left[ p_1 E(p_2|S_2,F_2) - E(p_i)E(p_j|S_2,S_i,F_2) \right] E(p_2)(1 - E(p_2|S_2)) w_{SS,FS} \\
& + \left[ p_1(1 - E(p_2|S_2,F_2)) - E(p_i)(1 - E(p_j|S_2,S_i,F_2)) \right] E(p_2)(1 - E(p_2|S_2)) w_{SS,FF}
\end{aligned}$$

$$\begin{aligned}
\Delta W_{SF} = & \left[ (1-p_1)E(p_2|S_2,S_2) - (1 - E(p_i))E(p_k|S_2,F_i,S_2) \right] E(p_2)E(p_2|S_2) w_{SF,SS} \\
& + \left[ (1-p_1)(1 - E(p_2|S_2,S_2)) - (1 - E(p_i))(1 - E(p_k|S_2,F_i,S_2)) \right] E(p_2)E(p_2|S_2) w_{SF,SF} \\
& + \left[ (1-p_1)E(p_2|S_2,F_2) - (1 - E(p_i))E(p_k|S_2,F_i,F_2) \right] E(p_2)(1 - E(p_2|S_2)) w_{SF,FS} \\
& + \left[ (1-p_1)(1 - E(p_2|S_2,F_2)) - (1 - E(p_i))(1 - E(p_k|S_2,F_i,F_2)) \right] E(p_2)(1 - E(p_2|S_2)) w_{SF,FF}
\end{aligned}$$

$$\begin{aligned}
\Delta W_{FS} = & \left[ p_1^2 - E(p_i)E(p_l|F_2,S_i) \right] (1 - E(p_2)) \left[ p_1 w_{FS,SS} + (1-p_1) w_{FS,FS} \right] \\
& + \left[ p_1(1-p_1) - E(p_i)(1 - E(p_l|F_2,S_i)) \right] (1 - E(p_2)) \left[ p_1 w_{FS,SF} + (1-p_1) w_{FS,FF} \right]
\end{aligned}$$

$$\begin{aligned}
\Delta W_{FF} = & \left[ (1-p_1)p_1 - (1 - E(p_i))E(p_m|F_2,F_i) \right] (1 - E(p_2)) \left[ p_1 w_{FF,SS} + (1-p_1) w_{FF,FS} \right] \\
& + \left[ (1-p_1)^2 - (1 - E(p_i))(1 - E(p_m|F_2,F_i)) \right] (1 - E(p_2)) \left[ p_1 w_{FF,SF} + (1-p_1) w_{FF,FF} \right]
\end{aligned}$$

and

$$\Delta C = c_1 - c_i + E(p_2)\left(p_1 c_2 - E(p_i)c_j\right) + E(p_2)\left[(1-p_1)c_2 - (1-E(p_i))c_k\right] \\ + (1-E(p_2))\left(p_1 c_1 - E(p_i)c_l\right) + (1-E(p_2))\left[(1-p_1)c_1 - (1-E(p_i))c_m\right].$$

First, I can set

$$w_{\cdot S} \equiv w_{SS} = w_{FS} \text{ and } w_{\cdot F} \equiv w_{FS} = w_{FF}$$

as well as

$$w_{FS,\cdot S} \equiv w_{FS,SS} = w_{FS,FS} \text{ and } w_{FS,\cdot F} \equiv w_{FS,SF} = w_{FS,FF}$$
$$w_{FF,\cdot S} \equiv w_{FF,SS} = w_{FF,FS} \text{ and } w_{FF,\cdot F} \equiv w_{FF,SF} = w_{FF,FF}$$

since this contract pays agent $A$ the same wage independent of the performance of agent $B$, it satisfies all incentive compatibility constraints and it has the same wage bill for the principal.

Next, I argue that

$$w_{\cdot F} = w_{FF,\cdot F} = 0 \text{ and } w_{FS,\cdot F} = 0.$$

Suppose that $w_{\cdot F} > 0$ or $w_{FF,\cdot F} > 0$. A contract $\overrightarrow{w}'$ that offers the same wages as $\overrightarrow{w}$ but has $w'_{\cdot F} = w'_{FF,\cdot F} = 0$ satisfies all incentive compatibility constraints and has a strictly lower expected wage bill for the principal. Suppose now that $w_{FS,\cdot F} > 0$. Let the contract $\overrightarrow{w}'$ be the same as $\overrightarrow{w}$ except that $w'_{FS,\cdot F} = 0$, $w'_{FS,\cdot S} = w_{FS,\cdot S} - w_{FS,\cdot F}$ and $w'_{\cdot S} = w_{\cdot S} + (1 - E(p_2))w_{SS,F\cdot}$. The contract $\overrightarrow{w}'$ satisfies all incentive compatibility constraints and has the same wage bill, but the contract $\overrightarrow{w}'$ pays the agent earlier than $\overrightarrow{w}$.

I now argue that some incentive compatibility constraints following a failure of the exploring agent are redundant. If $(i,l) \neq (1,1)$, then it follows from $\langle 1,2,2,1,0\rangle$ and $\langle i,j,k,l,1\rangle$ that $\langle i,j,k,l,0\rangle$ are redundant. If $(i,m) \neq (1,1)$, then it follows from $\langle 1,2,2,0,1\rangle$ and $\langle i,j,k,1,m\rangle$ that $\langle i,j,k,0,m\rangle$ are redundant. If $(i,l,m) \neq (3,3,1)$ and either $i=3$, $l=3$, or $m=3$, then it follows from

$$\frac{c_3}{c_1} \geq \frac{E(p_3) - p_0}{p_1 - p_0}$$

that $\langle i,2,2,l,m\rangle$ are redundant. Following a failure of the exploring agent the constraints that are not redundant are

$$(p_1 - p_0)\, w_{FS,\cdot S} \geq c_1 \text{ and } (p_1 - p_0)\, w_{FF,\cdot S} \geq c_1.$$

as well as the constraints $\langle 0,2,2,1,1\rangle$ and $\langle 3,2,2,3,1\rangle$.

I now turn to the determination of wages for the exploiting agent following a success of the exploring agent. First, I show that

$$w_{SS,FS} = w_{SF,FS} = 0.$$

Suppose $w_{SS,FS} > 0$ or $w_{SF,FS} > 0$. A contract $\overrightarrow{w}'$ that offers the same wages as $\overrightarrow{w}$ but has

$$w'_{SS,FS} = w'_{SF,FS} = 0$$
$$w'_{SS,SS} = w_{SS,SS} + \frac{1 - E(p_2|S_2,S_2)}{E(p_2|S_2,S_2)} w_{SS,FS} - \varepsilon$$
$$w'_{SF,SS} = w_{SF,SS} + \frac{1 - E(p_2|S_2,S_2)}{E(p_2|S_2,S_2)} w_{SF,FS} - \varepsilon$$

where $\varepsilon > 0$, satisfies all incentive compatibility constraints and yields a strictly lower expected wage bill for the principal. Next I show that

$$w_{SS,SF} = w_{SF,SF} = 0.$$

Suppose $w_{SS,SF} > 0$ or $w_{SF,SF} > 0$. A contract $\overrightarrow{w}'$ that offers the same wages as $\overrightarrow{w}$ but has

$$\begin{aligned} w'_{SS,SF} &= w'_{SF,SF} = 0 \\ w'_{SS,FF} &= w_{SS,FF} + \frac{E(p_2|S_2,F_2)}{1-E(p_2|S_2,F_2)} w_{SS,SF} - \varepsilon \\ w'_{SF,FF} &= w_{SF,FF} + \frac{E(p_2|S_2,F_2)}{1-E(p_2|S_2,F_2)} w_{SF,SF} - \varepsilon \end{aligned}$$

satisfies all incentive compatibility constraints and yields a strictly lower expected wage bill for the principal. Finally, I show that

$$w_{SS,FF} = w_{SF,FF} = 0.$$

Suppose $w_{SS,FF} > 0$ or $w_{SF,FF} > 0$. A contract $\overrightarrow{w}'$ that offers the same wages as $\overrightarrow{w}$ but has

$$\begin{aligned} w'_{SS,FF} &= w'_{SF,FF} = 0 \\ w'_{SS,SS} &= w_{SS,SS} + \frac{(1-E(p_2|S_2,F_2))(1-E(p_2|S_2))}{E(p_2|S_2,S_2)E(p_2|S_2)} w_{SS,FF} - \varepsilon \\ w'_{SF,SS} &= w_{SF,SS} + \frac{(1-E(p_2|S_2,F_2))(1-E(p_2|S_2))}{E(p_2|S_2,S_2)E(p_2|S_2)} w_{SF,FF} - \varepsilon \end{aligned}$$

satisfies all incentive compatibility constraints since $E(p_2|S_2,F_2) \geq p_1$ and yields a strictly lower expected wage bill for the principal.

Thus the remaining constraints are

$$\begin{aligned} E(p_2|S_2)(E(p_2|S_2,S_2) - p_j) w_{SS,SS} &\geq c_2 - c_j \text{ for } j = 0,1 \\ E(p_2|S_2)(E(p_2|S_2,S_2) - p_k) w_{SF,SS} &\geq c_2 - c_k \text{ for } k = 0,1 \\ (p_1 - p_0)\, w_{FS,\cdot S} &\geq c_1 \\ (p_1 - p_0)\, w_{FF,\cdot S} &\geq c_1 . \end{aligned}$$

and the constraints $\langle 0,2,2,1,1\rangle$ and $\langle 3,2,2,3,1\rangle$. Following the same procedure as in Proposition 2 I can show that the above inequalities are binding. Thus, the remaining constraints $\langle 0,2,2,1,1\rangle$ and $\langle 3,2,2,3,1\rangle$ reduce to

$$(p_1 - p_0) w_{\cdot S} \geq c_1$$

and

$$[p_1 - E(p_3)]\, w_{\cdot S} - (1 - E(p_2))E(p_3)\,[E(p_3|S_3) - p_1]\,\frac{c_1}{p_1 - p_0} \geq c_1 - c_3 + (1 - E(p_2))E(p_3)\,(c_1 - c_3)\,.$$

If $\frac{c_2}{c_1} \geq \beta_2$ then the first constraint is binding, otherwise the second constraint is binding. Finally, it remains to verify that the candidate contract also deters deviations in the first period to action 2. The only relevant deviation action plan is $\langle 2,2,2,2,1\rangle$ which is implied by $\langle 3,2,2,3,1\rangle$. ■

**Proof of Proposition 4.** The principal wishes to implement the action plan $\langle 1,2,2,1,1\rangle$ for agent $A$ (exploiter) and the action plan $\langle 2,2,2,1,1\rangle$ for agent $B$ (explorer). The optimal contract for agent $A$ that implements these action plans then satisfies the following incentive compatibility constraints which I denote by $\langle i,j,k,l,m\rangle$:

$$\Delta W_1 + \Delta W_{SS} + \Delta W_{SF} + \Delta W_{FS} + \Delta W_{FF} \geq \Delta C$$

where

$$\Delta W_1 = (E(p_2) - E(p_i))\,[p_1 w_{SS} + (1-p_1) w_{SF}] - (E(p_2) - E(p_i))\,[p_1 w_{FS} + (1-p_1) w_{FF}]$$

$$\Delta W_{SS} = [E(p_2)E(p_2|S_2)E(p_2|S_2,S_2) - E(p_i)E(p_j|S_i)E(p_2|S_i,S_j)]\, p_1 w_{SS,SS}$$
$$+ [E(p_2)E(p_2|S_2)(1 - E(p_2|S_2,S_2)) - E(p_i)E(p_j|S_i)(1 - E(p_2|S_i,S_j))]\, p_1 w_{SS,SF}$$
$$+ [E(p_2)(1 - E(p_2|S_2))E(p_2|S_2,F_2) - E(p_i)(1 - E(p_j|S_i))E(p_2|S_i,F_j)]\, p_1 w_{SS,FS}$$
$$+ [E(p_2)(1 - E(p_2|S_2))(1 - E(p_2|S_2,F_2)) - E(p_i)(1 - E(p_j|S_i))(1 - E(p_2|S_i,F_j))]\, p_1 w_{SS,FF}$$

$$\Delta W_{SF} = [E(p_2)E(p_2|S_2)E(p_2|S_2,S_2) - E(p_i)E(p_k|S_i)E(p_2|S_i,S_k)]\,(1-p_1) w_{SF,SS}$$
$$+ [E(p_2)E(p_2|S_2)(1 - E(p_2|S_2,S_2)) - E(p_i)E(p_k|S_i)(1 - E(p_2|S_i,S_k))]\,(1-p_1) w_{SF,SF}$$
$$+ [E(p_2)(1 - E(p_2|S_2))E(p_2|S_2,F_2) - E(p_i)(1 - E(p_k|S_i))E(p_2|S_i,F_k)]\,(1-p_1) w_{SF,FS}$$
$$+ [E(p_2)(1 - E(p_2|S_2))(1 - E(p_2|S_2,F_2)) - E(p_i)(1 - E(p_k|S_i))(1 - E(p_2|S_i,F_k))]\,(1-p_1) w_{SF,FF}$$

$$\Delta W_{FS} = [(1 - E(p_2))p_1 - (1 - E(p_i))E(p_l|F_i)]\, p_1\, [p_1 w_{FS,SS} + (1-p_1) w_{FS,SF}]$$
$$+ [(1 - E(p_2))(1-p_1) - (1 - E(p_i))(1 - E(p_l|F_i))]\, p_1\, [p_1 w_{FS,FS} + (1-p_1) w_{FS,FF}]$$

$$\Delta W_{FF} = [(1 - E(p_2))p_1 - (1 - E(p_i))E(p_m|F_i)]\,(1-p_1)\, [p_1 w_{FF,SS} + (1-p_1) w_{FF,SF}]$$
$$+ [(1 - E(p_2))(1-p_1) - (1 - E(p_i))(1 - E(p_m|F_i))]\,(1-p_1)\, [p_1 w_{FF,FS} + (1-p_1) w_{FF,FF}]$$

and

$$\Delta C = c_2 - c_i + p_1\,(E(p_2)c_2 - E(p_i)c_j) + (1-p_1)\,(E(p_2)c_2 - E(p_i)c_k)$$
$$+ p_1\,[(1 - E(p_2))c_1 - (1 - E(p_i))c_l] + (1-p_1)\,[(1 - E(p_2))c_1 - (1 - E(p_i))c_m]\,.$$

First, I can set

$$w_{S\cdot} \equiv w_{SS} = w_{SF} \text{ and } w_{F\cdot} \equiv w_{FS} = w_{FF}$$

as well as

$$w_{FS,S\cdot} \equiv w_{FS,SS} = w_{FS,SF} \text{ and } w_{FS,F\cdot} \equiv w_{FS,FS} = w_{FS,FF}$$
$$w_{FF,S\cdot} \equiv w_{FF,SS} = w_{FF,SF} \text{ and } w_{FF,F\cdot} \equiv w_{FF,FS} = w_{FF,FF}$$

since this contract pays agent $A$ the same wage independent of the performance of agent $B$ in the second period, it satisfies all incentive compatibility constraints and it has the same wage bill for the principal. Furthermore, first period performance of the exploiting agent has no effect on the incentives given to the exploring agent since it reveals no information. I can therefore restrict attention to contracts such that the exploring agent chooses $j = k$ and $l = m$

$$w_{S\cdot,AB} \equiv w_{SS,AB} = w_{SF,AB} \text{ and } w_{F\cdot,A\cdot} \equiv w_{FS,A\cdot} = w_{FF,A\cdot} \text{ for } A = \{S,F\} \text{ and } B = \{S,F\}$$

since this contract pays agent $A$ the same wage independent of the performance of agent $B$ in the first period, it satisfies all incentive compatibility constraints and it has the same wage bill for the principal. Thus, I can simplify the set of incentive compatibility constraints given by $\langle i,j,k,l,m\rangle$ to $\langle i,j,j,l,l\rangle$.

Next, I show that $w_{S\cdot} = w_{F\cdot,F\cdot} = 0$. Suppose that $w_{S\cdot} > 0$. Let the contract $\overrightarrow{w}'$ be the same as $\overrightarrow{w}$ except that $w'_{S\cdot} = 0$ and $w'_{S\cdot,SS} = w_{S\cdot,SS} + \frac{1}{E(p_2|S_2)E(p_2|S_2,S_2)} w_{S\cdot} - \varepsilon$ where $\varepsilon > 0$. This contract satisfies all incentive compatibility constraints and yields a strictly lower expected wage bill for the principal. Suppose that $w_{F\cdot,F\cdot} > 0$. If the contract $\overrightarrow{w}'$ is the same as $\overrightarrow{w}$ except that $w'_{F\cdot,F\cdot} = 0$ and $w'_{F\cdot} = w_{F\cdot} + (1-p_1) w_{F\cdot,F\cdot}$, then all incentive compatibility constraints are still satisfied, the principal incurs the same expected wage bill and the contract $\overrightarrow{w}'$ pays the agent earlier.

I now focus on the wages paid following a failure of the exploring agent. From the constraints $\langle 2,2,2,0,0\rangle$ and $\langle i,j,j,1,1\rangle$ it follows that $w_{F\cdot,S\cdot} \geq \frac{c_1}{p_1 - p_0}$. It also follows that $\langle i,j,j,0,0\rangle$, $\langle i,j,j,2,2\rangle$ and $\langle i,j,j,3,3\rangle$ are redundant since

$$\frac{c_2}{c_1} \geq \frac{E(p_2) - p_0}{p_1 - p_0} \text{ and } c_2 = c_3.$$

I now show that the constraint $\langle 2,2,2,0,0\rangle$ is binding so that $w_{F\cdot,S\cdot} = \frac{c_1}{p_1 - p_0}$. Suppose $w_{F\cdot,S\cdot} > \frac{c_1}{p_1-p_0}$. Let the contract $\overrightarrow{w}'$ be the same as $\overrightarrow{w}$ except that $w'_{F\cdot,S\cdot} = \frac{c_1}{p_1-p_0}$ and $w'_{F\cdot} = w_{F\cdot} + p_1(w_{F\cdot,S\cdot} - w'_{F\cdot,S\cdot})$. This contract repays faster, has the same wage bill and satisfies all the remaining $\langle i,j,j,1,1\rangle$ incentive compatibility constraints.

I now turn to the determination of the optimal wage levels following a success of the exploring agent. For the wages following a success of the explorer I first show that $w_{S\cdot,SF} = 0$. A contract $\overrightarrow{w}'$ that offers the same wages as $\overrightarrow{w}$ but has $w'_{S\cdot,SF} = 0$ and $w'_{S\cdot,SS} = w_{S\cdot,SS} + \frac{1-E(p_2|S_2,S_2)}{E(p_2|S_2,S_2)} w_{S\cdot,SF} - \varepsilon$ satisfies all the incentive compatibility constraints and yields a strictly lower wage bill. Next, I show that $w_{S\cdot,FS} = 0$. Consider the contract $\overrightarrow{w}'$ which is the same as $\overrightarrow{w}$ except for $w'_{S\cdot,FS} = 0$ and $w'_{S\cdot,SS} = w_{S\cdot,SS} + \frac{(1-E(p_2|S_2))E(p_2|S_2,F_2)}{E(p_2|S_2)E(p_2|S_2,S_2)} w_{S\cdot,FS} - \varepsilon$. This contract again yields a strictly lower wage bill while satisfying all incentive compatibility constraints. Finally, I show that $w_{S\cdot,FF} = 0$. Let $w'_{S\cdot,FF} = 0$.and $w'_{S\cdot,SS} = w_{S\cdot,SS} + \frac{(1-E(p_2|S_2))(1-E(p_2|S_2,F_2))}{E(p_2|S_2,S_2)E(p_2|S_2)} w_{S\cdot,FF} - \varepsilon$ then such a contract yields a strictly lower wage bill without violating any incentive compatibility constraints. Since $c_2 = c_3$ all incentive compatibility constraints $\langle i,3,3,1,1\rangle$ are redundant.

The only wages that remain to be determined are $w_{F\cdot}$ and $w_{S\cdot,SS}$. The remaining incentive compatibility constraints are the constraint $\langle 2,2,2,0,0\rangle$ which is binding and thus pins down $w_{F\cdot,S\cdot} = \frac{c_1}{p_1-p_0}$, and the constraints $\langle i,j,j,1,1\rangle$ where $j \neq 3$. The constraints $\langle 2,0,0,1,1\rangle$, $\langle 1,0,0,1,1\rangle$, $\langle 1,2,2,1,1\rangle$ and $\langle 2,1,1,1,1\rangle$ are redundant. In particular, $\langle 0,2,2,1,1\rangle$ implies $\langle 2,0,0,1,1\rangle$ while $\langle 0,1,1,1,1\rangle$ and $\langle 0,1,1,2,2\rangle$ imply $\langle 1,0,0,1,1\rangle$. If $c_2 < c_1$, $\langle 1,2,2,1,1\rangle$ is trivially satisfied. If $c_2 > c_1$, $\langle 0,2,2,1,1\rangle$ and $\langle 1,1,1,1,1\rangle$ imply $\langle 1,2,2,1,1\rangle$. Finally, $\langle 1,1,1,1,1\rangle$, $\langle 0,1,1,1,1\rangle$ and $\langle 0,2,2,1,1\rangle$ imply $\langle 2,1,1,1,1\rangle$. Thus the remaining constraints are $\langle 0,0,0,1,1\rangle$, $\langle 0,2,2,1,1\rangle$, $\langle 0,1,1,1,1\rangle$, and $\langle 1,1,1,1,1\rangle$.

If $\frac{c_2}{c_1} \geq \beta_2$, then $\langle 0,1,1,1,1\rangle$ implies $\langle 0,0,0,1,1\rangle$ and $\langle 0,2,2,1,1\rangle$. Either $w_{F\cdot} > 0$, and $\langle 1,1,1,1,1\rangle$ and $\langle 0,1,1,1,1\rangle$ are binding or $w_{F\cdot} = 0$ and $\langle 1,1,1,1,1\rangle$ is binding. With these remaining constraints it is straightforward to show that if

$$\frac{1 - E(p_2)}{1 - p_1} \geq \frac{E(p_2|S_2)E(p_2|S_2,S_2)}{p_1 p_1}$$

it is cheaper for the principal to use the former contract and to use the latter contract otherwise.

If $\frac{c_2}{c_1} < \beta_2$, then the candidate for the optimal contract is such that the constraints $\langle 0,2,2,1,1\rangle$, $\langle 0,0,0,1,1\rangle$, and $\langle 0,1,1,1,1\rangle$ are binding and $w_{F\cdot} = 0$. The minimum wage $w_{S\cdot,SS}$ that satisfies these constraints with equality is given by

$$w_{S\cdot,SS} = \max_{j=0,1,2} \frac{(1 + E(p_2))c_2 - p_0 c_j + (E(p_2) - p_0)p_0\alpha_1}{E(p_2)\left[E(p_2|S_2)E(p_2|S_2,S_2) - p_0 E(p_j|S_2)\right]}.$$

It remains to verify that this wage payment also satisfies the incentive constraint $\langle 1,1,1,1,1\rangle$. Substituting the wage payment into the constraint shows that the contract is indeed feasible. ■

**Proof of Proposition 5.** I focus on symmetric contracts for the two agents so that agents make symmetric action choices. The principal wishes to implement the action plan $\langle 2,2,2,3,1\rangle$ for agent $A$ and the action plan $\langle 3,3,2,3,1\rangle$ for agent $B$. Assume for the moment that action 3 is not available for the exploring agent $A$ and action 2 is not available to the exploiting agent $B$ in the first period. I later show that all incentive compatibility constraints that involve such deviations in the first period are redundant. The optimal contract for agent $A$ that implements these action plans then satisfies the following incentive compatibility constraints which I denote by $\langle i,j,k,l,m\rangle$:

$$\Delta W_1 + \Delta W_{SS} + \Delta W_{SF} + \Delta W_{FS} + \Delta W_{FF} \geq \Delta C.$$

where

$$\Delta W_1 = (E(p_2) - E(p_i))\left[E(p_3)w_{SS} + (1 - E(p_3))w_{SF}\right] - (E(p_2) - E(p_i))\left[E(p_3)w_{FS} + (1 - E(p_3))w_{FF}\right]$$

$$\Delta W_{SS} = [E(p_2)E(p_2|S_2)E(p_3|S_3) - E(p_i)E(p_j|S_i,S_3)E(p_3|S_i,S_3,S_j)]\,E(p_3)w_{SS,SS}$$
$$+ [E(p_2)E(p_2|S_2)(1-E(p_3|S_3)) - E(p_i)E(p_j|S_i,S_3)(1-E(p_3|S_i,S_3,S_j))]\,E(p_3)w_{SS,SF}$$
$$+ [E(p_2)(1-E(p_2|S_2))E(p_3|S_3) - E(p_i)(1-E(p_j|S_i,S_3))E(p_3|S_i,S_3,F_j)]\,E(p_3)w_{SS,FS}$$
$$+ [E(p_2)(1-E(p_2|S_2))(1-E(p_3|S_3)) - E(p_i)(1-E(p_j|S_i,S_3))(1-E(p_3|S_i,S_3,F_j))]\,E(p_3)w_{SS,FF}$$

$$\Delta W_{SF} = [E(p_2)E(p_2|S_2)E(p_2|S_2,S_2) - E(p_i)E(p_k|S_i,F_3)E(p_2|S_i,F_3,S_k)]\,(1-E(p_3))w_{SF,SS}$$
$$+ [E(p_2)E(p_2|S_2)(1-E(p_2|S_2,S_2)) - E(p_i)E(p_k|S_i,F_3)(1-E(p_2|S_i,F_3,S_k))]\,(1-E(p_3))w_{SF,SF}$$
$$+ [E(p_2)(1-E(p_2|S_2))E(p_2|S_2,F_2) - E(p_i)(1-E(p_k|S_i,F_3))E(p_2|S_i,F_3,F_k)]\,(1-E(p_3))w_{SF,FS}$$
$$+ [E(p_2)(1-E(p_2|S_2))(1-E(p_2|S_2,F_2)) - E(p_i)(1-E(p_k|S_i,F_3))(1-E(p_2|S_i,F_3,F_k))]\,(1-E(p_3))w_{SF,FF}$$

$$\Delta W_{FS} = [(1-E(p_2))E(p_3|S_3)E(p_3|S_3,S_3) - (1-E(p_i))E(p_l|F_i,S_3)E(p_3|F_i,S_3,S_3)]\,E(p_3)w_{FS,SS}$$
$$+ [(1-E(p_2))E(p_3|S_3)(1-E(p_3|S_3,S_3)) - (1-E(p_i))E(p_l|F_i,S_3)(1-E(p_3|F_i,S_3,S_3))]\,E(p_3)w_{FS,SF}$$
$$+ [(1-E(p_2))(1-E(p_3|S_3))E(p_3|S_3,F_3) - (1-E(p_i))(1-E(p_l|F_i,S_3))E(p_3|F_i,S_3,F_3)]\,E(p_3)w_{FS,FS}$$
$$+ [(1-E(p_2))(1-E(p_3|S_3))(1-E(p_3|S_3,F_3)) - (1-E(p_i))(1-E(p_l|F_i,S_3))(1-E(p_3|F_i,S_3,F_3))]\,E(p_3)w_{FS,FF}$$

$$\Delta W_{FF} = [(1-E(p_2))p_1 - (1-E(p_i))E(p_m|F_i,F_3)]\,(1-E(p_3))\,[p_1 w_{FF,SS} + (1-p_1)w_{FF,SF}]$$
$$+ [(1-E(p_2))(1-p_1) - (1-E(p_i))(1-E(p_m|F_i,F_3))]\,(1-E(p_3))\,[p_1 w_{FF,FS} + (1-p_1)w_{FF,FF}]$$

and

$$\Delta C = c_2 - c_i + E(p_3)\,(E(p_2)c_2 - E(p_i)c_j) + (1-E(p_3))\,(E(p_2)c_2 - E(p_i)c_l)$$
$$+ E(p_3)\,[(1-E(p_2))c_3 - (1-E(p_i))c_k] + (1-E(p_3))\,[(1-E(p_2))c_1 - (1-E(p_i))c_m]\,.$$

First, I can set

$$w_{S\cdot} \equiv w_{SS} = w_{SF} \text{ and } w_{F\cdot} \equiv w_{FS} = w_{FF}$$

as well as

$$w_{FF,S\cdot} \equiv w_{FF,SS} = w_{FF,SF} \text{ and } w_{FF,F\cdot} \equiv w_{FF,FS} = w_{FF,FF}$$

since this contract pays agent $A$ the same wage independent of the performance of agent $B$ in the second period, it satisfies all incentive compatibility constraints and it has the same wage bill for the principal.

Next, I show that $w_{S\cdot} = w_{FF,F\cdot} = 0$. Suppose that $w_{S\cdot} > 0$. Consider the contract $\overrightarrow{w}'$ which offer the same wages as the contract $\overrightarrow{w}$ except that $w'_{S\cdot} = 0$ and $w'_{SS,SF} = w_{SS,SF} + \frac{1}{E(p_3)E(p_2|S_2)(1-E(p_3|S_3))} w_{S\cdot} - \varepsilon$. Such a contract yields a lower expected wage bill for the principal and satisfies all the incentive compatibility constraints. Suppose that $w_{FF,F\cdot} = 0$. If the contract $\overrightarrow{w}'$ is the same as $\overrightarrow{w}$ except that $w'_{FF,F\cdot} = 0$ and $w'_{F\cdot} = w_{F\cdot} + (1-E(p_3))(1-p_1)w_{FF,F\cdot}$, then all incentive compatibility constraints are still satisfied, the principal incurs the same expected wage bill and the contract $\overrightarrow{w}'$ pays the agent earlier.

It follows from $\langle 2,2,2,3,0\rangle$ and $\langle i,j,k,l,1\rangle$ that $\langle i,j,k,l,m\rangle$ for $m \neq 1$ are redundant. From $\langle 2,2,2,3,0\rangle$ I have that $w_{FF,S\cdot} \geq \frac{c_1}{p_1-p_0}$. Note that this constraint is binding. Suppose $w_{FF,S\cdot} > \frac{c_1}{p_1-p_0}$. If $\overrightarrow{w}'$ is the same as $\overrightarrow{w}$ except that $w'_{FF,S\cdot} = \frac{c_1}{p_1-p_0}$ and $w'_{F\cdot} = w_{F\cdot} + (1-E(p_3))p_1(w_{FS} - w'_{FS})$, then all incentive compatibility constraints are satisfied, the expected wage bill for the principal is unchanged, but $\overrightarrow{w}'$ pays the agent earlier than $\overrightarrow{w}$.

Next I turn to the case where agent $A$ has a failure in the first period, while agent $B$ has a success. First, I show that $w_{FS,AB} = 0$ for $AB \neq SS$. Suppose that $w_{FS,SF} > 0$. A contract $\overrightarrow{w}'$ that is the same as $\overrightarrow{w}$ except that $w'_{FS,SF} = 0$ and $w'_{FS,SS} = w_{FS,SS} + \frac{1-E(p_3|S_3,S_3)}{E(p_3|S_3,S_3)} w_{FS,SF} - \varepsilon$, satisfies all incentive compatibility constraints and yields a strictly lower wage bill. Suppose that $w_{FS,FS} > 0$. A contract $\overrightarrow{w}'$ that is the same as $\overrightarrow{w}$ except that $w'_{FS,FS} = 0$ and $w'_{FS,SS} = w_{FS,SS} + \frac{(1-E(p_3|S_3))E(p_3|S_3,F_3)}{E(p_3|S_3)E(p_3|S_3,S_3)} w_{FS,FS} - \varepsilon$, satisfies all incentive compatibility constraints and yields a strictly lower wage bill. Finally, suppose that $w_{FS,FF} > 0$. A contract $\overrightarrow{w}'$ that is the same as $\overrightarrow{w}$ except that $w'_{FS,FF} = 0$ and $w'_{FS,SS} = w_{FS,SS} + \frac{(1-E(p_3|S_3,F_3))(1-E(p_3|S_3))}{E(p_3|S_3,S_3)E(p_3|S_3)} w_{FS,FF} - \varepsilon$, satisfies all incentive compatibility constraints and yields a strictly lower wage bill. It follows from $\langle 2,2,2,0,1\rangle$, $\langle 2,2,2,1,1\rangle$, $\langle i,j,k,0,m\rangle$ and $\langle i,j,k,1,m\rangle$ that $\langle i,j,k,3,m\rangle$ is redundant. Furthermore, either $\langle 2,2,2,0,1\rangle$ or $\langle 2,2,2,1,1\rangle$ are binding. These two inequality constraints imply $w_{FS,SS} \geq \alpha_2$. Suppose that $w_{FS,SS} > \alpha_2$. If $\overrightarrow{w}'$ is the same as $\overrightarrow{w}$ except that

$$w'_{FS,SS} = \alpha_2 \text{ and } w'_{F\cdot} = w_{F\cdot} + (1-E(p_3))E(p_3|S_3)E(p_3|S_3,S_3)(w_{FS} - w'_{FS})$$

then all incentive compatibility constraints are satisfied, the expected wage bill for the principal is unchanged, but $\overrightarrow{w}'$ pays the agent earlier than $\overrightarrow{w}$.

I now show that $w_{SS,FS} = w_{SS,FF} = 0$. Suppose that $w_{SS,FF} > 0$. If $\overrightarrow{w}'$ is the same as $\overrightarrow{w}$ except that $w'_{SS,FF} = 0$ and $w'_{SS,SF} = w_{SS,SF} + \frac{1-E(p_2|S_2)}{E(p_2|S_2)} w_{SS,FF} - \varepsilon$ then this contract satisfies all incentive compatibility constraints and yields a strictly lower wage bill. Suppose that $w_{SS,FS} > 0$. If $\overrightarrow{w}'$ is the same as $\overrightarrow{w}$ except that $w'_{SS,FS} = 0$ and $w'_{SS,SF} = w_{SS,SF} + \frac{E(p_3|S_3)(1-E(p_2|S_2))}{(1-E(p_3|S_3))E(p_2|S_2)} w_{SS,FS} - \varepsilon$ then this contract satisfies all incentive compatibility constraints and yields a strictly lower wage bill. This leaves $w_{SS,SS}$ and $w_{SS,SF}$ to be determined following a success of both agents.

Finally, it is straightforward to show that $w_{SF,AB} = 0$ for $AB \neq SS$ using the same proof as for $w_{FS,AB}$ for $AB \neq SS$ leaving only the wage $w_{SF,SS}$ to be determined following a success of agent $A$ and a failure of agent $B$. Note that since the two agents are to be induced to choose different actions (action 2 and action 3) in the second period if they are both successful in the first period, but to choose the same task (action 2) following a success of agent $A$ and a failure of agent $B$ and $E(p_2|S_2) = E(p_3|S_3) < E(p_2|S_2,S_2)$, it is always cheaper to use $w_{SF,SS}$ instead of $w_{SS,SS}$ or $w_{SS,SF}$ to deter action deviations in the first period unless $\langle 0,3,2,3,1\rangle$ is binding.

As long as no incentive compatibility constraint $\langle i,3,k,l,m\rangle$ is binding I can set $w_{SS,SS} = w_{SS,SF}$ since this pays the agent solely for his individual performance. The only reason for $w_{SS,SS} \neq w_{SS,SF}$ is when a constraint with $j = 3$ is binding. To deter such deviations the principal has to set $w_{SS,SS} < w_{SS,SF}$. Since $c_2 = c_3$, all constraints $\langle 2,3,k,l,m\rangle$ are redundant. Thus the only constraints that require $w_{SS,SS} < w_{SS,SF}$ are $\langle 0,3,2,3,1\rangle$ and $\langle 1,3,2,3,1\rangle$.

Consider first the case where $w_{F\cdot} = 0$. This leaves the wages $w_{SS,SS}$, $w_{SS,SF}$ and $w_{SF,SS}$ to be determined. For $\frac{c_3}{c_1} \leq \beta_4$ the constraints $\langle 0,3,2,3,1\rangle$ and $\langle 0,0,2,3,1\rangle$ are binding and $w_{SS,SS} = 0$. For $\beta_4 < \frac{c_3}{c_1} \leq \frac{E(p_3|S_3)-p_0}{p_1-p_0}$ the constraints $\langle 0,3,2,3,1\rangle$, $\langle 0,0,2,3,1\rangle$ and $\langle 0,1,2,3,1\rangle$ are binding. For $\frac{E(p_3|S_3)-p_0}{p_1-p_0} < \frac{c_3}{c_1} \leq \beta_5$ I have $w_{SS,SS} = w_{SS,SF}$ and the constraints $\langle 0,1,2,3,1\rangle$ and $\langle 2,1,2,3,1\rangle$ are binding and for $\beta_5 < \frac{c_3}{c_1}$ the constraints $\langle 2,1,2,3,1\rangle$ and $\langle 1,1,2,3,1\rangle$ are binding.

Solving the remaining incentive compatibility constraints yields

$$\begin{aligned}
\alpha_5 = \max_{j=0,1} & \frac{c_2 + E(p_2)c_2 - p_0 c_j - \left[E(p_2)E(p_2|S_2) - p_0 p_j\right](1-E(p_3|S_3))\alpha_4 E(p_3)}{\left[E(p_2|S_2,S_2) - p_0\right]E(p_2)E(p_2|S_2)(1-E(p_3))} \\
&+ \frac{\left(E(p_2) - p_0\right)c_2(1-E(p_3)) + (E(p_2)-p_0)E(p_3)(E(p_3|S_3)E(p_3|S_3,S_3)\alpha_4 - c_3)}{\left[E(p_2|S_2,S_2) - p_0\right]E(p_2)E(p_2|S_2)(1-E(p_3))} \\
&+ \frac{(E(p_2)-p_0)(1-E(p_3))p_0\alpha_1}{\left[E(p_2|S_2,S_2) - p_0\right]E(p_2)E(p_2|S_2)(1-E(p_3))}
\end{aligned}$$

$$\begin{aligned}
\beta_4 &= \frac{E(p_3|S_3) - p_0 - E(p_3|S_3)\left(E(p_3|S_3,S_3) - p_0\right)}{(1-E(p_3|S_3))(p_1-p_0)} \\
\beta_5 &= \frac{E(p_2|S_2)E(p_2|S_2,S_2) - p_0 p_1 + p_1(E(p_2|S_2)E(p_2|S_2,S_2) - E(p_2)p_0))}{(1-E(p_2|S_2))(1+E(p_2))(p_1-p_0)p_1}
\end{aligned}$$

$$\gamma_4 = \frac{\left[E(p_3|S_3) - p_0 - E(p_3|S_3)\left(E(p_3|S_3,S_3) - p_0\right)\right] c_1}{E(p_3|S_3)\left(E(p_3|S_3,S_3) - E(p_3|S_3)\right)\left(E(p_2|S_2) - p_0\right)}$$
$$\gamma_5 = \frac{E(p_3|S_3)\left(E(p_3|S_3,S_3) - p_0\right) c_1}{\left(E(p_3|S_3) - p_0\right)\left[E(p_3|S_3) - p_0 - E(p_3|S_3)\left(E(p_3|S_3,S_3) - p_0\right)\right]}$$
$$\gamma_6 = \frac{\left(E(p_3|S_3,S_3) - p_0\right) c_1}{\left(E(p_3|S_3,S_3) - E(p_3|S_3)\right)\left(E(p_3|S_3) - p_0\right)}$$
$$\gamma_7 = \frac{(1 - E(p_2|S_2))p_1(p_1 - p_0)(1 + E(p_2))c_1}{E(p_2)\left[E(p_2|S_2)E(p_2|S_2,S_2) - p_1 p_1\right]\left[E(p_2|S_2)E(p_2|S_2,S_2) - p_0 p_1\right]}$$

Now consider the case where $w_{F\cdot}$ is not restricted to be equal to zero. The same incentive compatibility constraints hold. However, if $\frac{1-E(p_2)}{1-p_1} \geq \frac{E(p_2|S_2,S_2)}{p_1}$ it is cheaper to satisfy $\langle 1,1,2,3,1 \rangle$ using $w_{F\cdot}$ rather than $w_{SF,SS}$. The modified expressions are

$$\gamma_8 = \frac{(1 - E(p_2|S_2))p_1(1 + E(p_2))c_1}{E(p_2|S_2)E(p_2|S_2,S_2) - p_1 E(p_2)}$$
$$\gamma_9 = \frac{(1 - E(p_2|S_2))p_1(E(p_2) - p_0)(1 + E(p_2))c_1}{E(p_2)\left[E(p_2|S_2)E(p_2|S_2,S_2) - p_0 p_1\right]\left[E(p_2|S_2)E(p_2|S_2,S_2) - p_1 E(p_2)\right]}$$

It remains to show that agent $A$ does not want to deviate to action 3 in the first period. It is straightforward to check that since $E(p_2|S_2,F_2) > p_1$ the agent is never willing to deviate to action 3 given the optimal wage levels I found. ■

# B Experimental Instructions

**Instructions**

You are now taking part in an economic experiment. Please read the following instructions carefully. Everything that you need to know in order to participate in this experiment is explained below. Should you have any difficulties in understanding these instructions please notify us. We will answer your questions at your cubicle.

During the course of the experiment you can earn money. The amount that you earn during the experiment depends on your decisions. All the gains that you make during the course of the experiment will be exchanged into cash at the end of the experiment. The exchange rate will be:

100 francs = \$1

The experiment is divided into 20 periods. In each period you have to make decisions, which you will enter on a computer screen. The decisions you make and the amount of money you earn will not be made known to the other participants - only you will know them.

Please note that communication between participants is strictly prohibited during the experiment. In addition we would like to point out that you may only use the computer functions which are required for the experiment. Communication between participants and unnecessary interference with computers will lead to the exclusion from the experiment. In case you have any questions don't hesitate to ask us.

**Experimental Procedures**

In this experiment, you will take on the role of an individual running a lemonade stand. There will be 20 periods in which you will have to make decisions on how to run the business. These decisions will involve the location of the stand, the sugar and lemon content and the lemonade color and price. The decisions you make in one period, will be the default choices for the next period.

At the end of each period, you will learn what profits you made during that period. You will also hear some customer reactions that may help you with your choices in the following periods.

**Previous Manager Guidelines**

Dear X,

I have enclosed the following guidelines that you may find helpful in running your lemonade stand. These guidelines are based on my previous experience running this stand.

When running my business, I followed these basic guidelines:

| | |
|---:|---|
| Location: | Business District |
| Sugar Content: | 3% |
| Lemon Content: | 7% |
| Lemonade Color: | Green |
| Price: | 8.2 francs |

With these choices, I was able to make an average profit of 85 francs per period.

I have experimented with alternative choices of sugar and lemon content, as well as lemonade color and price. The above choices were the ones I found to be the best. I have not experimented with alternative choices of location though. They may require very different strategies.

Regards,

Previous Manager

**Compensation**

(The following paragraph is used in the instructions for subjects in the treatment with the pay-for-performance contract.) Your compensation will be based on the profits you make with your lemonade stand. You will get paid 50% of your own total lemonade stand profits during the 20 periods of the experiment.

(The following paragraph is used in the instructions for subjects in the treatment with the exploration contract.) Your compensation will be based on the profits you make with your lemonade stand. You will get paid 50% of your own lemonade stand profits in the last 10 periods of the experiment.

(The following paragraph is used in the instructions for subjects in the treatment with the team exploration contract.) Your compensation will be based on the profits you make with your lemonade stand and the profits the other person makes with his lemonade stand. You will get paid 25% of the profits of your own lemonade stand in the last 10 periods of the experiment plus 25% of the profits of the lemonade stand of the other person in the last 10 periods of the experiment.

# C Experimental Design

## C.1 Parameters of the Business Game

The subjects were able to make the following parameter choices:

- Location = {Business District, School, Stadium}
- Sugar Content = $\{0, 0.1, 0.2, ..., 9.9, 10\}$
- Lemon Content = $\{0, 0.1, 0.2, ..., 9.9, 10\}$
- Lemonade Color = {Green, Pink}
- Price = $\{0, 0.1, 0.2, ..., 9.9, 10\}$

The table below shows the optimal product mix in each location.

| | Business District | School | Stadium |
|---|---|---|---|
| Sugar | 1.5% | 9.5% | 5.5% |
| Lemon | 7.5% | 1.5% | 5.5% |
| Lemonade Color | Green | Pink | Green |
| Price | 7.5 | 2.5 | 7.5 |
| Maximum Profit | 100 | 200 | 60 |

In order to calculate the profits in each location when the choices are different from the optimal choices above, I implemented a linear penalty function. In each location, the penalty factors associated with a deviation of one unit for each of the variables are given by the next table.

| | Business District | School | Stadium |
|---|---|---|---|
| Sugar | 5 | 6 | 0.5 |
| Lemon | 5 | 6 | 0.5 |
| Lemonade Color | 20 | 60 | 0.5 |
| Price | 5 | 6 | 0.5 |

## C.2 Eliciting Risk Aversion

I measured the subjects' risk aversion by observing choices under uncertainty in an experiment that took place after the business game experiment. As part of this study, the subjects participated in a series of lotteries of the following form.

**Lottery A:** Win \$10 with probability 1/2, or win \$2 with probability 1/2. If subjects reject lottery A they receive \$7.

**Lottery B:** Win \$10 with probability 1/2, or win \$2 with probability 1/2. If subjects reject lottery B they receive \$6.

**Lottery C:** Win \$10 with probability 1/2, or win \$2 with probability 1/2. If subjects reject lottery C they receive \$5.

**Lottery D:** Win \$10 with probability 1/2, or win \$2 with probability 1/2. If subjects reject lottery D they receive \$4.

**Lottery E:** Win \$10 with probability 1/2, or win \$2 with probability 1/2. If subjects reject lottery E they receive \$3.

After subjects had made their choices one lottery was chosen at random and each subject was compensated according to his or her choice. The above lotteries enable me to construct individual measures of risk aversion.

I then use the median risk aversion measure to split the sample into a more risk-averse group and a less risk-averse group.

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