Essays on Incentives for Innovation
by
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Abstract

This thesis consists of three independent essays that examine the role of incentives for innovation in organizations.

Chapter 2 studies the provision of incentives when workers explore new work methods in parallel. In such a setting, under-exploration may result as workers attempt to free-ride on the new ideas of co-workers. Optimal incentives for routine activities take the form of standard pay-for-performance where only individual success determines compensation while optimal incentives for parallel innovation tolerate early failure and provide workers with long-term group incentives for joint success. Using data from a controlled laboratory experiment, I show that this link between incentives and innovation is causal. Innovation success and performance is highest under a group incentive scheme that rewards long-term joint success.

In Chapter 3, which is co-authored with Gustavo Manso, I provide evidence that the combination of tolerance for early failure and reward for long-term success is effective in motivating innovation. Subjects under such an incentive scheme explore more, get closer to discovering the optimal business strategy, and produce higher average revenues than subjects under fixed-wage and standard pay-for-performance incentive schemes. I also show that the threat of termination can undermine incentives for innovation, while golden parachutes can alleviate these innovation-reducing effects.

Finally, in Chapter 4, I investigate the choice of organizations to conduct interim performance evaluations. When ability does not influence workers’ marginal benefit of effort, the choice between giving workers feedback or not depends on the shape of the cost of effort function. However, when effort and ability are complementary, feedback policies have several competing effects. They inform workers about their relative position in the tournament as well as their relative productivity. In addition, performance appraisals create signal-jamming incentives to exert effort prior to performance evaluation.
Für Elfriede, Othmar und Matthias
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Chapter 1

Introduction

This thesis consists of three independent essays that examine the role of incentives for innovation in organizations.

Chapter 2 studies a crucial aspect of the innovation process, namely 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 by co-workers exploring alternative approaches. I show that 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 long-term incentives, profit sharing, employee ownership, and broad-based stock option plans are positively associated with innovative activity. Using data from a controlled laboratory experiment I show that this link between incentives and innovation is causal. Subjects attempt to free-ride on exploration success when they are 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.

In Chapter 3 which is co-authored with Gustavo Manso, I provide evidence that the combination of tolerance for early failure and reward for long-term success is effective in motivating innovation. Subjects under such an incentive scheme explore more, get closer to discovering the optimal business strategy, and produce higher average revenues than subjects under fixed-wage and standard pay-for-performance incentive schemes. I also show that the
threat of termination can undermine incentives for innovation, while golden parachutes can alleviate these innovation-reducing effects. These results suggest that financial incentives, as long as appropriately designed, are useful in motivating creativity and innovation.

Finally, in Chapter 4, I investigate the choice of organizations to conduct interim performance evaluations in a dynamic tournament model. When ability does not influence workers marginal benefit of effort, the choice between giving workers feedback or not depends on the shape of the cost of effort function. However, when effort and ability are complementary, feedback policies have several competing effects. They inform workers about their relative position in the tournament (evaluation effect) as well as their relative productivity (motivation effect). In addition, performance appraisals create signal-jamming incentives for workers to exert effort prior to performance evaluation in order to influence the inference process of their competitors in the tournament. The choice of the optimal feedback policy therefore depends on the relative strength of these effects. It further suggests a fundamental trade-off of interim performance evaluations between evaluation and motivation in accordance with organizational behavior research and performance appraisal practices.
Chapter 2

Incentives for Parallel Innovation

2.1 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

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\(^2\)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.”
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 chapter 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, 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 chapter 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 (1982b) 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 chapter 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 chapter is organized as follows. Section 2.2 develops the multi-agent bandit problem and illustrates the free-riding effect that arises naturally in innovation settings. Section 2.3 discusses the setup of the principal-agent model, Section 2.4 studies optimal incentives for
several forms of exploitation and exploration. Section 2.5 presents the results of a laboratory experiment of multi-agent incentives for innovation. Section 2.6 concludes. Omitted proofs and experimental instructions are contained in the appendices.

2.2 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

\[
E(p_j|F_j, F_j) < E(p_j|F_j) < E(p_j) < E(p_j|S_j) < E(p_j|S_j, S_j) \text{ for } j = 2, 3. \tag{2.1}
\]

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
\[ E(p_j) < p_1 < E(p_j | S_j) \text{ for } j = 2, 3. \] (2.2)

Finally, I assume that
\[ p_1 < E(p_j | S_j, F_j) \text{ for } j = 2, 3. \] (2.3)

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.

### 2.2.1 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

\[ p_1 + E(p_2) + 2p_1 (1 - E(p_2)) + 2E(p_2|S_2)E(p_2). \]

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

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

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

Therefore, pure exploitation is optimal if

\[ p_1 \geq E(p_2) \frac{1 + 2E(p_2|S_2)}{1 + 2E(p_2)} \] (2.4)

while single innovation is optimal if

\[ E(p_2) \frac{1 + 2E(p_2|S_2)}{1 + 2E(p_2)} \geq p_1 \geq E(p_2) \frac{1 + 2(1 - E(p_2))E(p_2|S_2)}{1 + 2(1 - E(p_2))E(p_2)} \] (2.5)

and parallel innovation is optimal if

\[ p_1 \leq E(p_2) \frac{1 + 2(1 - E(p_2))E(p_2|S_2)}{1 + 2(1 - E(p_2))E(p_2)}. \] (2.6)

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.

2.2.2 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.

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.

**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

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

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

\[ p_1 \geq E(p_2) \frac{1 + E(p_2|S_2)}{1 + E(p_2)}. \] (2.7)

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

\[ E(p_2) \frac{1 + E(p_2|S_2)}{1 + E(p_2)} \geq p_1 \geq E(p_2) \frac{1 + (1 - E(p_2))E(p_2|S_2)}{1 + (1 - E(p_2))E(p_2)}. \] (2.8)

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
\[
p_1 \leq E(p_2) \frac{1 + (1 - E(p_2))E(p_2|S_2)}{1 + (1 - E(p_2))E(p_2)}.
\] (2.9)

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 \( p_1 \).

### 2.2.3 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 (2.4), (2.5), (2.6), (2.7), (2.8), and (2.9) 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.

2.3 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

$$p_0 < E(p_i) \text{ for } i = 1, 2, 3. \quad (2.10)$$

To motivate the agents to employ the productive work methods the principal publicly offers each agent $h = A, B$ a wage contract $\overline{w}^h = \{\overline{w}_1^h, \overline{w}_S^h, \overline{w}_{SF}^h, \overline{w}_{FS}^h, \overline{w}_{FF}^h\}$, which specifies agent $h$’s wages in the first and the second period. In the first period the wage vector is $\overline{w}_1^h$. In the second period following successes of both agents it is $\overline{w}_{SS}^h$ while following a success of agent $A$ and a failure of agent $B$ it is $\overline{w}_{SF}^h$. Similarly, following a failure of agent $A$ and a success of agent $B$ the wage vector is $\overline{w}_{FS}^h$, and following failures of both agents it
Figure 2-1: Actions taken and wages paid to agent $h$ in the first and second period given the outcomes of both agents.

is $\overrightarrow{w}_{FF}^h$. The 20 wages offered to agent $h$ are

$$\overrightarrow{w}_{1}^h = \{w_{SS}^h, w_{SF}^h, w_{FS}^h, w_{FF}^h\}$$

$$\overrightarrow{w}_{SS}^h = \{w_{SS,SS}^h, w_{SS,SF}^h, w_{SS,FS}^h, w_{SS,FF}^h\}$$

$$\overrightarrow{w}_{SF}^h = \{w_{SF,SS}^h, w_{SF,SF}^h, w_{SF,FS}^h, w_{SF,FF}^h\}$$

$$\overrightarrow{w}_{FS}^h = \{w_{FS,SS}^h, w_{FS,SF}^h, w_{FS,FS}^h, w_{FS,FF}^h\}$$

$$\overrightarrow{w}_{FF}^h = \{w_{FF,SS}^h, w_{FF,SF}^h, w_{FF,FS}^h, w_{FF,FF}^h\}.$$

That is, the wage $w_{SF}^h$ 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 $w_{FS,SS}^h$ 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 2-1 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 $\langle i^h_j \rangle$ to maximize his total expected payments $W^h(\mathbf{w}^h, \langle i^h_j \rangle)$ 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 $\langle i^h_j \rangle$ is $C(\langle i^h_j \rangle)$.

An optimal contract that implements the desired action plan $\langle i^h_j \rangle$ for agent $h$ is a contract that minimizes the total expected wage payments $W^A + W^B$ subject to the incentive compatibility constraint $IC_{\langle i^h_j \rangle}$ of each agent $h$

\[
W^h(\mathbf{w}^h, \langle i^h_j \rangle) - C(\langle i^h_j \rangle) \geq W^h(\mathbf{w}^h, \langle n^h_{ij} \rangle) - C(\langle n^h_{ij} \rangle) \text{ for } h = A, B. \quad (2.11)
\]

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,

\[
w_A \equiv w_{AS} = w_{AF} \\
w_{AB,S} \equiv w_{AB,SS} = w_{AB, SF}.
\]
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.

### 2.4 Optimal Incentive Schemes

In this section I analyze optimal contracts that implement pure exploitation, single innovation and parallel innovation. This chapter 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.

#### 2.4.1 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 $\langle 1 \rangle$ for both agents. The following expressions will be helpful in stating the proposition regarding optimal incentives for pure exploitation

$$
\alpha_1 = \frac{c_1}{p_1 - p_0}
$$

$$
\beta_1 = \frac{E(p_2) - p_0 + E(p_2)(E(p_2|S_2) - p_0)}{(1 + E(p_2))(p_1 - p_0)}
$$

$$(x)^+ \equiv \max\{x, 0\}.
$$

Furthermore, I write $w_F = w_{FS} = w_{FF}$ 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
\[ w_S = \alpha_1 + \frac{c_1 (1 + E(p_2))}{p_1 - E(p_2)} \left( \beta_1 - \frac{c_2}{c_1} \right)^+ \] and \( w_F = 0 \)

and the second-period wages are
\[ w_{S,S} = w_{F,S} = \alpha_1 \] and \( w_{S,F} = w_{F,F} = 0 \).

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.

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 \( IC(\alpha_1^2) \) 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 \( w_S = w_{S,S} = w_{F,S} = \alpha_1 \). 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,
Figure 2-2: Wages in the first and second period for agent A under the optimal contract that implements pure exploitation.

so that \( w_S \geq w_{S,s} = w_{F,s} = \alpha_1 \). Naturally, this premium is decreasing in the relative private costs of the new work method.

Figure 2-2 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. The agent is rewarded only for individual success and his wages do not depend on the performance of the other agent.

2.4.2 Incentives for Single Innovation

I now focus on the optimal contract that implements single innovation. The principal wishes to implement the action plan \( \langle z_1^2 \rangle \) for agent A (explorer) and the action plan \( \langle z_1^2 \rangle \) for agent B (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

---

\(^3\)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 \( E(p_2|F_2,F_2) = 0.0664 \).
agent B as it is similar to the optimal contract given to agents under pure exploitation.

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

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

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

\[
w_s = \alpha_1 + \frac{c_1 [1 + E(p_2)(1 - E(p_2))]}{p_1 - E(p_2)} \left( \frac{\beta_2 - c_2}{c_1} \right)^+ \text{ and } w_F = 0
\]

and the second-period wages are

\[
w_{s,ss} = \alpha_2 \text{ and } w_{s,sf} = w_{s,fs} = w_{s,ff} = 0 \\
w_{f,s} = \alpha_1 \text{ and } w_{f,f} = 0.
\]

**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 \( \frac{\alpha_2}{c_1} \geq \beta_2 \), then the exploration constraint \( IC_{(\beta_3, \beta_2)} \) 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 \( w_S = w_{F,S} = \alpha_1 \). On the other hand, if \( \frac{\alpha_2}{c_1} < \beta_2 \) 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 \( w_S \geq w_{F,S} = \alpha_1 \). 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 2-3 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.
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:

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

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

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

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

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

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

\[w_{S} = 0\] and \[w_{F} = 0\]

and the second-period wages are

\[w_{S,SS} = \alpha_3 + \gamma_1 \left( \frac{c_2}{c_1} - \beta_3 \right)^+ \] and \[w_{S,SF} = w_{S,FS} = w_{S,FF} = 0\]

\[w_{F,S} = \alpha_1\] and \[w_{F,F} = 0\].
On the other hand if exploration is very radical

\[ w_F = \gamma_2 \left( \frac{c_2}{c_1} - \beta_3 \right)^+ \]
\[ w_{S,SS} = \alpha_3 + \gamma_3 \left( \frac{c_2}{c_1} - \beta_3 \right)^+ . \]

**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 in 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 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 \( \frac{\alpha_3}{\alpha_1} < \beta_3 \), then the new work method is relatively cheap compared to the conventional work method and therefore the exploitation constraint \( IC(1) \) is not binding and the principal only needs to deter the exploring agent from shirking. To do so, the principal pays the agent \( w_{S,SS} = \alpha_3 \), which just deters the agent from shirking in the first period and in the second period after a success in the first period. If \( \frac{\alpha_3}{\alpha_1} \geq \beta_3 \), 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 \( w_{S,SS} \) and/or \( w_F \), 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 \( w_F \) 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 2-4 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.
Figure 2-4: Wages in the first and second period for the exploring agent $A$ under the optimal contract that implements single innovation.

### 2.4.3 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 $\langle 2,2 \rangle$ for agent $A$ and the action plan $\langle 3,3 \rangle$ 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 $w_F$ 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

\[
\frac{c_3}{c_1} < \frac{E(p_3 | S_3) - p_0}{p_1 - p_0}
\]

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

\[
\begin{align*}
    w_{SS} &= w_{SS,FS} = w_{SS,FF} = w_{SF,FS} = w_{SF,SS} = w_{SF,FF} = 0 \\
    w_{FS,SS} &= w_{FS,FS} = w_{FS,FF} = w_{FF,FS} = w_{FF,SS} = w_{FF,FF} = 0 \\
    w_{FF,FS} &= \alpha_1 \\
    w_{FS,SS} &= \alpha_3.
\end{align*}
\]

If free-riding is cheap

\[
\begin{align*}
    w_{SS,SS} &= \alpha_4 - \gamma_4 \left( \frac{c_3}{c_1} - \beta_4 \right) \\
    w_{SS,SF} &= \begin{cases} 
    \alpha_4 + \gamma_5 \frac{c_4}{c_1} & \text{if } \frac{c_4}{c_1} \leq \beta_4 \\
    \alpha_4 + \gamma_6 \left( \beta_4 - \frac{c_4}{c_1} \right) & \text{if } \frac{c_4}{c_1} > \beta_4
    \end{cases}
\end{align*}
\]

while if free-riding is costly

\[
    w_{SS,SS} = w_{SS,FS} = \alpha_4.
\]
If \( \frac{1 - E(p_2)}{1 - p_2} < \frac{E(p_2|S_2, S_2)}{p_1} \) then

\[
w_F. = 0 \quad w_{SF, SS} = \alpha_5 + \gamma_7 \left( \frac{c_2}{c_1} - \beta_5 \right)^+.
\]

Otherwise

\[
w_F. = \gamma_8 \left( \frac{c_2}{c_1} - \beta_5 \right)^+ \quad w_{SF, SS} = \alpha_5 + \gamma_9 \left( \frac{c_2}{c_1} - \beta_5 \right)^+.
\]

**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 2-5 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.

Second, the agents receive no rewards for success in the first period since \( w_S = 0 \). 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 \( w_F. \) 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 $\frac{\omega_2}{c_1} \leq \beta_3$ then the new work approach is relatively cheap and the exploitation constraint $\mathcal{IC}_{(3,1)}$ is not binding. The principal pays $w_{SF,SS} = \alpha_5$ in this case, while he has to pay a premium if $\frac{\omega_2}{c_1} \geq \beta_3$. 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 $\frac{\omega_3}{c_3} \geq \frac{E(p_3|S_3)-p_0}{p_1-p_0}$, 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 $\frac{\omega_3}{c_3} < \frac{E(p_3|S_3)-p_0}{p_1-p_0}$, then free-riding is cheap and the constraint $\mathcal{IC}_{(3,1)}$ 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,

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

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 $\langle a_3 \rangle$. 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.

2.5 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.

2.5.1 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.

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.
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.

**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.
2.5.2 Results

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

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 2-6 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). In contrast, the improvement in innovation for subjects under exploration

\footnote{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 2-6: 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.

The 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 by subjects throughout the course of the experiment, as in Figure 2-7. 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 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

Figure 2-7: Average maximum and final period profits for the pay-for-performance and exploration contracts under individual and social learning.
effects of risk aversion are of much smaller magnitude and not statistically significant when subjects are given exploration contracts.

**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 2-8 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 have 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 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.

**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*
Figure 2-9: 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.

The proportion of subjects by 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 2-9 provides suggestive evidence that the team exploration contract leads to better final period location choice than the exploration contract. The improvement, however, is relatively 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 2-10. 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 2-11, and this difference is statistically significant (p-value 0.0435).

**2.6 Conclusion**

This chapter 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
Figure 2-11: 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.

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.
2.A Omitted Proofs

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

\[ \Delta W_1 = W_1((n, o, p, q, r)) - W_1((i, j, k, l, m)) \]
\[ \Delta W_{SS} = W_{SS}((n, o, p, q, r)) - W_{SS}((i, j, k, l, m)) \]
\[ \Delta W_{SF} = W_{SF}((n, o, p, q, r)) - W_{SF}((i, j, k, l, m)) \]
\[ \Delta W_{FS} = W_{FS}((n, o, p, q, r)) - W_{FS}((i, j, k, l, m)) \]
\[ \Delta W_{FF} = W_{FF}((n, o, p, q, r)) - W_{FF}((i, j, k, l, m)) \]

where \((n, o, p, q, r)\) denotes the desired equilibrium action plan and \((i, j, k, l, m)\) 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

\[ \Delta C = C((i, j, k, l, m)) - C((n, o, p, q, r)). \]

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

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

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

where

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

\[ \Delta W_{SS} = (p_1^2 - E(p_i)E(p_j|S_i)) p_1 [p_1 w_{SS,SS} + (1 - p_1) w_{SS,SF}] \]
\[ + [1 - p_1] p_1 - E(p_i)(1 - E(p_j|S_i))] p_1 [p_1 w_{SS,FS} + (1 - p_1) w_{SS,FF}] \]

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

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

and

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

First, I can set

\[w_S \equiv w_{SS} = w_{SF}\] and \[w_F. \equiv w_{FS} = w_{FF}\]

as well as

\[w_{AB,S.} \equiv w_{AB,SS} = w_{AB,SF}\] and \[w_{AB,F.} \equiv w_{AB,FS} = w_{AB,FF}\] for \(A = \{S, F\}\) 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

\[w_F. = w_{FS,F.} = w_{FF,F.} = 0\]

and

\[w_{SS,F.} = w_{SF,F.} = 0.\]

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

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.
\((i, j, k, l) \neq (1, 1, 1, 1)\) then it follows from \((1, 1, 1, 0)\) and \((i, j, k, l, 1)\) that \((i, j, k, l, 0)\) are redundant. If \((i, j, k, m) \neq (1, 1, 1, 1)\) then it follows from \((1, 1, 1, 0, 1)\) and \((i, j, k, 1, m)\) that \((i, j, k, 0, m)\) are redundant. If \((i, j, l, m) \neq (1, 1, 1, 1)\) then it follows from \((1, 1, 0, 1, 1)\) and \((i, j, 1, l, m)\) that \((i, j, 0, l, m)\) are redundant. If \((i, k, l, m) \neq (1, 1, 1, 1)\) then it follows from \((1, 0, 1, 1, 1)\) and \((i, 1, k, l, m)\) that \((i, 0, k, l, m)\) 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 \((i, j, k, l, m)\) are redundant. The incentive compatibility constraints that are not redundant are

\[
(p_1 - p_0) w_{SS,S} \geq c_1 \quad \text{and} \quad (p_1 - p_0) w_{SF,S} \geq c_1
\]

\[
(p_1 - p_0) w_{FS,S} \geq c_1 \quad \text{and} \quad (p_1 - p_0) w_{FF,S} \geq c_1
\]

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

\[
(p_1 - E(p_2)) w_S + (p_1^2 - E(p_2)E(p_2|S_2)) \left[ p_1w_{SS,S} + (1 - p_1)w_{SF,S} \right] - (p_1^2 - E(p_2)p_1) \left[ p_1w_{FS,S} + (1 - p_1)w_{FF,S} \right] \geq c_1 - c_2 + E(p_2)(c_1 - c_2)
\]

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

\[
\delta_1 \equiv w_{SS,S} - \frac{c_1}{p_1 - p_0} > 0 \quad \text{and} \quad \delta_2 \equiv w_{SF,S} - \frac{c_1}{p_1 - p_0} > 0
\]

\[
\delta_3 \equiv w_{FS,S} - \frac{c_1}{p_1 - p_0} > 0 \quad \text{and} \quad \delta_4 \equiv w_{FF,S} - \frac{c_1}{p_1 - p_0} > 0
\]

Let the contract \(\bar{w}'\) be the same contract as \(\bar{w}\) except that

\[
w_{SS,S}' = w_{SS,S} - \delta_1 \quad \text{and} \quad w_{SF,S}' = w_{SF,S} - \delta_2
\]

\[
w_{FS,S}' = w_{FS,S} - \delta_3 \quad \text{and} \quad w_{FF,S}' = w_{FF,S} - \delta_4
\]

and

\[
w_S' = w_S + p_1 \left[ p_1 \delta_1 + (1 - p_1)\delta_2 \right]
\]

\[
w_F' = w_F + p_1 \left[ p_1 \delta_3 + (1 - p_1)\delta_4 \right].
\]

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

\[
\begin{align*}
  w_{S,S} &\equiv w_{SS,S} = w_{SSF,S} = \frac{c_1}{p_1 - p_0}, \\
  w_{F,S} &\equiv w_{FS,S} = w_{FFS} = \frac{c_1}{p_1 - p_0}.
\end{align*}
\]

The remaining incentive compatibility constraints are \( (0, 1, 1, 1, 1) \) and \( (3, 3, 3, 1, 1) \) and they become

\[
(p_1 - p_0)w_s \geq c_1
\]

\[
(p_1 - E(p_2))w_s + E(p_2)(p_1 - E(p_2|S_2)) \frac{c_1}{p_1 - p_0} \geq c_1 - c_2 + E(p_2)(c_1 - c_2).
\]

If \( \frac{c_1}{c_1} \geq \beta_1 \) then the first constraint is binding, otherwise the second constraint is binding. \( \blacksquare \)

**Proof of Proposition 3.** The principal wishes to implement the action plan \( (1, 2, 2, 1, 1) \) for agent \( A \) (exploiter) and the action plan \( (2, 2, 2, 1, 1) \) 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 \( (i, j, k, l, m) \):

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

where

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

\[
\Delta W_{SS} = [p_1 E(p_2|S_2, S_2) - E(p_1)E(p_2|S_2, S_1, S_2)] E(p_2)E(p_2|S_2)w_{SS,SS}
\]

\[
+ [p_1(1 - E(p_2|S_2, S_2)) - E(p_i)(1 - E(p_j|S_2, S_1, S_2))] E(p_2)E(p_2|S_2)w_{SS, SF}
\]

\[
+ [p_1 E(p_2|S_2, F_2) - E(p_i)E(p_j|S_2, S_1, F_2)] E(p_2)(1 - E(p_2|S_2))w_{SS, FS}
\]

\[
+ [p_1(1 - E(p_2|S_2, F_2)) - E(p_i)(1 - E(p_j|S_2, F_2))] E(p_2)(1 - E(p_2|S_2))w_{SS, FF}
\]

\[
\Delta W_{SF} = [(1 - p_1)E(p_2|S_2, S_2) - (1 - E(p_1))E(p_k|S_2, F_1, S_2)] E(p_2)E(p_2|S_2)w_{SF,SS}
\]

\[
+ [(1 - p_1)(1 - E(p_2|S_2, S_2)) - (1 - E(p_i))(1 - E(p_k|S_2, F_1, S_2))] E(p_2)E(p_2|S_2)w_{SF, SF}
\]

\[
+ [(1 - p_1)E(p_2|S_2, F_2) - (1 - E(p_i))E(p_k|S_2, F_1, F_2)] E(p_2)(1 - E(p_2|S_2))w_{SF, FS}
\]

\[
+ [(1 - p_1)(1 - E(p_2|S_2, F_2)) - (1 - E(p_i))(1 - E(p_k|S_2, F_1, F_2))] E(p_2)(1 - E(p_2|S_2))w_{SF, FF}
\]
\[ \Delta W_{FS} = \left[ p_1^2 - E(p_i)E(p_{F2}, S_i) \right] (1 - E(p_2)) \left[ p_1 w_{FS, SS} + (1 - p_1) w_{FS, FS} \right] \\
+ \left[ p_1 (1 - p_1) - E(p_i) (1 - E(p_{F2}, S_i)) \right] (1 - E(p_2)) \left[ p_1 w_{FS, SF} + (1 - p_1) w_{FS, FF} \right] \]

\[ \Delta W_{FF} = \left[ (1 - p_1) p_1 - (1 - E(p_i)) E(p_{m,F2, F_i}) \right] (1 - E(p_2)) \left[ p_1 w_{FF, SS} + (1 - p_1) w_{FF, FS} \right] \\
+ \left[ (1 - p_1)^2 - (1 - E(p_i)) (1 - E(p_{m,F2, F_i})) \right] (1 - E(p_2)) \left[ p_1 w_{FF, SF} + (1 - p_1) w_{FF, FF} \right] \]

and

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

First, I can set
\[ w_S \equiv w_{SS} = w_{FS} \text{ and } w_F \equiv w_{FS} = w_{FF} \]
as well as
\[ w_{FS, S} \equiv w_{FS, SS} = w_{FS, FS} \text{ and } w_{FS, F} \equiv w_{FS, SF} = w_{FS, FF} \]
\[ w_{FF, S} \equiv w_{FF, SS} = w_{FF, FS} \text{ and } w_{FF, F} \equiv w_{FF, SF} = w_{FF, FF} \]
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
\[ w_F = w_{FF, F} = 0 \text{ and } w_{FS, F} = 0. \]

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

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 \((1, 2, 2, 1,0)\) and \((i,j,k,l,1)\) that \((i,j,k,l,0)\) are redundant. If \((i, m) \neq (1, 1)\), then it follows from \((1,2,2,0,1)\) and \((i,j,k,1,m)\) that \((i,j,k,0,m)\) 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 \((i,2,2,l,m)\) are redundant. Following a failure of the exploring agent the constraints that are not
redundant are 

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

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 \( \bar{w}' \) that offers the same wages as \( \bar{w} \) 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

\[w_{SS,FS} = w_{SF,FS} = 0.\]

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

\[w'_{SS,SS} = w_{SS,SS} + \frac{E(p_2|S_2, F_2)}{1 - E(p_2|S_2, F_2)} w_{SS,SS} - \varepsilon\]

\[w'_{SF,SS} = w_{SF,SS} + \frac{E(p_2|S_2, F_2)}{1 - E(p_2|S_2, F_2)} w_{SF,SS} - \varepsilon\]

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

\[w_{SS,FS} = w_{SF,FS} = 0.\]

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

\[w'_{SS,FS} = w'_{SF,FS} = 0\]

\[w'_{SS,SS} = w_{SS,SS} + \frac{(1 - E(p_2|S_2, F_2))(1 - E(p_2|S_2))}{E(p_2|S_2, S_2)E(p_2|S_2)} w_{SS,FS} - \varepsilon\]

\[w'_{SF,SS} = w_{SF,SS} + \frac{(1 - E(p_2|S_2, F_2))(1 - E(p_2|S_2))}{E(p_2|S_2, S_2)E(p_2|S_2)} w_{SF,FS} - \varepsilon\]

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

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

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

\[ (p_1 - p_0)w_{S} \geq c_1 \]

and

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

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 \((2, 2, 2, 2, 1)\) which is implied by \((3, 2, 2, 3, 1)\). □

**Proof of Proposition 4.** The principal wishes to implement the action plan \((1, 2, 2, 1, 1)\) for agent A (exploiter) and the action plan \((2, 2, 2, 1, 1)\) 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 \((i, j, k, l, m)\):

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

where

\[ \Delta W_1 = (E(p_2) - E(p_1))[p_1w_{SS} + (1 - p_1)w_{SF}] - (E(p_2) - E(p_1))[p_1w_{FS} + (1 - p_1)w_{FF}] \]

\[ \Delta W_{SS} = [E(p_2)E(p_2|S_2)E(p_2|S_2, S_2) - E(p_i)E(p_j|S_i)E(p_2|S_i, S_j)]p_1w_{SS,SS} \]
\[ + [E(p_2)E(p_2|S_2)(1 - E(p_2|S_2, S_2)) - E(p_i)E(p_j|S_i)(1 - E(p_2|S_i, S_j))]p_1w_{SS, SF} \]
\[ + [E(p_2)(1 - E(p_2|S_2))E(p_2|S_2, F_2) - E(p_i)(1 - E(p_j|S_i))E(p_2|S_i, F_j)]p_1w_{SS, FS} \]
\[ + [E(p_2)(1 - E(p_2|S_2))(1 - E(p_2|S_2, F_2)) - E(p_i)(1 - E(p_j|S_i))(1 - E(p_2|S_i, F_j))]p_1w_{SS, FF} \]

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\[ \Delta W_{SF} = [E(p_2)E(p_2|S_2)E(p_2|S_2, S_2) - E(p_1)E(p_k|S_1)E(p_2|S_1, S_k)](1-p_1)w_{SF,SS} \]
\[ + [E(p_2)E(p_2|S_2)(1-E(p_2|S_2, S_2)) - E(p_1)E(p_k|S_1)(1-E(p_2|S_2, S_1))](1-p_1)w_{SF,SF} \]
\[ + [E(p_2)(1-E(p_2|S_2))E(p_2|S_2, F_2) - E(p_1)(1-E(p_k|S_1))E(p_2|S_1, F_k)](1-p_1)w_{SF,FS} \]
\[ + [E(p_2)(1-E(p_2|S_2))(1-E(p_2|S_2, F_2)) - E(p_1)(1-E(p_k|S_1))(1-E(p_2|S_2, F_k))](1-p_1)w_{SF,FF} \]

\[ \Delta W_{FS} = [(1-E(p_2))p_1 - (1-E(p_1))E(p_1|F_1)]p_1 [p_1w_{FS,SS} + (1-p_1)w_{FS,SF}] \]
\[ + [(1-E(p_2))(1-p_1) - (1-E(p_1))(1-E(p_1|F_1))]p_1 [p_1w_{FS,FS} + (1-p_1)w_{FS,FF}] \]

\[ \Delta W_{FF} = [(1-E(p_2))p_1 - (1-E(p_1))E(p_m|F_1)](1-p_1) [p_1w_{FF,SS} + (1-p_1)w_{FF,SF}] \]
\[ + [(1-E(p_2))(1-p_1) - (1-E(p_1))(1-E(p_m|F_1))](1-p_1) [p_1w_{FF,FS} + (1-p_1)w_{FF,FF}] \]

and

\[ \Delta C = c_2 - c_1 + p_1 (E(p_2)c_2 - E(p_1)c_1) + (1-p_1)(E(p_2)c_2 - E(p_1)c_1) \]
\[ + p_1 [(1-E(p_2))c_1 - (1-E(p_1))c_1] + (1-p_1) [(1-E(p_2))c_1 - (1-E(p_1))c_m]. \]

First, I can set
\[ w_{S} \equiv w_{SS} = w_{SF} \text{ and } w_{F} \equiv w_{FS} = w_{FF} \]
as well as
\[ w_{FS,S} \equiv w_{FS,SS} = w_{FS,SF} \text{ and } w_{FS,F} \equiv w_{FS,FS} = w_{FS,FF} \]
\[ w_{FF,S} \equiv w_{FF,SS} = w_{FF,SF} \text{ and } w_{FF,F} \equiv w_{FF,FS} = w_{FF,FF} \]
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 \( l = m \)

\[ w_{S,AB} \equiv w_{SS,AB} = w_{SF,AB} \text{ and } w_{F,A} \equiv w_{FS,A} = w_{FF,A}. \text{ for } A = \{S,F\} \text{ and } B = \{S,F\} \]
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 \( \langle i, j, l, l \rangle \).
Next, I show that $w_S = w_{F,F} = 0$. Suppose that $w_S > 0$. Let the contract $\tilde{w}'$ be the same as $\tilde{w}$ except that $w'_S = 0$ and $w'_{S,SS} = w_{S,SS} + \frac{1}{E(p_1|S_2)E(p_2|S_2,S_2)} w_S - \varepsilon$ where $\varepsilon > 0$. This contract satisfies all incentive compatibility constraints and yields a strictly lower expected wage bill for the principal. Suppose that $w_{F,F} > 0$. If the contract $\tilde{w}'$ is the same as $\tilde{w}$ except that $w'_{F,F} = 0$ and $w'_{F} = w_F + (1 - p_1)w_{F,F}$, then all incentive compatibility constraints are still satisfied, the principal incurs the same expected wage bill and the contract $\tilde{w}'$ pays the agent earlier.

I now focus on the wages paid following a failure of the exploring agent. From the constraints $(2,2,0,0)$ and $(i,j,j,1,1)$ it follows that $w_{F,S} \geq \frac{c_1}{p_1 - p_2}$. It also follows that $(i,j,j,2,2)$ and $(i,j,j,3,3)$ are redundant since

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

I now show that the constraint $(2,2,2,0,0)$ is binding so that $w_{F,S} = \frac{c_1}{p_1 - p_2}$. Suppose $w_{F,S} > \frac{c_1}{p_1 - p_2}$. Let the contract $\tilde{w}'$ be the same as $\tilde{w}$ except that $w'_{F,S} = \frac{c_1}{p_1 - p_2}$ and $w'_{F} = w_F + p_1(w_{F,S} - w_{F,F})$. This contract repays faster, has the same wage bill and satisfies all the remaining $(i,j,j,1,1)$ 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 $w_{S,FS} = 0$. A contract $\tilde{w}'$ that offers the same wages as $\tilde{w}$ but has $w'_{S,FS} = 0$ and $w'_{S,SS} = w_{S,SS} + \frac{1 - E(p_2|S_2)}{E(p_1|S_2)E(p_2|S_2,S_2)} w_S - \varepsilon$ satisfies all the incentive compatibility constraints and yields a strictly lower wage bill. Next, I show that $w_{S,FS} = 0$. Consider the contract $\tilde{w}'$ which is the same as $\tilde{w}$ except for $w'_{S,FS} = 0$ and $w'_{S,SS} = w_{S,SS} + \frac{1 - E(p_2|S_2)}{E(p_1|S_2)E(p_2|S_2,S_2)} w_{S,SS} - \varepsilon$. This contract again yields a strictly lower wage bill while satisfying all incentive compatibility constraints. Finally, I show that $w_{S,FF} = 0$. Let $w'_{S,FF} = 0$ and $w'_{S,SS} = w_{S,SS} + \frac{1 - E(p_2|S_2)}{E(p_1|S_2)E(p_2|S_2)} w_{S,SS} - \varepsilon$ 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 $(i,3,3,1,1)$ are redundant.

The only wages that remain to be determined are $w_F$ and $w_{S,SS}$. The remaining incentive compatibility constraints are the constraint $(2,2,2,0,0)$ which is binding and thus pins down $w_{F,S} = \frac{c_1}{p_1 - p_2}$, and the constraints $(i,j,j,1,1)$ where $j \neq 3$. The constraints $(2,0,0,1,1), (1,0,0,1,1), (1,2,2,1,1)$ and $(2,1,1,1,1)$ are redundant. In particular, $(0,2,2,1,1)$ implies $(2,0,0,1,1)$ while $(0,1,1,1,1)$ and $(0,1,1,2,2)$ imply $(1,0,0,1,1)$. If $c_2 < c_1$, $(1,2,2,1,1)$ is trivially satisfied. If $c_2 > c_1$, $(0,2,2,1,1)$ and $(1,1,1,1,1)$ imply $(1,2,2,1,1)$. Finally, $(1,1,1,1,1), (0,1,1,1,1) \text{ and } (0,2,2,1,1) \text{ imply } (2,1,1,1,1)$. Thus the remaining constraints are $(0,0,0,1,1), (0,2,2,1,1), (0,1,1,1,1) \text{ and } (1,1,1,1,1)$. 

If $\frac{E}{c_1} \geq \beta_2$, then $(0,1,1,1,1) \text{ and } (0,2,2,1,1). \text{ Either } w_F > 0, \text{ and } (1,1,1,1,1) \text{ and } (0,1,1,1,1) \text{ are binding or } w_F = 0 \text{ and } (1,1,1,1,1) \text{ is binding. With these remaining constraints it is straightforward to show that if}$

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

it is cheaper for the principal to use the former contract and to use the latter contract otherwise.
If $\frac{c_1}{c_2} < \beta_2$, then the candidate for the optimal contract is such that the constraints $(0, 2, 2, 1, 1)$, $(0, 0, 0, 1, 1)$, and $(0, 1, 1, 1, 1)$ are binding and $w_F = 0$. The minimum wage $w_{ss,ss}$ that satisfies these constraints with equality is given by

$$w_{ss,ss} = \max_{j=0,1,2} \frac{(1 + E(p_2))c_2 - p_0 c_j + (E(p_2) - p_0)p_0\alpha_1}{E(p_2)|E(p_2|S_2)E(p_2|S_2, S_2) - p_0 E(p_2|S_2)}.$$

It remains to verify that this wage payment also satisfies the incentive constraint $(1, 1, 1, 1, 1)$. 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 $(2, 2, 2, 3, 1)$ for agent $A$ and the action plan $(3, 3, 2, 3, 1)$ 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 $(i, j, k, l, m)$:

$$\Delta W_1 + \Delta W_{ss} + \Delta W_{sf} + \Delta W_{fs} + \Delta W_{ff} \geq \Delta C.$$

where

$$\Delta W_1 = (E(p_2) - E(p_1))[E(p_3)w_{ss} + (1 - E(p_3))w_{sf}] - (E(p_2) - E(p_1))[E(p_3)w_{fs} + (1 - E(p_3))w_{ff}]$$

$$\Delta W_{ss} = [E(p_2)E(p_2|S_2)E(p_3|S_3) - E(p_1)E(p_1|S_1, S_3)E(p_3|S_1, S_3, S_3)] E(p_3)w_{ss,ss}$$

$$+ [E(p_2)E(p_2|S_2)(1 - E(p_3|S_3)) - E(p_1)E(p_1|S_1, S_3)(1 - E(p_3|S_1, S_3, S_3))] E(p_3)w_{ss,sf}$$

$$+ [E(p_2)(1 - E(p_2|S_2))E(p_3|S_3) - E(p_1)(1 - E(p_1|S_1, S_3))E(p_3|S_1, S_3, F)] E(p_3)w_{ss,fs}$$

$$+ [E(p_2)(1 - E(p_2|S_2))(1 - E(p_3|S_3)) - E(p_1)(1 - E(p_1|S_1, S_3))(1 - E(p_3|S_1, S_3, F))] E(p_3)w_{ss,ff}$$

$$\Delta W_{sf} = [E(p_2)E(p_2|S_2)E(p_2|S_2, S_2) - E(p_1)E(p_1|S_1, F_3)E(p_2|S_1, F_3, S_4)] (1 - E(p_3))w_{sf,ss}$$

$$+ [E(p_2)E(p_2|S_2)(1 - E(p_2|S_2, S_2)) - E(p_1)E(p_1|S_1, F_3)(1 - E(p_2|S_1, F_3, S_4))] (1 - E(p_3))w_{sf,df}$$

$$+ [E(p_2)(1 - E(p_2|S_2))E(p_2|S_2, F_2) - E(p_1)(1 - E(p_1|S_1, F_3))E(p_2|S_1, F_3, F_4)] (1 - E(p_3))w_{sf,fs}$$

$$+ [E(p_2)(1 - E(p_2|S_2))(1 - E(p_2|S_2, F_2)) - E(p_1)(1 - E(p_1|S_1, F_3))(1 - E(p_2|S_1, F_3, F_4))]$$

$$+ (1 - E(p_3))w_{sf,ff}$$

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\[ \Delta W_{FS} = [(1 - E(p_2))E(p_3|S_3)E(p_3|S_3, S_3) - (1 - E(p_1))E(p_1|F, S_3)E(p_3|F, S_3, S_3)] E(p_3)w_{FS, SS} \\
+ [(1 - E(p_2))E(p_3|S_3)(1 - E(p_3|S_3, S_3)) - (1 - E(p_1))E(p_1|F, S_3)(1 - E(p_3|F, S_3, S_3))] E(p_3)w_{FS, SF} \\
+ [(1 - E(p_2))(1 - E(p_3|S_3))E(p_3|S_3, F_3) - (1 - E(p_1))(1 - E(p_1|F, S_3))E(p_3|F, S_3, F_3)] E(p_3)w_{FS, FS} \\
+ [(1 - E(p_2))(1 - E(p_3|S_3))(1 - E(p_3|S_3, F_3)) - (1 - E(p_1))(1 - E(p_1|F, S_3))(1 - E(p_3|F, S_3, F_3))]
\]

\[ E(p_3)w_{FS, FF} \]

\[ \Delta W_{FF} = [(1 - E(p_2))p_1 - (1 - E(p_1))E(p_m|F, F_3)(1 - E(p_3)) [p_1w_{FF, SS} + (1 - p_1)w_{FF, SF}] \\
+ [(1 - E(p_2))(1 - p_1) - (1 - E(p_1))(1 - E(p_m|F, F_3))(1 - E(p_3)) [p_1w_{FF, FS} + (1 - p_1)w_{FF, FF}] \\
\]

and

\[ \Delta C = c_2 - c_1 + E(p_3)(E(p_2)c_2 - E(p_1)c_1) + (1 - E(p_1))(E(p_2)c_2 - E(p_1)c_1) \\
+ E(p_3) [(1 - E(p_2))c_3 - (1 - E(p_1))c_k] + (1 - E(p_3)) [(1 - E(p_2))c_1 - (1 - E(p_1))c_m]. \]

First, I can set

\[ w_S. \equiv w_{SS} = w_S \text{ and } w_F. \equiv w_{FS} = w_F \]

as well as

\[ w_{FF, S} \equiv w_{FF, SS} = w_{FF, SF} \text{ and } w_{FF, F} \equiv w_{FF, FS} = w_{FF, FF} \]

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

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

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 \( \bar{w}' \) that is the same as \( \bar{w} \) 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 $w_{F,S,F} > 0$. A contract $\bar{w}'$ that is the same as $\bar{w}$ except that $w'_{F,S,F} = 0$ and $w'_{F,S,S} = w_{F,S,S} + \frac{(1-E(p_3|S_3))E(p_3|S_3,F_3)}{E(p_3|S_3,S_3)} w_{F,S,F} - \varepsilon$, satisfies all incentive compatibility constraints and yields a strictly lower wage bill. Finally, suppose that $w_{F,S,F} > 0$. A contract $\bar{w}'$ that is the same as $\bar{w}$ except that $w'_{F,S,F} = 0$ and $w'_{F,S,S} = w_{F,S,S} + \frac{(1-E(p_3|S_3))E(p_3|S_3,F_3)}{E(p_3|S_3,S_3)} w_{F,S,F} - \varepsilon$, satisfies all incentive compatibility constraints and yields a strictly lower wage bill. It follows from $(2, 2, 2, 0, 1), (2, 2, 2, 1, 1), (i, j, k, 0, m)$ and $(i, j, k, 1, m)$ that $(i, j, k, 3, m)$ is redundant. Furthermore, either $(2, 2, 2, 0, 1)$ or $(2, 2, 2, 1, 1)$ are binding. These two inequality constraints imply $w_{F,S,S} \geq \alpha_2$. Suppose that $w_{F,S,S} > \alpha_2$. If $\bar{w}'$ is the same as $\bar{w}$ except that $$w'_{F,S,S} = \alpha_2 \quad \text{and} \quad w'_{F} = w_{F} + (1 - E(p_3))E(p_3|S_3)E(p_3|S_3,S_3)(w_{F} - w'_{F})$$ then all incentive compatibility constraints are satisfied, the expected wage bill for the principal is unchanged, but $\bar{w}'$ pays the agent earlier than $\bar{w}$.

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

Finally, it is straightforward to show that $w_{S,F,AB} = 0$ for $AB \neq SS$ using the same proof as for $w_{F,AB}$ for $AB \neq SS$ leaving only the wage $w_{S,S,F}$ 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 $w_{S,F,S}$ instead of $w_{S,S,S}$ or $w_{S,F,F}$ to deter action deviations in the first period unless $(0, 3, 2, 3, 1)$ is binding.

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

Consider first the case where $w_{F} = 0$. This leaves the wages $w_{S,S,S}, w_{S,S,F}$ and $w_{S,F,S}$ to be determined. For $c_2 \leq \beta_4$ the constraints $(0, 3, 2, 3, 1)$ and $(0, 0, 2, 3, 1)$ are binding and $w_{S,S,S} = 0$. For $\beta_4 < c_2 \leq \beta_5$ the constraints $(0, 3, 2, 3, 1), (0, 0, 2, 3, 1)$ and $(0, 1, 2, 3, 1)$ are binding. For $c_2 \leq \beta_6$ I have $w_{S,S,S} = w_{S,S,F}$ and the constraints $(0, 1, 2, 3, 1)$ and $(2, 1, 2, 3, 1)$ are binding and for $\beta_5 < c_2 \leq \beta_6$ the constraints $(2, 1, 2, 3, 1)$ and $(1, 1, 2, 3, 1)$ are binding.
Solving the remaining incentive compatibility constraints yields

\[
\alpha_5 = \max_{\gamma = 0, 1} \frac{c_2 + E(p_2)c_2 - p_0c_2 - [E(p_2)E(p_2|S_2) - p_0p_3]}{[E(p_2|S_2, S_2) - p_0] E(p_2)E(p_2|S_2)(1 - E(p_3))} \left(1 - E(p_3)S_3\right)\alpha_4 E(p_3) \\
+ \frac{(E(p_2) - p_0)c_2(1 - E(p_3)) + (E(p_2) - p_0)E(p_3)(E(p_3|S_3)E(p_3|S_3, S_3)\alpha_4 - c_3)}{[E(p_2|S_2, S_2) - p_0] E(p_2)E(p_2|S_2)(1 - E(p_3))} \\
+ \frac{(E(p_2) - p_0)(1 - E(p_3))p_0\alpha_1}{[E(p_2|S_2, S_2) - p_0] E(p_2)E(p_2|S_2)(1 - E(p_3))}
\]

\[
\beta_4 = \frac{E(p_3|S_3) - p_0 - E(p_3|S_3)(E(p_3|S_3, S_3) - p_0)}{(1 - E(p_3|S_3))(p_1 - p_0)} \\
\beta_5 = \frac{E(p_2|S_2)E(p_2|S_2, S_2) - p_0p_1 + p_1(E(p_2|S_2)E(p_2|S_2, S_2) - E(p_2)p_0)}{(1 - E(p_2|S_2))(1 + E(p_2))(p_1 - p_0)p_1}
\]

\[
\gamma_4 = \frac{[E(p_3|S_3) - p_0 - E(p_3|S_3)(E(p_3|S_3, S_3) - p_0)]c_1}{E(p_3|S_3)(E(p_3|S_3, S_3) - E(p_3|S_3))(E(p_2|S_2) - p_0)} \\
\gamma_5 = \frac{(E(p_3|S_3) - p_0)[E(p_3|S_3) - p_0 - E(p_3|S_3)(E(p_3|S_3, S_3) - p_0)]}{E(p_3|S_3, S_3) - p_0}\frac{c_1}{E(p_3|S_3)} \\
\gamma_6 = \frac{(E(p_3|S_3, S_3) - E(p_3|S_3))(E(p_3|S_3) - p_0)}{(1 - E(p_2|S_2))p_1(p_1 - p_0)(1 + E(p_2))c_1} \\
\gamma_7 = \frac{E(p_2|S_2)E(p_2|S_2, S_2) - p_0p_1}{E(p_2|S_2)E(p_2|S_2, S_2) - p_0p_1}
\]

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

\[
\gamma_8 = \frac{(1 - E(p_2|S_2))p_1(1 + E(p_2))c_1}{E(p_2|S_2)E(p_2|S_2, S_2) - p_0E(p_2)} \\
\gamma_9 = \frac{(1 - E(p_2|S_2))p_1(E(p_2) - p_0)(1 + E(p_2))c_1}{E(p_2)[E(p_2|S_2)E(p_2|S_2, S_2) - p_0p_1][E(p_2|S_2)E(p_2|S_2, S_2) - p_1E(p_2)]}
\]

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. ■

### 2. 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:

\[
100 \text{ francs} = \$1
\]

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.

2.C Experimental Design

2.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.
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.

<table>
<thead>
<tr>
<th></th>
<th>Business District</th>
<th>School</th>
<th>Stadium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>1.5%</td>
<td>9.5%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Lemon</td>
<td>7.5%</td>
<td>1.5%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Lemonade Color</td>
<td>Green</td>
<td>Pink</td>
<td>Green</td>
</tr>
<tr>
<td>Price</td>
<td>7.5</td>
<td>2.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Maximum Profit</td>
<td>100</td>
<td>200</td>
<td>60</td>
</tr>
</tbody>
</table>

2.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.
Chapter 3

Is Pay-for-Performance Detrimental to Innovation?

(joint with Gustavo Manso, MIT Sloan)

3.1 Introduction

Previous research in economics advocates that paying the agent based on his performance induces the agent to exert more effort thereby improving productivity. There is ample evidence supporting this thesis in different types of studies. For example, Lazear (2000) shows that the productivity of windshield installers in Safelite Glass Corporation increased when management changed their compensation from fixed wages to piece-rate pay. Shearer (2004) finds similar evidence in a randomized field experiment with Canadian tree planters. Dickinson (1999) shows that subjects in a laboratory experiment type more letters when their compensation is more sensitive to performance. As in the above examples, most of the existing evidence of the effect of financial incentives on performance comes from studying simple routine tasks, in which effort is the main determinant of productivity.

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 conclude that in tasks that involve creativity and innovation, monetary incentives should not be used to motivate agents.

Can performance-based financial incentives motivate innovation in creative tasks? Using a task that involves innovation through experimentation, we study subject performance under different incentive schemes in a controlled experimental setting. The chapter provides evidence that incentive schemes that tolerate early failure and reward long-term success lead to more innovation and better performance than fixed wages or standard pay-for-performance incentive schemes. This result stands in contrast to previous research in psychology, which suggests that financial incentives inhibit innovation.\(^1\) It also stands in contrast to principal-agent models of repeated effort, according to which incentive schemes that tolerate early failure should produce lower effort and productivity than standard pay-for-performance incentive schemes.\(^2\)

Innovation is the production of knowledge through experimentation (Arrow, 1969; Weitzman, 1979). As pointed out by March (1991), the central concern that arises when learning through experimentation is the tension between the exploration of new untested approaches and the exploitation of well-known approaches. Manso (2008) incorporates this tension into a principal-agent model to study incentives for creativity and innovation. He shows that the optimal incentive scheme that motivates innovation exhibits substantial tolerance for early failure and reward for long-term success.

In our experiment, subjects control the operations of a lemonade stand for 20 periods. In each period of the experiment, subjects make decisions on how to run the lemonade stand and observe the profits produced by their inputs. Subjects must choose 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 better strategy ("exploration").

To study the impact of different incentive schemes on productivity and innovation, we

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\(^1\) See Kohn (1993) and Amabile (1996) for surveys of the psychology literature on this theme.

\(^2\) See, for example, Rogerson (1985), Holmstrom and Milgrom (1987) and Sannikov (forthcoming). These models do not incorporate learning from experimentation which is a central component of the innovation process and also of the task used in our experiment.
consider three different treatment groups. The only difference across these treatment groups is the compensation offered to subjects. Subjects in the first group receive a fixed-wage in each period of the experiment. Subjects in the second treatment group are given a standard pay-for-performance (or profit sharing) contract, receiving 50% of the profits produced during the 20 periods of the experiment. Subjects in the third treatment group are allocated a contract that is tailored to motivate exploration. Their compensation is 50% of the profits produced during the last 10 periods of the experiment.

Our main hypothesis is that subjects under the exploration contract are more likely to find the optimal business strategy than subjects under the fixed-wage and standard pay-for-performance contracts. Two features of the exploration contract encourage subjects to explore. First, tolerance for early failure permits subjects to fail at no cost in the first 10 periods while they explore different strategies. Second, the perspective of being paid for performance later on encourages subjects to learn better ways of performing the task.

Our results provide strong support to the main hypothesis stated above. Subjects under the exploration contract end the experiment in the best location 80% of the time, while subjects under the fixed-wage and the pay-for-performance contracts end the experiment in the best location only 60% and 40% of the time respectively. To explain these differences we look at the reasons behind the poor performance of subjects under the fixed wage and pay-for-performance contracts. Even though subjects under the fixed-wage contract explore a lot, they are not as systematic in their exploration as subjects who are given an exploration contract. For example, when we analyze the notes subjects take in a table we provide to them at the beginning of the experiment, we find that only 55% of the subjects under the fixed-wage contract carefully keep track of their choices and profits while under the exploration contract 82% of the subjects keep track of their choices and profits using the table. Subjects under the pay-for-performance contract, on the other hand, tend to direct their effort towards fine-tuning the previous manager’s product mix, instead of searching for better locations. During the first 10 periods of the experiment, subjects under the exploration contract choose a location other than the business district 80% of the time, while subjects under the pay-for-performance contract do so only 50% of the time.

We also compare the overall profits of subjects under the different contracts. Subjects
under the exploration contract obtain higher average profits than subjects under the fixed-wage and pay-for-performance contracts. This result does not arise in a theoretical model in which the agent is risk-neutral. A risk-neutral agent who is paid 50% of his total profits should deliver higher profits than a risk-neutral agent who is paid 50% of his total profits in the last 10 periods of the experiment. This leads us to study the effects of different attitudes towards risk on the observed outcome under the different contracts. We find that risk aversion plays an important role in explaining differences in the exploration behavior and performance of the subjects under the pay-for-performance contract. Under the pay-for-performance contract, more risk-averse subjects are less likely to find the optimal strategy and they obtain lower average profits than less risk-averse subjects. Other explanations, such as pessimism about exploration, are also possible.

Finally, to study the effects of termination on innovation and performance, we introduce two new treatment groups: a termination treatment group and a termination with golden parachute treatment group. Subjects in both groups receive the exploration contract and are also told that the experiment will end early if their profits in the first 10 periods are lower than a certain threshold. Subjects in the termination with golden parachute treatment group are told that they will receive a reparation payment if the experiment ends after 10 periods. Our hypothesis is that subjects in the termination treatment are less likely to find the optimal location than subjects in the exploration treatment. We further hypothesize that subjects in the termination with golden parachute treatment group are more likely to find the optimal location than subjects in the pure termination treatment group. This hypothesis is supported by the data, since only 45% of the subjects in the termination treatment group find the optimal location, while approximately 65% of the subjects in the termination with golden parachute treatment group find the optimal location.

A common approach to the study of incentives using laboratory experiments is to give subjects a cost function and require them to choose an effort level (Bull, Schotter and Weigelt, 1987; Fehr, Gächter and Kirchsteiger, 1997; Nalbantian and Schotter, 1997). More recently, however, researchers in the experimental economics literature have conducted studies in which subjects have to exert real effort. In these studies, 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. In this chapter, we introduce a task which involves real effort and also incorporates the trade-off between exploration and exploitation, essential in innovation activities.

Other papers in economics have found that pay-for-performance does not always increase performance. For example, Gneezy and Rustichini (2000) find that the effect of monetary incentives can be, for small amounts, detrimental to performance. Their interpretation is that a small compensation per unit of output may insult subjects leading them to exert less effort than if they were paid a fixed wage. In Fehr, Gächter and Kirchsteiger (1997) and Fehr and Rockenbach (2003), the introduction of explicit incentives reduces the performance of workers in a firm-worker relationship because reciprocity was compromised. The focus of these papers differs from ours. They are concerned with tasks in which effort is the main input of the worker, and creativity is not an important determinant of performance.

Some other papers study the tension between exploitation and exploration in an experimental setting. In their analysis of an finite-horizon bandit problem Meyer and Shi (1995) show that subjects underexperimentered with promising options and overexperimented with unpromising options. Banks, Olson and Porter (1997) study infinite-horizon bandit problems. They find that subjects use cut-off strategies and that discount rates and success probabilities affect subject behavior in the direction predicted by the theoretical model. Using a single-agent tournament game Merlo and Schotter (1999) demonstrate that learning and performance are lower in a setting where subjects are learning while they receive compensation than in a setting where subjects are learning before they receive compensation.

Finally, several recent papers study the effects of incentives on innovation. For example, Acharya and Subramanian (2007) investigate whether debtor-friendly bankruptcy laws foster innovation. Sapra, Subramanian and Subramanian (2007) and Atanassov (2007) study whether takeover pressure affects managers investment in innovation, while Aghion, van Reenen and Zingales (2008) analyze the effects of competition and institutional ownership on innovation. Acharya, Baghai, Wadji and Subramanian (2009) study whether stringent labor laws that restrict the dismissal of employees encourage innovation. Azoulay, Graff
Zivin and Manso (2007) study whether funding policies with tolerance for early failure and long horizons to evaluate results motivate creativity in scientific research. These papers provide support for the thesis that tolerance for early failure and reward for long-term success motivate innovation. However, because they use naturally occurring data, the variation in the incentive schemes is not exogenous and therefore estimation of the coefficients may be inconsistent. In this chapter, we are able to study the effects of incentives on innovation by exogenously varying compensation schemes in a controlled laboratory environment.

3.2 Experimental Design

We establish an environment in which we can measure the effects of different incentive schemes on innovation and performance. For this purpose we conduct experiments in which participants have to solve a real task in which the trade-off between exploration and exploitation is central.

3.2.1 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 using an online recruitment system. A total of 379 subjects participated in our experiments.

After subjects complete the experiment we elicit their degree of risk aversion and ambiguity aversion. We describe the exact procedures, which are standard, in the appendix. Subjects are 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.
3.2.2 The Task

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.\footnote{This feedback is only relevant to the location in which the subject chose to sell.} For example, if the computer selects sugar content and the subject has chosen a sugar content that is above the optimal level for the particular location chosen by the subject, the feedback takes the form: “Many of your customers told you that the lemonade is too sweet.”

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 well for this manager and offers an accurate description of a good business strategy for one particular lemonade stand location. 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 that he 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. We use the information subjects record in this table as one measure of their effort during the experiment.

### 3.2.3 Treatment Groups and Predictions

We initially implement three treatment conditions in order to examine how different incentive schemes affect innovation success, exploration behavior, time allocation and effort choices. The only difference between the groups is the way subjects are compensated. The compensation language used in each of the treatment groups is as follows:

**Treatment Group 1 (Fixed-Wage):**

“You will be paid a fixed wage of 50 francs per period.”

**Treatment Group 2 (Pay-for-Performance):**

“You will be paid 50% of the profits you make during the 20 periods of the experiment.”

**Treatment Group 3 (Exploration):**

“You will be paid 50% of the profits you make during the last 10 periods of the experiment.”

The first two treatment groups are motivated by previous research in economics and psychology. The third treatment group is motivated by previous theoretical research (Manso, 2008), which argues that tolerance for early failure and reward for long-term success is optimal to motivate innovation. Under the exploration contract, subjects that perform poorly in the first 10 periods and perform well in the last 10 periods receive a higher compensation than subjects that perform well in the first 10 periods and poorly in the last 10 periods.
Our experiment allows us to address a number of hypotheses. Our main hypothesis concerns the extent to which the different payment schemes considered in our treatment groups affect the exploration activity of subjects. In particular, we hypothesize that subjects under the exploration contract condition should find the optimal business strategy more often than subjects in the other treatments.

**Main Hypothesis:** Subjects under the exploration contract get closer to the optimal business strategy than subjects under the fixed-wage and pay-for-performance contracts.

The main hypothesis addresses the key question of our research agenda. To effectively motivate innovation and exploration subjects should be given a compensation contract that tolerates early failure but rewards success in later periods. Tolerance for early failure allows subjects to explore different strategies early on without being concerned with losses in terms of their compensation. At the same time, the long-term reward induces subjects to exert effort to learn better ways of performing the task.

What are the alternative hypotheses in this setting? As pointed out by the psychology literature, financial incentives reduce intrinsic motivation, an important ingredient for innovation. According to this view, subjects under the fixed wage contract should get closer to the optimal business strategy than subjects under the other two treatment groups, which have their compensation tied to performance. On the other hand, according to dynamic principal-agent models in which the main concern is to induce the agent to exert effort, subjects under the fixed wage or exploration contracts should engage in shirking, while subjects under the pay-for-performance contract should provide effort during the 20 periods of the experiment.

Our main hypothesis naturally leads us to two sub-hypotheses which deal with the problems of the two other contracts we consider in this study. Relative to subjects under the exploration contract, subjects under the pay-for-performance contract engage in less exploration, while subjects under the fixed-wage contract exert less effort.

**Exploration Sub-Hypothesis:** Subjects under the exploration contract are more likely to explore than subjects under the pay-for-performance contract who are more likely to focus on exploitation activities.
Since the compensation of subjects under the pay-for-performance contract depends on their performance from the very first period, we hypothesize that they will explore less than subjects under the exploration contract. A subject under the pay-for-performance contract who uses his first few periods to explore different strategies is likely to obtain lower profits and consequently lower compensation during those periods.

While the exploration hypothesis explains the differential effects of exploration and pay-for-performance contracts it does not predict how subjects under the fixed-wage contract behave. Subjects under the fixed wage contract are guaranteed a fixed compensation and therefore do not face any costs from failing while they explore different strategies. Under a fixed-wage contract, however, subjects do not have explicit incentives for performance and we would therefore expect them to minimize the costly contemplation effort necessary to find the best business strategy.

**Shirking Sub-Hypothesis:** *Subjects under the fixed-wage contract exert less effort than subjects under the exploration contract.*

Since their compensation is independent of performance, subjects under the fixed-wage contract do not have incentives to perform well. Since performance in the task requires effort in the form of costly contemplation of choices and outcomes, we hypothesize that shirking will be more prevalent in the fixed-wage contract.

Note that while we predict that subjects under the exploration contract are more likely to explore than subjects under the pay-for-performance contract and less likely to shirk than subjects in the fixed-wage contract, it need not be the case that they also produce better average performance than subjects under these two other contracts.

### 3.3 Results

In this section we present the results obtained in our experiments comparing the outcome across the three main treatments (fixed-wage contract, pay-for-performance contract and exploration contract). There were 51, 46 and 47 subjects in each of these three treatments.
3.3.1 Innovation, Exploration Behavior and Effort Choice

We first focus on the exploration behavior of subjects across the three different conditions. Our first result shows that the prediction that the exploration contract leads to more innovation than the other two contracts is confirmed by the data.

**Result 1 (innovation):** *Subjects under the fixed-wage and pay-for-performance contracts are significantly less likely to choose to sell at the school (highest profit location) in the final period of the experiment than subjects under the exploration contract. Subjects under the exploration contract come closest to finding the optimal business strategy.*

Initial supporting evidence for Result 1 comes from Figure 3-1 which shows the proportion of subjects under the fixed-wage, pay-for-performance, and exploration contract conditions choosing to sell lemonade in a particular location in the final period. Consistent with our exploration hypothesis, subjects under the exploration contract setting are more likely to sell at the school which is the location with the highest profits in the final period of the experiment than subjects under the fixed-wage and pay-for-performance conditions. Whereas in the exploration contract condition more than 80% of subjects choose to sell lemonade at the school, only 40% of subjects choose to do so in the pay-for-performance condition and 60% choose to do so under the fixed-wage contract. Using Wilcoxon tests for independent samples we can show that these differences are highly significant between the exploration contract and the fixed-wage contract (p-value 0.0042) and the exploration and the pay-for-performance contract (p-value 0.0001). The difference is less marked between the fixed-wage and the pay-for-performance contract (p-value 0.0865).\(^4\)

We 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 by subjects throughout the course of the experiment. Per period profit is a more

\(^4\)In addition, we estimated a logit model where the dependent binary variable takes the value 1 if the final location choice is the school which is the optimal location choice in the experiment, and 0 otherwise. The independent variables are binary variables for the three different contracts. As before, the coefficient estimates show that subjects under the pay-for-performance (p-value 0.0001) and fixed-wage contract (p-value 0.0054) are significantly less likely to choose to sell in the school in the final period of the experiment than subjects in the exploration contract. The negative effect on finding the optimal location in which to sell is particularly pronounced for the pay-for-performance contract while the difference between fixed-wage and pay-for-performance contracts is not as significant (p-value 0.0865).
Figure 3-1: Proportion of subjects by location in the final period of the experiment for the fixed-wage, pay-for-performance and exploration contracts.

comprehensive measure than location choice. It captures the multi-dimensional aspect of the task which involves the choice of several variables. On average, subjects under the exploration contract achieve the highest maximum per period profits (145 francs) while subjects under the fixed-wage (128 francs) and the pay-for-performance (117 francs) contracts perform worse on this dimension. The same pattern holds for final period profit where the respective values are 140 (exploration), 120 (fixed wage) and 111 francs (pay-for-performance). As before the differences in maximum per period profit as well as final period profit between the exploration contract and the other two contracts are highly significant (p-values of 0.013 and 0.0001 for maximum profit, p-values of 0.009 and 0.0001 for final period profit) while the difference between the fixed-wage and the pay-for-performance contract is not statistically significant (p-value 0.1144 for maximum profit, p-value 0.28 for final period profit).

To explain why subjects under the exploration contract are more likely to find the optimal location and business strategy than subjects under the other two contracts, we analyze different measures of exploration and effort. The next result shows that subjects under the exploration contract explore more than subjects under the fixed-wage contract while subjects under the pay-for-performance contract explore the least.
Result 2 (exploration behavior): *Subjects under the pay-for-performance contract explore less than subjects under the fixed-wage contract and the exploration contract with the latter exploring the most.*

Using the different choice variables available to the agents we can construct several measures of exploration activity. We first analyze location choice behavior. Subjects in the pay-for-performance condition explore locations other than the default location (business district) less often than subjects under the other two contracts with subjects under the exploration contract choosing to explore the most often. While subjects under the exploration contract choose a location other than the default location in 82% and 85% of cases in the first and the last 10 periods, subjects under the fixed-wage contract choose to do so only in 60% and 63% of cases and the proportions are as low as 51% and 48% for subjects in the pay-for-performance contract. The tolerance for early failure of the exploration contract relative to the fixed-wage and pay-for-performance contracts encouraged individuals to attempt new untried approaches in the first 10 periods. Using Wilcoxon tests for independent samples reveals that this difference in location choice behavior between the different contracts is statistically significant. In the first 10 periods subjects under the exploration contract choose to explore a different location more often than subjects under the fixed-wage contract (*p*-value 0.0053) and the pay-for-performance contract (*p*-value 0.0001). The difference in exploration behavior as measured by location choice in the first 10 periods is not statistically significant between subjects under the fixed-wage and the pay-for-performance contracts (*p*-value 0.1482), but subjects under the fixed-wage contract choose to explore significantly more often than subjects under the pay-for-performance contract in the last 10 periods of the experiment (*p*-value 0.0985).

This particular form of exploration activity is also reflected in Figure 3-2 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. This standard deviation measure captures variation in all the variables of this multi-dimensional choice problem. There are several features of note.

First, the variability of action choices significantly declines over the course of the experiment in the pay-for-performance (*p*-value 0.0005) and the exploration contracts (*p*-value
Figure 3-2: 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 the fixed-wage, pay-for-performance and exploration contracts.

0.0001). This occurs because in periods 11 to 20 the beneficial learning effects of exploration relative to exploitation are no longer as large as at the beginning of the experiment since the time horizon is shorter. In contrast, the variability of action choices only decreases slightly in the fixed-wage contract and this decline is not statistically significant (p-value 0.2194). Since agents are not penalized for low profits, exploration behavior in the fixed-wage contract is exclusively driven by intrinsic motives and subjects may therefore continue to explore even though the additional benefits of exploration are small.

Second, the variability of action choices in the first 10 periods is significantly higher in the exploration contract than in the pay-for-performance (p-value 0.0012) and the fixed-wage contracts (p-value 0.0027). This shows that subjects under the exploration contract experiment and consciously make very different action choices in a directed attempt to find more promising strategies. In contrast, in the pay-for-performance contract the standard deviation of action choices is much lower as subjects opt to fine-tune the default values. This is also true for subjects under the fixed-wage contract who explore less than subjects under the exploration contract during the first 10 periods. However, because subjects in
the other two treatments explore much less in the later periods of the experiment when their compensation is directly linked to their performance, the variability of action choices of subjects under the fixed-wage contract is higher (though not always significantly so) than in the pay-for-performance (p-value 0.0246) and the exploration contracts (p-value 0.6567). The relatively high exploration behavior of subjects under the fixed-wage contract in the last 10 periods of the experiment also explains why they are more likely to find the highest-profit location than subjects under the pay-for-performance contract who explore the least over the entire course of the experiment among the three contract treatment groups.

We also expect the variability of profits to mirror the variability of action choices. This is indeed the case. First, the variability of profits significantly declines over time with the decline in variability being particularly marked for the exploration contract and the pay-for-performance contracts. Second, the variability of profits in the first 10 periods is significantly higher for subjects under the exploration contract than subjects under the other two contracts, while there is no significant difference in profit variability across subjects under the three contracts in the last 10 periods.

Furthermore, we use Cox hazard rate models to analyze the dynamics that govern the strategy choices of individuals in the experiment. In particular, this allows us to test whether the different treatment conditions also influence whether, once they have decided to explore, subjects continue to explore and what other factors contribute to making them persist in their exploration activities. We classify subjects as having entered an explorative phase as soon as they choose a location other than the default location (business district) suggested by the previous manager. An explorative phase ends when subjects make only small changes to strategy choices relative to the previous period or switch back to the default location. As can be seen from column 1 of Table 3.1, the hazard rate of ending an explorative phase is significantly higher under the pay-for-performance contract than under the exploration contract. The hazard rate is also higher in the fixed-wage contract although this effect is not statistically significant. Moreover, higher profits significantly decrease the hazard rate as

\footnote{In particular, an explorative phase is defined as ending when a subject switches back to the default location or when a subject does not change location and lemonade color and also does not change lemon content, sugar content and price by more than 0.25 units. As a robustness check we also used other definitions thresholds for the end of an exploration phase. The resulting magnitudes and significance levels are very similar.}
Table 3.1: Estimates from a Cox hazard rate model reporting the hazard rates for exiting an exploration phase with the exploration contract as the baseline. Separate estimations are shown for the entire 20 periods of the experiment and the first 10 periods. Robust standard errors are reported in brackets. Statistical significance at the ten, five and one percent level is indicated by *, ** and ***.

subjects are encouraged to persist in their exploration effort. Column 2 of Table 3.1 shows that the estimates for the first 10 periods are qualitatively similar.

Finally, answers in the open-ended post-experimental questionnaire in which all subjects were asked to describe their strategies and the effect the compensation scheme had on their choices also reflected the described exploration pattern. Subjects under the exploration contract spontaneously argued that the tolerance for early failure of the compensation scheme as well as the strong rewards for success in later periods influenced their strategic choices, causing them to experiment with untested locations and action choices early on and then to choose and fine-tune the best available strategy beginning in period 11.

So far, our results have largely focused on exploration behavior. However, we also predicted that subjects under the fixed-wage contract should exert less effort than subjects under the other two contracts since their compensation does not depend on their performance in the experiment. As Result 3 shows, this is indeed the case.
Result 3 (time allocation and effort choice): Subjects under the fixed-wage contract spend less time making and evaluating decisions and exert less effort recording their previous choices and outcomes in the experiment than subjects under the pay-for-performance and exploration contracts.

A principal deciding whether to pay agents a fixed wage might worry that absent any intrinsic motivation and implicit incentives the agent will choose to minimize costly effort. Similarly, in our experiment—where subjects have to mentally focus and record past choices to try to maximize their performance—subjects whose compensation does not depend on their performance may choose to minimize costly and time-consuming contemplation and deliberation effort. Indeed, many subjects under the fixed-wage contract claimed in the post-experimental questionnaire that they attempted to minimize the time and effort necessary to complete the experiment since their performance did not affect their compensation. This pattern is also borne out in our experiment data.

While subjects under the fixed-wage contract spend only an average of 24 seconds on the decision screen (where subjects enter their strategy choices), subjects under the exploration and the pay-for-performance contracts spend 31 and 30 seconds respectively. That is, over the entire duration of the experiment, subjects under the exploration and the pay-for-performance contract condition spend almost 30% more time on the decision screen than subjects under the fixed-wage condition and these differences are statistically significant (p-values of 0.0014 and 0.0175) over the course of the entire experiment as well as in subperiods. Moreover, subjects in the exploration contract treatment spend significantly more time on the decision screen than subjects in the fixed-wage treatment (p-value 0.022) even during the first 10 periods of the experiment when they receive no compensation while this difference in time spent between the exploration and pay-for-performance contracts is not significant (p-value 0.8477). This evidence stands in contrast to dynamic principal-agent models of repeated effort, such as Rogerson (1985), Holmstrom and Milgrom (1987) and Sannikov (forthcoming), which predict that the exploration contract should induce more shirking during the first ten periods of the experiment than the pay-for-performance contract since under the exploration contract a subject’s compensation is not tied to his performance during the first ten periods of the experiment. These models fail to incorporate the learning produced by the exploration
of new strategies, which potentially enhances performance in later periods, and may thus provide incentives for the agent to exert effort in early periods, even when his compensation does not depend on productivity in those early periods. The results above suggest that experimentation and learning can indeed be important components in incentive problems, and should be taken into account when designing compensation schemes for innovative tasks.

Furthermore, in addition to spending less time making decisions, subjects under the fixed-wage contract also exert less effort by entering less information into the sheet given to them than subjects under the pay-for-performance and exploration contracts. Figure 3-3 shows that across the three contracts there is a considerably smaller proportion of subjects under the fixed-wage contract who fill out half or more of the fields in the decision table than in the other two contract treatments. This difference in effort choice is statistically significant between the exploration contract and the fixed-wage contract (\(p\)-value 0.0053) as well as between the pay-for-performance and the fixed-wage contract (\(p\)-value 0.0804). Subjects who are given the exploration contract or the pay-for-performance contract, record their past choices significantly more frequently in the table. The reward for success is sufficient to motivate subjects under the exploration or the pay-for-performance contract to exert more effort in the experiment. In the first 10 periods of the experiment subjects under the exploration contract are significantly more likely to record information than subjects in the fixed-wage contract (\(p\)-value 0.0111) thereby refuting once more the shirking prediction of the standard repeated moral-hazard model. The difference in effort exerted during the first 10 periods between subjects under the exploration contract and the pay-for-performance contract is not significant (\(p\)-value 0.5782).

The difference in effort choice between the exploration contract and the pay-for-performance contract is positive but not statistically significant (\(p\)-value 0.29). On the one hand, subjects under the pay-for-performance contract are given more powerful incentives overall since their compensation depends on performance both in the first and the last 10 periods of the experiment. On the other hand, since subjects under the exploration contract choose to experiment with very different strategies in the first 10 periods as we showed in Result 2, they need to exert more effort when evaluating their decisions than subjects under the pay-for-performance contract. This is also visible in Figure 3-3 which shows that effort declines
in the pay-for-performance contract. This occurs since subjects in the pay-for-performance contract essentially stop exploring and experimenting with different choices very early in the experiment and therefore they barely change their choices in the last 10 periods. Since there is little change, they do not have to record their choices as carefully as subjects in the exploration contract treatment.

We also note that time allocation and effort choice in the fixed-wage is strictly greater than zero since some of the subjects are sufficiently motivated by intrinsic rewards to exert effort. An inspection of effort choices by subjects in the fixed-wage treatment reveals a bimodal distribution. Subjects either fully record or do not record any of their past choices. Moreover, subjects in the fixed-wage treatment who exert more effort are more likely to successfully innovate: 65% of them end up selling at the school in the final period compared to 47% of the subjects who exert less effort, but this difference is not statistically significant (p-value 0.2047). However, maximum profits are significantly higher for subjects in the fixed-wage treatment who exert more effort (p-value 0.0298).6

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6For a study of the effect of intrinsic motivation on innovation productivity, see for example Sauermann and Cohen (2008).
3.3.2 Average Performance

Having confirmed that the innovation success, exploration behavior, time allocation and effort choice across the different contracts is in accordance with our theoretical predictions, we now turn to analyzing average performance differences. In particular, we show that subjects’ overall performance in the experiment as measured by average profit is highest in the exploration contract.

**Result 4 (performance): Subjects under the exploration contract produce higher average profits than subjects under the pay-for-performance and fixed-wage contracts.**

Preliminary evidence for Result 4 comes from inspecting the average profit for the three contracts. This performance measure is highest in the exploration contract (111 francs) and the difference in performance between the exploration contract and the pay-for-performance (96 francs) and the fixed-wage contract (102 francs) is statistically significant ($p$-values of 0.0009 and 0.0253). This difference in performance exists despite the fact that the average wage received by subjects under the exploration contract is lower than in the other two contracts.

We can also investigate the evolution of profits over time in Figure 3-4. From Result 1 we know that subjects under the exploration contract undertake thorough innovation efforts to find the best strategy in the first 10 periods. It is therefore not surprising that the variation in profits in the first 10 periods is also highest in the exploration contract. However, in terms of average profits the three contracts are virtually indistinguishable during the first 10 periods of the experiment. It is only after period 10 that the performance under the different contracts begin to diverge as subjects under the exploration contract revert to and subsequently fine-tune the best strategy they found during the first 10 periods of the experiment.

The result that profits are higher under the exploration contract than under the pay-for-performance contract does not arise in a model with a risk-neutral agent such as Manso (2008). If a risk-neutral agent is paid for overall performance, he should deliver higher performance than a risk-neutral agent who is only paid for performance in the last 10 periods of the experiment. The differences in performance documented in Result 4 naturally lead us to investigate what factors cause the departure from the theoretical predictions. As the
following result shows, attitudes toward risk play an important role in explaining some of the heterogeneity in exploration behavior and performance of experimental subjects.

**Result 5 (risk aversion):** Under the pay-for-performance contract more risk-averse subjects are significantly less likely to explore and to choose to sell in the optimal location in the final period of the experiment. They also produce significantly lower profits. Attitudes to risk have a similar (though statistically insignificant) effect in the exploration contract, while no systematic effects of risk are found for the fixed-wage contract.

We now incorporate the subjects’ different attitudes toward risk into our analysis. Using the data from the separate risk aversion experiment we classify subjects into more and less risk-averse groups. Figure 3-5 provides a first indication for the sign and magnitude of the effect of risk aversion on the likelihood of finding the best strategy. In this figure we use our risk aversion measures to further analyze the final period location choice as we did in Figure 3-1. We separately present final location choices for more and less risk-averse subjects for each of the three contracts. In the pay-for-performance contract, more risk-averse subjects are less likely to find the optimal location as they are less likely to explore than the less
risk-averse subjects. This innovation-reducing effect of risk is statistically significant in the pay-for-performance contract treatment (p-value 0.0170) but it is not statistically significant in the other two treatments. This lower rate of innovation success caused by risk aversion is driven by the lower levels of exploration under the pay-for-performance contract since in this treatment the proportion of location choices other than the default location (p-value 0.0075) as well as the variability of action choices (p-value 0.0181) are significantly lower for subjects with higher risk aversion. However, in the exploration contract where subjects’ failure is tolerated in early periods of the experiment and compensation has a much smaller risky component, as we would expect, the effect is smaller in magnitude and not statistically significant. The same is true in the fixed-wage contract where compensation entails no risk.\footnote{Qualitatively similar results hold for a similarly constructed ambiguity aversion measure which we elicited using the experiment described in the appendix. The effects are of the same sign as the effects of risk aversion, but they are generally smaller in magnitude and in some cases not statistically significant.}

Since more risk-averse subjects under the pay-for-performance contract are less likely to explore and therefore less likely to sell lemonade in the optimal location in the final period, they also produce lower profits as can be seen in Figure 3-6. This profit-reducing effect

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure3-5.png}
\caption{Proportion of subjects by location in the final period of the experiment for the fixed-wage, pay-for-performance and exploration contracts adjusting for differences in risk aversion.}
\end{figure}
of risk aversion in the pay-for-performance contract is large in magnitude and statistically significant for maximum profit (p-value 0.0563) and final period profit (p-value 0.0382), but it is not statistically significant for average profit (p-value 0.1846). Furthermore, as in the case of the final period location choice, risk aversion also has a small negative but statistically insignificant effect on profit measures in the exploration and the fixed-wage contract treatment.

There could be reasons in addition to risk aversion for the difference in average profits across the three treatment groups. For example, in our experiment subjects are not given precise information about the profits associated with each of the available choices.\(^8\) The differences in average profits across the three treatment groups could thus be due to subjects being pessimistic about the returns to exploration. The explanation is exactly the same as the one in the above two paragraphs with pessimism in place of risk-aversion.

\(^8\)This is also the case in some psychology experiments which find that subjects under a fixed-wage contract perform better than subjects under a pay-for-performance contract. For a survey of this literature, see McGraw (1978), McCullers (1978), Kohn (1993) and Amabile (1996).
3.4 Termination

Having analyzed our main three treatment groups we now turn to investigating how the threat of early termination influences exploration behavior and performance. Early termination can undermine the exploration behavior induced by the exploration contract by eliminating the tolerance for early failure. We also show that this effect can be mitigated by the use of “golden parachutes” or reparation payments which subjects receive in case of early termination since these payments reintroduce tolerance for early failure.

We leave the design of the experiment unchanged, but introduce two new treatment groups that enable us to investigate the effects of termination and golden parachutes. The compensation for these two treatment groups is identical to the one in the exploration contract, except that we change the following sentences in the description of the compensation.

**Treatment Group 4 (Termination):**

“You will be paid 50% of the profits you make during the last 10 periods of the experiment. However, if the profits you make during the first 10 periods of the experiment are below 800 francs, the experiment will end early.”

**Treatment Group 5 (Termination with Golden Parachute):**

“You will be paid 50% of the profits you make during the last 10 periods of the experiment. If the profits you make during the first 10 periods of the experiment are below 800 francs, the experiment will end early and you will receive a payment of 250 francs.”

Pure termination inhibits exploration activities because it undermines a crucial aspect of an exploration contract, namely the tolerance for early failure. While the threat of termination produces strong incentives for good performance, it also forces individuals to focus on producing good performance from the very beginning and thus reduces the incentives for exploration. In contrast, in the golden parachute treatment we expect subjects to explore a little more intensively than in the termination treatment at the beginning of the experiment despite the pending threat of termination since the golden parachute payment provides them with some insurance in case of failure. In particular, we have the following prediction:
Termination Hypothesis: Subjects under the termination contract are less likely to find the optimal business strategy than subjects under the exploration treatment since the threat of termination has an exploration-deterring effect. However, subjects under the golden parachute treatment are more likely to find the optimal business strategy than subjects in the termination treatment since the reparation payment encourages exploration.

In a setting where exploration is a key ingredient for achieving good performance, the threat of early termination is predicted to have adverse effects on innovation success and exploration. However, these effects are predicted to be mitigated by the use of golden parachutes. As we will show, these predictions are also borne out in our experiment data. We begin our analysis by showing that the threat of termination reduces the probability that subjects successfully innovate because the threat of early termination reduces exploration activities. Furthermore, the next result also shows that the adverse effects of termination are less pronounced in the golden parachute treatment.

Result 6 (termination): The threat of termination has adverse effects on innovation success and exploration activities, but golden parachutes alleviate these negative effects. Risk aversion further reduces innovation success, exploration activities and performance in the termination treatment.

There were a total of 71 and 78 subjects who participated in the termination and the golden parachute treatments. Figure 3-7 shows final period location choices in the exploration contract, termination and golden parachute treatments where in the case of the latter two treatments we eliminated subjects that are terminated after the first 10 periods. The threat of termination in the pure termination and golden parachute treatment significantly reduces the probability that subjects end up choosing to sell at the best location in the final period of the experiment relative to the exploration contract treatment (p-values 0.0001 and 0.0200) while the use of golden parachutes raises the innovation success probability (p-value 0.0485) relative to the termination treatment. The same picture emerges when focusing exclusively on the final location choice after the first 10 periods using all the subjects in the termination and golden parachute treatments. As before, the threat of termination reduces the probability of finding the best location relative to the exploration treatment (p-values 0.0063 and 0.0562)
and the use of reparation payments increases the innovation success probability in the golden parachute treatment relative to the termination treatment, although this effect is not large enough to be significant (p-value 0.3176).

We also analyze differences among treatments in the maximum profit and final period profit a subject achieves which serves as our other measure of innovation success. Focusing on subjects that are not terminated we again find that termination has an innovation-reducing effect since average maximum profit in the exploration contract treatment (145 francs) is significantly higher than in the termination (126 francs) and the golden parachute treatments (134 francs). The respective p-values are 0.0037 and 0.0772. Comparing the maximum profits for the termination and golden parachute treatments shows that the use of golden parachutes slightly mitigates these adverse effects, though the effect is not significant (p-value 0.1784).

The adverse effect of termination is more pronounced if we consider the full sample of subjects and only focus on the first 10 periods. The average maximum profit in the termination and the golden parachute treatments is again significantly lower than in exploration contract treatment (p-values 0.0032 and 0.0037). However, the difference between the termination and the golden parachute treatments is not statistically significant (p-value 0.7989).

**Figure 3-7:** Proportion of subjects by location in the final period of the experiment for the exploration contract, termination and golden parachute treatments.
As in our analysis of the three baseline treatments, we can trace the differences in innovation success back to differences in exploration behavior. To this end we again compare the number of times subjects choose to deviate from the proposed strategy and to explore a location other than the business district. To guard against potential selection effects arising from attrition we focus exclusively on choices in the first 10 periods. As expected, exploration is lower in the termination treatment where subjects shy away from exploring other locations in the first 10 periods. While the average proportion of location choices other than the default location is 82% in the exploration contract it is only 47% in the termination treatment and 59% in the golden parachute treatment. This exploration-reducing effect of the threat of termination is statistically significant (p-values 0.0001 and 0.0009). Moreover, as postulated before, golden parachutes increase exploration activities relative to the pure termination treatment and this beneficial effect is statistically significant (p-value 0.0495).

In the post-experiment questionnaire subjects argued that the threat of termination forced them to concentrate on selling in the business district and left no leeway for exploration. Further evidence for the exploration-reducing effect of the threat of termination and the exploration-increasing effect of reparation payments comes from comparing the variability of action choices in the first 10 periods for the full sample of subjects. The subject-specific standard deviation of action choices in the first 10 periods is highest in the exploration contract (standard deviation 1.09). This measure is significantly lower in the termination treatment (standard deviation 0.74, p-value 0.0014) and in the golden parachute treatment (standard deviation 0.79, p-value 0.0071). As before, the use of golden parachutes slightly increases exploration activity relative to the termination treatment, but this effect is not statistically significant (p-value 0.2821).9

Using the same hazard rate model as in our analysis of the baseline treatments though concentrating exclusively on the first 10 periods we can investigate how likely subjects are to persist in their exploration activities in the different treatments. Column 3 of Table 3.1 shows that both in the termination treatment and in the golden parachute treatment subjects

9The different proportions of subjects who are terminated in the termination and the golden parachute treatments are also in line with subjects exploring more in the latter case. While in the termination treatment 13 out of 71 subjects (18%) do not meet or exceed the termination threshold, 21 out of 78 subjects (27%) are terminated in the golden parachute treatment, but the difference is not statistically significant (p-value 0.2124).
Figure 3-8: Proportion of subjects by location in the final period of the experiment for the exploration contract, termination and golden parachute treatment adjusting for differences in risk aversion.

are significantly more likely to stop exploring than in the exploration contract. Moreover, subjects in the termination treatment are also significantly more likely to stop exploring than subjects under the golden parachute treatment (p-value 0.0663). Column 4 of Table 3.1 reports estimates for the first 10 periods showing statistically significant differences in the hazard rate between the exploration contract treatment and the termination treatment as well as the golden parachute treatment. Note further that the difference between termination and golden parachute is also statistically significant (p-value 0.0604).

Risk aversion plays an important role in the termination treatment as can be seen in Figure 3-8, which shows final period location choice, and in Figure 3-9, which presents the different profit measures. More risk-averse subjects in the termination treatment are less likely to sell in the school in the final period of the experiment and they achieve lower maximum, final period and average profits. Throughout, there is a statistically significant negative effect of risk aversion in the termination treatment on the correct final period location choice (p-value 0.0041) as well as maximum profits (p-value 0.0023), final period profits (p-value 0.0041) and average profits (p-value 0.0037). This finding is in line with our previous analysis where
we found similarly strong effects of risk aversion for the pay-for-performance contract which also induces individuals to achieve profits from the very beginning of the experiment instead of learning through exploration. In contrast, like our finding for the exploration contract treatment there is no statistically significant effect of risk aversion in the golden parachute treatment.

Finally, we can also confirm that in the termination treatment a high degree of risk aversion significantly decreases subjects’ propensity to explore. In the termination treatment the number of times subjects choose to deviate from the proposed strategy and to explore a location other than the business district in the first 10 periods is significantly lower for subjects who are more risk-averse (p-value 0.0114). Similarly, in the termination treatment the variability of action choices in the first 10 periods is also significantly lower for more risk-averse subjects (p-value 0.0040). There are also small negative effects of risk aversion on exploration activity in the golden parachute treatment, but these effects are never statistically significant.
3.5 Robustness

In this section we show that our results are robust to modifications in the experimental design. In particular, we address potential signaling effects of incentive contracts. In the analysis we previously conducted each subject only ever saw one particular incentive contract. The subjects were not made aware that a variety of different incentive schemes were administered to different subjects. This means that subjects might make different inferences from the different contracts they are given about what the best strategy to play is. For example, while subjects under the pay-for-performance contract might infer that the best strategy is not to explore, subjects under the exploration contract might infer that the best strategy is to explore.

To account for these potential signaling effects we administered another treatment in which subjects were able to see that both pay-for-performance and exploration contracts were available. In this treatment, after having observed the set of possible contracts (pay-for-performance or exploration) the incentive scheme relevant to each subject was determined by having the subject roll a dice. After having observed the outcome of the dice roll the experimenter circled the relevant compensation scheme and crossed out the irrelevant compensation scheme. A total of 70 subjects participated in this treatment of which 32 subjects rolled the dice to receive a pay-for-performance contract and 38 subjects an exploration contract.

Figure 3-10 confirms our results about the importance of correctly structured incentives for motivating innovation. As before, subjects who are given an exploration contract are significantly more likely (p-value 0.0152) to choose the best location in the final period of the experiment than subjects who receive a pay-for-performance contract. Subjects with an exploration contract also again achieve significantly higher maximum profits (138 francs) and higher final period profits (134 francs) than subjects under a pay-for-performance contract (120 francs, 118 francs). The respective p-values for the comparisons are 0.0372 and 0.0654.

As before this difference in innovation success is driven by the differences in exploration behavior that incentive schemes induce. In particular, the proportion of location choices other than the default location is significantly higher for subjects who obtain an exploration contract following their dice roll (p-value 0.0045) and the variability of strategy choices is also
Figure 3-10: Proportion of subjects by location in the final period of the experiment for the pay-for-performance (dice roll) and exploration (dice roll) contracts.

higher, although this difference is not significant (p-value 0.1343) due to the smaller sample size.

Mirroring our previous results, subjects under the pay-for-performance contract also have low average profits although this effect is not statistically significant (p-value 0.1591). Furthermore, risk aversion again has an innovation- and profit-reducing effect in the pay-for-performance treatment. In the pay-for-performance treatment there is a statistically significant negative effect of risk aversion on the correct final period location choice (p-value 0.0583) but there is no significant effect in the exploration contract treatment. The negative effect of risk aversion when subjects obtain a pay-for-performance contract is also apparent in the lower profits for more risk-averse subjects, but this effect is not statistically significant due to the small sample size.

3.6 Conclusion

In this chapter, we argued that appropriately designed incentive schemes are effective in motivating innovation. In a task that involves innovation through experimentation, we find
that subjects under an incentive scheme that tolerates early failure and rewards long-term success explore more and are more likely to discover a novel business strategy than subjects under fixed-wage or standard pay-for-performance incentive schemes. We also find that the threat of termination may undermine innovation, and that this effect is mitigated by the presence of a golden parachute.

Several important questions remain unanswered. For example, when agents work in teams, what is the optimal balance between individual and team incentives that motivate exploration? Moreover, when there are different types of agents, how do we design contracts to attract the creative types while keeping shirkers and conventional types away? We leave these questions for future research.
3.A  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 fixed wage contract.) You will get paid a fixed wage of 50 francs per period during the 20 periods of the experiment. Your final compensation does not depend on your profits from the lemonade stand.

(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 termination contract.) Your compensation will be based on the profits you make with your lemonade stand. You will get paid 50% of the profits you make during the last 10 periods of the experiment. However, if the profits you make during the first 10 periods of the experiment are below 800 francs, the experiment will end early.

(The following paragraph is used in the instructions for subjects in the treatment with the golden parachute contract.) You will get paid 50% of the profits you make during the last 10 periods of the experiment. If the profits you make during the first 10 periods of the experiment are below 800 francs, the experiment will end early and you will receive a payment of 250 francs.
3.B Experimental Design

3.B.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.

<table>
<thead>
<tr>
<th></th>
<th>Business District</th>
<th>School</th>
<th>Stadium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>1.5%</td>
<td>9.5%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Lemon</td>
<td>7.5%</td>
<td>1.5%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Lemonade Color</td>
<td>Green</td>
<td>Pink</td>
<td>Green</td>
</tr>
<tr>
<td>Price</td>
<td>7.5</td>
<td>2.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Maximum Profit</td>
<td>100</td>
<td>200</td>
<td>60</td>
</tr>
</tbody>
</table>

In order to calculate the profits in each location when the choices are different from the optimal choices above, we 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.

<table>
<thead>
<tr>
<th></th>
<th>Business District</th>
<th>School</th>
<th>Stadium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>5</td>
<td>6</td>
<td>0.5</td>
</tr>
<tr>
<td>Lemon</td>
<td>5</td>
<td>6</td>
<td>0.5</td>
</tr>
<tr>
<td>Lemonade Color</td>
<td>20</td>
<td>60</td>
<td>0.5</td>
</tr>
<tr>
<td>Price</td>
<td>5</td>
<td>6</td>
<td>0.5</td>
</tr>
</tbody>
</table>
3.B.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 us to construct individual measures of risk aversion. We then used the median risk aversion measure to split the sample into a more risk-averse group and a less risk-averse group.

3.B.3 Eliciting Ambiguity Aversion

We also measured the subjects’ ambiguity aversion by observing choices under uncertainty in another experiment that took place after the business game experiment and the risk aversion experiment. As part of this study, we presented the subjects with the opportunity to participate in a series of lotteries of the following form.

If a red ball is chosen you will win $7, if a blue ball is chosen you will win $2.

**Case A:** Choose Urn 1 containing 20 balls that are either red or blue OR choose Urn 2 containing 16 red balls and 4 blue balls.

**Case B:** Choose Urn 1 containing 20 balls that are either red or blue OR choose Urn 2 containing 14 red balls and 6 blue balls.

**Case C:** Choose Urn 1 containing 20 balls that are either red or blue OR choose Urn 2 containing 12 red balls and 8 blue balls.
Case D: Choose Urn 1 containing 20 balls that are either red or blue OR choose Urn 2 containing 10 red balls and 10 blue balls.

Case E: Choose Urn 1 containing 20 balls that are either red or blue OR choose Urn 2 containing 8 red balls and 12 blue balls.

Case F: Choose Urn 1 containing 20 balls that are either red or blue OR choose Urn 2 containing 6 red balls and 14 blue balls.

Case G: Choose Urn 1 containing 20 balls that are either red or blue OR choose Urn 2 containing 4 red balls and 16 blue balls.

After subjects had made their choices one case was chosen at random and the subject was compensated according to his choice. The above lotteries enable us to construct individual measures of ambiguity aversion.

We then used the median ambiguity aversion measure to split the sample into a more ambiguity-averse group and a less ambiguity-averse group.
Chapter 4

Feedback and Motivation in Dynamic Tournaments

4.1 Introduction

This chapter studies interim performance appraisals. Interim performance evaluations occur at some point, usually midway, through the completion of a task when evaluators inform individuals of their progress towards achieving a specific goal, e.g. a promotion. In particular, we are interested in how organizations decide whether or not to provide feedback to their workers on how their performance to date has been evaluated and how the choice of feedback policy affects the effort choice and performance of workers.

Feedback policies are pervasive in organizational settings. Citing a series of human resource studies Murphy and Cleveland (1995) document that between 74% and 89% of business organizations have a formal performance appraisal and feedback system. DeVries, Morrison, Shullman and Gerlach (1986) note that since the 1960s performance appraisals were increasingly used for employee development and feedback. In fact, in almost all organizations, at least some information is revealed to workers at regular intervals about how well they have performed in the past. Companies in which promotion decisions constitute a large part of rewards such as law firms or consulting firms, inform their workers about their previous performance and prospects long before the actual promotion decisions are made. In universities, junior faculty members are given feedback through formal review processes about past per-
formance and their prospects of obtaining tenure. Midterm exams that count towards the final grade that students receive for a particular course are another example of a case where information about performance is revealed to students in advance of the final results.

There are also many other examples of informational feedback mechanisms outside of organizations. In patent races, the governing body has to decide whether or not to force companies to reveal how much progress they have made towards a particular discovery. In sports competitions much attention is devoted to the design of the information feedback scheme. For example, the games in the final leg of any soccer league competition are usually held at the same time so that vital information is obscured to the contestants whereas contestants in a race are provided with information about split times relative to other competitors or previous records. Finally, feedback mechanisms such as opinion polls may also influence candidates’ and voters’ decisions in political elections. Until recently, Austrian law prohibited the publication of opinion polls in the last week before an election whereas other countries allowed information to be released to the public.

Despite their pervasiveness, interim performance appraisals have, until recently, received scant attention in the economic literature. Given the widespread use of interim performance appraisals it is even more surprising that the previous contributions that deal with the issue of feedback in dynamic moral hazard problems cast a pessimistic light on the role of interim evaluations. In fact, they mostly provide convincing explanations for why we should not observe interim evaluations in practice (Lizzeri, Meyer and Persico, 2002; Fuchs, 2007).1 There is, however, a large organizational behavior and human resource management literature that discusses the effects of organizational feedback mechanisms. In a number of studies (Stone and Stone, 1985; Ashford, 1986; Locke and Latham, 1990) feedback is found “to provide critical input for forming realistic self-assessments in the work setting” and “is a key to maintaining high levels of work motivation” (Murphy and Cleveland, 1995, p. 328). Furthermore, there is evidence that the introduction of feedback mechanisms can both enhance and lower performance (Podsakoff and Farh, 1989; Liden and Mitchell, 1985) and that interim performance evaluations generally involve a trade-off between the conflicting objectives of

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1 However, Manso (2008) shows that feedback is crucial when the principal wants to incentivize workers to innovate.
‘development’ and ‘evaluation’ (Beer, 1987).

The negative verdict on interim performance evaluations in the economic literature and lack of consensus in the human resource literature about the desirability of interim performance appraisals may be linked to the multiplicity of effects that such mechanisms can have. First, performance appraisals affect the incentives of workers to exert effort after information has been revealed to them. This is true irrespective of whether the information that the firm transmits in such performance appraisals is given exogenously or is generated endogenously by the workers’ previous output levels. In either case, the subsequent contest between workers will be biased in favour of the worker that received positive feedback (evaluation effect). Second, interim performance evaluations affect the morale of workers as well as the confidence they have in their skills as they learn about their productivity (motivation effect). Third, feedback mechanisms can affect workers’ incentives to exert effort before information is revealed to them. Additional implicit incentives can arise because workers choose their actions strategically so as to influence the content of the interim performance appraisal. Finally, providing feedback on performance helps workers do their jobs or plan their futures better by giving them better information on which to base their decisions. In this way, interim performance appraisals affect how well workers tailor their effort choices to their ability level (sorting effect). While the previous economic literature has focused on the first of these forces which we call the evaluation effect, the present chapter is the first to formalize the other effects in a dynamic tournament setting and to analyze the optimal design of a feedback policy in their presence.

Tournaments are ubiquitous in economic organizations because performance is often rewarded by promoting high-performing employees. Therefore, the most natural setting in which to explore the question of interim performance evaluations in organizations is that of a contest between workers who compete for a fixed prize, for example a job promotion. First, such tournaments are inherently dynamic as during the contest the principal often observes some interim performance measures that she can use to provide feedback to the agents. Second, workers’ performance is generally private information of the manager or the firm’s personnel division. Workers, on the other hand, cannot fully observe their own performance because output can often only be measured by a combination of factors such
as social skills, originality, team-working ability and because there may be a significant subjective element in the evaluation of performance. Furthermore, organizations usually have much more experience in assessing the contributions of an individual worker who tends to have little experience with the tasks he is performing. Third, workers generally also differ in terms of their ability as well as the confidence they have in their skills.

We therefore study a two-period tournament model in which two risk-neutral agents make private effort choices but cannot observe their performances due to exogenous noise and incomplete knowledge of their own ability levels. The principal (she) is assumed to be risk-neutral and solely interested in maximizing expected total performance of the agents over the two periods. Furthermore, the principal privately observes the difference in agents’ performance realizations after the first stage and then chooses between the following two alternatives. In a no-feedback scenario, she does not transmit any of her private information to the agents so that when choosing second-period effort the agent does not know the first-period outcome. In a full-feedback scenario, the principal truthfully and publicly reveals the first-period output difference to the two contestants. Under such a policy the agents learn their relative standing before choosing second-period efforts. The optimal feedback policy is one that maximizes the expected output of the two agents over the two periods.

We begin the analysis by exploring the case in which the performance of each agent in each period is the sum of his privately chosen effort, a persistent ability component and a random noise term. This setup allows for heterogeneity in ability among contestants as well as learning about ability levels on behalf of the contestants when they receive an interim performance evaluation. The optimal feedback policy takes a simple form which crucially depends on the functional form of the disutility of effort. If the marginal cost of effort is concave, a full-feedback policy elicits higher expected second-period effort and output from the agents than a no-feedback policy. If the marginal cost of effort is convex, the opposite relation holds. Under the common assumption of linear marginal cost of effort both feedback policies yield the same expected effort and output levels.

To examine the effects of organizational feedback mechanisms on motivation and morale

\[2^\text{Note, however, that there might be circumstances under which the principal may find it more appropriate to send private messages to the agents.}\]
we enrich the basic model by assuming that effort and ability are complementary so that beliefs about ability directly impact the effort choice of agents. We identify several effects of interim performance evaluations that are emphasized in the human resource management and organizational behavior literature, yet were previously not documented in the economic literature. We show that the two different feedback policies will lead to different expected effort and performance levels even when the marginal disutility of effort is linear. As before when information about relative past performance is revealed, workers learn about ability. However, since effort and ability are complementary, their beliefs about ability directly influence the workers’ perceived marginal benefit of effort. Workers will therefore tailor their second-period effort choices to the beliefs they hold about their ability level. We call this result the motivation effect of interim performance evaluations since it motivates contestants who (correctly) believe themselves to be more able to exert more effort. However, this motivation effect is a double-edged sword since it also discourages effort exertion by less able contestants. Yet, the efficient sorting that results from this motivation effect leads to higher expected second-period output than if no information is revealed to the contestants since more able contestants exert more effort while less able contestants exert less effort. Furthermore, we demonstrate that a procedure that gives full feedback to agents creates implicit incentives prior to the revelation of information that are absent in the no feedback case. These implicit incentives arise since, in a model where effort and ability are complementary, each contestant would like to make his opponent believe that his own ability (i.e., marginal benefit of effort) is higher than it actually is. This can be achieved by increasing first-period effort and therefore biasing the first-period output difference in one’s favour. As a result, first-period effort and output are higher under a full-feedback policy. However, all these beneficial effects will have to be weighed against the adverse consequences that result from the asymmetries that a full-feedback policy generates whenever it reveals that the first-period output difference is in favour of one of the contestants. Equilibrium effort in the second-period contest is highest when the contestants are close to each other in terms of first-period output, but effort is decreasing as the difference in first-period outputs grows large and thus strongly favours one of the agents. This is the evaluation or lack-of-competition effect which has been the focus of the previous literature and it will tend to reduce the benefits of interim
performance evaluations. My analysis suggests a fundamental trade-off between evaluation and motivation effects that firms face when deciding whether and how to provide interim performance evaluation.

**Related Literature** While tournaments have received significant attention in personnel economics (Lazear and Rosen, 1981; Green and Stokey, 1983), earlier contributions have mostly focused on the static case of one-shot interaction where contestants make a single effort choice. However, tournaments are often dynamic in nature (Rosen, 1986; Meyer, 1991, 1992). More recently, several contributions have studied the effect of information release on incentives in dynamic tournament settings (Lizzeri, Meyer and Persico, 1999, 2002; Yildirim, 2005; Aoyagi, 2007; Gershkov and Perry, 2008; Goltsman and Mukherjee, 2008). These papers show that the release of interim information creates endogenous asymmetries between contestants and that the information revelation policy can affect effort choices both before and after the release of information.

Gershkov and Perry (2007) study midterm reviews in a two period setting without ability heterogeneity. In contrast to the present contribution which explores the question of optimal information release, they analyze whether it is optimal to give equal importance to the performance of contestants in the two periods. Goltsman and Mukherjee (2008) also investigate a dynamic tournament setting without heterogeneity in ability and binary output, but allow for more general feedback policies. Interestingly, they show that the principal is strictly better off using a partial disclosure policy that does not reveal all information. Finally, Lizzeri, Meyer and Persico (1999) and Aoyagi (2007) are most closely related to the present analysis. Both contributions explore dynamic tournament models in which agents do not vary with respect to ability and, like in our model, contrast incentive effects that are present under the polar opposites of no- and full-feedback. They derive conditions under which the full-feedback or no-feedback policies are optimal and that the choice in favour of interim performance appraisals depends on the third derivative of the cost of effort function.³

³There are interesting similarities of the effect of information release in the literature on all-pay auctions (Baye, Kovenock and de Vries, 1993; Krishna and Morgan, 1997; Siegel, 2009) which also studies settings where bidders make irreversible investments (bids) to obtain a prize (good). In such auctions, bidders may be asked to submit sealed or open bids. Since bidders learn less about their relative standing during the auction with sealed bids than under open bidding, these two settings may be compared to the no- and full-
However, we show that this conclusion relies on symmetry properties that are also present in our model if there are no ability differences or if ability enters additively into the agents’ production function, but the effort equivalence result fails to hold once learning about ability also influences subsequent effort choices. My model further demonstrates that if contestants can learn about their abilities and ability influences the marginal benefit of effort, interim information release has important motivation and sorting effects which need to be taken into account when deciding whether and how to provide interim performance appraisals.4

The remainder of the chapter is structured as follows. In Section 4.2 I present the general model. Section 4.3 analyzes the role of interim performance evaluation when agents do not differ with respect to ability and when ability is additive so that the motivation effect is absent. Section 4.4 demonstrates that the conclusions about the usefulness of organizational feedback mechanisms change dramatically once one allows for complementarity between effort and ability. Finally, in Section 4.5 I suggest how the present model could be extended and conclude.

4.2 The Model

Consider a tournament for a fixed prize between two risk-neutral agents $i = A, B$ which takes place over 2 periods, $t = 1, 2$. The utility of winning the contest is normalized to 1 and the utility of losing is equal to 0. In each stage, the agents’ output gives rise to a stochastic score which indicates their relative performance. At the end of stage 2, the principal aggregates the scores from both stages to determine the winner of the contest. Agent $A$ wins the contest if his accumulated output is greater than that of agent $B$, i.e., if $x_1^A + x_2^A > x_1^B + x_2^B$ agent $A$ wins and agent $B$ wins if the reverse inequality holds.

feedback scenarios studied in the dynamic tournaments literature. If the assumptions of revenue equivalence are satisfied (risk neutrality, independent private signals, efficient allocation of the good) bidders will make the same expected payments, a result that is similar to the effort equivalence result under linear marginal effort costs in the dynamic tournaments literature. However, the linkage principle (Milgrom and Weber, 1982) asserts that when bidders’ signals are affiliated, the seller’s expected revenue is higher in open-bid than sealed-bid second-price auctions. This suggests that interim information transmission may be beneficial also in other auction settings. Unfortunately, such a result does not exist for open- and sealed-bid all-pay auctions.

While not considering interim performance appraisals per se, Fang and Moscarini (2005) also discuss sorting and motivation effects that result from the informational content of wage-setting policies.
Agent $i$’s output in period $t$ is given by $x_i = h(a_i, e_i^i) + \varepsilon_i^i$ where $a_i$ is the agent’s ability, $e_i^i$ is the effort level and $\varepsilon_i^i$ is an error term. Each agent’s ability $a_i$ is identically and independently distributed and is initially unknown to the two agents and the principal. I assume that all players are Bayesian rational and have the same and correct prior beliefs about the distribution of ability. I further assume that these beliefs are common knowledge. Each agent’s effort $e_i^i$ is his private information and observed by neither the principal nor the other agent. Define the noise difference $\Delta \varepsilon_i \equiv \varepsilon_i^A - \varepsilon_i^B$ and assume that $\Delta \varepsilon_1$ and $\Delta \varepsilon_2$ are distributed independently and symmetrically around 0. Furthermore, I assume that $\Delta \varepsilon_i$ is distributed according to the cumulative density function $F(\cdot)$ and the density $f(\cdot)$ which is unimodal at 0 and twice continuously differentiable.

When exerting effort in period $t$ agent $i$ incurs a cost $c(e_i^i)$. I assume that $c(\cdot)$ is convex, $c'(0) = 0$ and $\lim_{e \to -\infty} c(e) = \infty$. For simplicity, I shall assume that first order conditions are sufficient to characterize optima. The payoffs to agent $i$ are

$$U_i = \Pr(x_1^i + x_2^i > x_1^i + x_2^i) - c(e_i^i) - c(e_i^j).$$

After the first stage, the principal privately observes the difference in first-period outputs between the two agents given by $\Delta x_1 \equiv x_1^A - x_1^B$. I assume that the principal wishes to maximize the sum of outputs of the contestants and that he can decide whether or not to credibly and publicly reveal this information to both players before the start of period 2. Indeed, firms often commit to a feedback policy where employment contracts specify the performance evaluation schedule. I assume that the principal is committed to her feedback policy for any realization of the first-period output difference. This assumption is primarily made for expositional purposes and can be relaxed as shown in Ederer and Fehr (2007). This simplification allows us to suppress considerations of incentive problems on behalf of the principal such as misreporting the first-period output difference to elicit higher efforts or to selectively announce interim information. The first-period output difference is favourable to agent $A$ when $\Delta x_1 > 0$, favourable to agent $B$ when $\Delta x_1 < 0$ and neutral or balanced when.

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5However, this is not true in general as has been frequently noted in the tournament literature. For a more detailed discussion of this point see, for example, Nalebuff and Stiglitz (1983), O’Keefe, Viscusi and Zeckhauser (1984) and Meyer (1992).
Δx_1 = 0. In the no-feedback scenario, neither of the agents knows first-period output when choosing second-period effort. In the feedback scenario, the principal is assumed to provide a truthful interim performance evaluation, so each agent learns the first-period outcome before choosing second-period efforts. I denote equilibrium efforts and outputs by e^* and x^* if the principal chooses a no-feedback policy and by ˜e and ˜x if she chooses to reveal information.

4.3 Interim Performance Evaluation without the Motivation Effect

In order to build intuition I consider a special case of the general model in which the motivation effect is absent. This is the case in a model in which there is no heterogeneity in ability or when ability enters additively in the production function, i.e., \( x_1^i = a_i^i + e_1^i + \varepsilon_i^1 \). If ability enters additively in the production function, learning plays no role in the agent’s effort choice because the marginal benefit of effort is unaffected. By introducing heterogeneity in ability I allow for time-persistent differences in relative outputs. When information is revealed, agents learn about relative first-period performance Δx_1 and update their beliefs about the ability difference between the two agents \( E[\Delta a \mid \Delta x_1] \) where \( \Delta a \equiv a^A - a^B \) which given the prior distributional assumptions is symmetrically distributed around 0.

4.3.1 No Feedback

If the principal chooses not to give feedback, then each agent only knows the effort he chose in the first period and so each agent’s information is exactly the same in both periods. Thus, the problem is strategically equivalent to one where the first- and second-period efforts are chosen simultaneously at the beginning of stage 1. Agent A chooses first- and second-period efforts e_1^A and e_2^A to maximize

\[
U^A = \Pr(x_1^A + x_2^A > x_1^B + x_2^B) - c(e_1^A) - c(e_2^A) = E_{a^A,a^B,\Delta x_1} [F(a^A + e_1^A + a^A + e_2^A - a^B - e_1^B - a^B - e_2^B + \Delta \varepsilon_1)] - c(e_1^A) - c(e_2^A).
\]
The first order condition yields
\[ c'(e_t^A) = E_{a_t^A, a_t^B, \Delta \varepsilon_1} [f(2\Delta a + e_1^A + e_2^A - e_1^B - e_2^B + \Delta \varepsilon_1)] \]
for \( t = 1, 2 \). Since the density function of the noise difference \( f(\cdot) \) is symmetric around 0 and ability levels \( a^i \) are identically independently distributed, the expected marginal return to effort is the same for agent A and agent B. Given our assumptions, there is a unique interior solution to the first order conditions for A and B, where \( e^* \equiv e_t^i \) for \( i = A, B \) and \( t = 1, 2 \) solves the following first order condition
\[ c'(e^*) = E_{a_A, a_B, \Delta \varepsilon_1} [f(2\Delta a + \Delta \varepsilon_1)]. \] (4.1)

### 4.3.2 Feedback

If the principal chooses to reveal information then the agents observe the gap in performance \( \Delta x_1 \) after the first period and take this into account when making their choice about second-period effort. I first solve for second-period effort levels for agent \( i \) for a given realization of \( \Delta x_1 \) and then solve for the optimal first-period efforts.

**Second-period effort**

In the second period agent \( A \) solves the following maximization problem
\[
\max_{e_A^2} E_{a_A, a_B} [F(\Delta x_1 + a_A + e_2^A - a_B - e_2^B) | \Delta x_1] - c(e_2^A).
\]

The best-response effort choice in the second period is a function of the difference in first-period outputs \( \Delta x_1 \) as well as each agent’s conjecture about the effort chosen by the opposing player in the first period. As we shall see in the analysis of the first period, agents will exert the same effort \( \bar{e}_1 \) in the first period. The symmetric second-period equilibrium, \( \bar{e}_2(\Delta x_1) \equiv \)

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\(^6\)In what follows the first-order conditions for the two agents will be symmetric and so I omit writing them out for agent \( B \).
\( \bar{e}_2(\Delta x_1) \) for \( i = A, B \) is unique and \( \bar{e}_2(\Delta x_1) \) solves
\[
\begin{align*}
&c'(\bar{e}_2(\Delta x_1)) = E_{a^A,a^B} [f(\Delta x_1 + \Delta a) \mid \Delta x_1].
\end{align*}
\] (4.2)

From equation (4.2) we can see that revealing the first-period output difference \( \Delta x_1 \) has two effects. First, it informs contestants how large the difference is that favours one of the agents in the second period. Second, the revelation of \( \Delta x_1 \) also provides contestants with information about their relative ability difference \( \Delta a \).

Consider first the case when there is no heterogeneity in ability so that \( \Delta a \) is always zero. In this case \( \Delta x_1 \) only reveals information about the gap that the ‘interim loser’ of the tournament has to overcome in order to win. Second-period equilibrium effort \( \bar{e}_2(\Delta x_1) \) is greatest when \( \Delta x_1 = 0 \) as the density \( f(\cdot) \) reaches its maximum at this point. Moreover, due to the symmetry of the density of the noise difference around 0, second-period equilibrium effort is also symmetric around zero, i.e. \( \bar{e}_2(-\Delta x_1) = \bar{e}_2(\Delta x_1) \) and decreasing in the absolute value of the first-period output difference \( |\Delta x_1| \). This means that equilibrium effort is lower the less balanced the second-period contest is between the two agents. This is the well-known evaluation effect or lack-of-competition effect that has received much attention in the literature on asymmetric tournaments (Schotter and Weigelt 1992). Surprisingly, adding heterogeneity in ability to the model does not change these qualitative predictions given the symmetry assumptions I made about the distribution of ability. However, as I discuss below the quantitative effects of a revelation policy are more pronounced when agents also use the feedback given to them to update their beliefs about relative ability levels.

Since revealing information about the first-period output difference also reduces the noise that is present when agents make their choice about second-period output it is immediately clear that for sufficiently small values of \( |\Delta x_1| \) second-period effort under a full-feedback policy is higher than second-period effort when no information is revealed. I call this effect the noise reduction effect of a full-feedback policy.
First-period effort

In the first period, agent A’s maximization problem is

$$\max_{e_1^A} E_{a^A, a^B, \Delta e_1} \left[ F(2\Delta a + e_1^A + \tilde{e}_2^A - e_1^B - \tilde{e}_2^B + \Delta e_1) \right] - c(e_1^A) - E_{a^A, a^B, \Delta e_1} \left[ c(\tilde{e}_2^A) \right].$$

To obtain the first order conditions I differentiate with respect to $e_1^A$. The first order conditions are

$$c'(e_1^A) = E_{a^A, a^B, \Delta e_1} \left[ f(2\Delta a + e_1^A + \tilde{e}_2^A - e_1^B - \tilde{e}_2^B + \Delta e_1) \right]$$

$$+ E_{a^A, a^B, \Delta e_1} \left\{ f(2\Delta a + e_1^A + \tilde{e}_2^A - e_1^B - \tilde{e}_2^B + \Delta e_1) - c'(\tilde{e}_2^A) \right\} \frac{d\tilde{e}_2^A}{de_1^A},$$

$$- E_{a^A, a^B, \Delta e_1} \left[ f(2\Delta a + e_1^A + \tilde{e}_2^A - e_1^B - \tilde{e}_2^B + \Delta e_1) \frac{d\tilde{e}_2^B}{de_1^A} \right]. \quad (4.3)$$

The right-hand side of equation (4.3) is the marginal benefit of first-period effort which is composed of three parts. The first line captures the direct effect of first-period effort on the probability of winning the tournament while the second and third line capture the indirect effects on the contestant’s own second-period effort $e_2^A$ and on the other contestant’s second-period effort $e_2^B$. The following Lemma shows that in equilibrium only the direct effect will be present.

**Lemma 1**  The unique first-period effort level under a feedback policy is given by

$$c'(\tilde{e}_1) = E_{a^A, a^B, \Delta e_1} \left[ f(2\Delta a + \Delta e_1) \right]. \quad (4.4)$$

**Proof.** See appendix. ■

Lemma 1 demonstrates that in a setting where there is no heterogeneity in ability or when ability enters additively in the production function the contestants do not have any strategic incentive in the first period to exert effort to influence the second-period effort choice of his opponent. The key insight to show that the strategic effect is zero is the use of the symmetry property of the noise and ability difference.
4.3.3 Discussion

I begin the discussion by comparing effort and output levels under the two possible feedback policies.

**Proposition 6** First-period efforts are the same regardless of whether information is revealed or not, if the density of the sum of the per-period noise and the ability difference is symmetric around 0.

The expected effort in the second period when information is revealed is lower (higher) than when information is not revealed if $c'$ is convex (concave). Expected second-period effort (and overall effort) are the same under the two feedback policies if the cost function is quadratic.

**Proof.** Using Lemma 1 I can compare equation (4.1) and (4.4) to show that $e^* = \bar{e}_1$. This completes the first part of the proof.

Note further that since $\bar{e}_1 \equiv \bar{e}_1^A = \bar{e}_1^B$ we have $\Delta x_1 = \Delta a + \Delta \varepsilon_1$. Hence, equation (4.1) can be rewritten in the following form

$$c'(e^*) = E_{a,A,a^B,\Delta \varepsilon_1} [f(2Aa + \Delta \varepsilon_1)] = E_{a,A,a^B,\Delta \varepsilon_1} [f(\Delta x_1 + \Delta a)] = E_{a,A,a^B,\Delta \varepsilon_1} [c'(\bar{e}_2(\Delta x_1))]$$

which follows from equation (4.2) and the law of iterated expectations. Using Jensen’s inequality I can provide a ranking of $\bar{e}_2(\Delta x_1)$ which is a random variable that depends on the realization of $\Delta x_1$ and $e^*$ which is a constant. If $c'$ is convex, Jensen’s inequality implies

$$E[c'(\bar{e}_2(\Delta x_1))] \geq c'(E[\bar{e}_2(\Delta x_1)])$$

and since $c'$ is increasing I therefore have

$$e^* \geq E[\bar{e}_2(\Delta x_1)].$$

Clearly, if $c'$ is concave the reverse inequality holds. If the cost function is quadratic, then marginal cost is linear and expected second-period effort is the same regardless of whether information is revealed or not. ■
As illustrated by the analysis, revealing information about relative performance has two competing effects on effort choice which I termed *noise reduction* and *evaluation effect*. On the one hand, revealing information reduces the overall noise component of output in the second period and thus increases incentives for second-period effort relative to the no-feedback scenario. On the other hand, revealing information about first-period performance invariably creates asymmetries between the agents and therefore tends to decrease second-period equilibrium efforts. If one agent has an advantage over the other, the contest will be less close and both agents will exert less effort. In our model this phenomenon is reflected in the fact that second-period equilibrium effort \( \tilde{e}_2(\Delta x_1) \) is decreasing in the absolute value of first-period performance difference \(|\Delta x_1|\). As a result, for realizations of \( \Delta x_1 \) that are close to 0, second-period effort will be higher under a full-feedback policy than under a no-feedback policy, whereas the opposite will be the case when \( \Delta x_1 \) is large in absolute terms. Whether the first or the latter effect prevails in expectation depends, as shown above, on the shape of the marginal cost function. As Proposition 6 shows, first-period effort is not altered by the revelation of information due to the absence of a strategic effect. In the examined model, under a full-feedback policy agents do not have an incentive to exert larger effort in the first period in order to carve out a leading position for the second period.  

I also showed that the same conclusions hold regardless of whether or not the agent’s production function includes an additive ability term. The intuition for this result is the following. In a model without ability under a feedback policy second-period equilibrium effort depends on \( \Delta x_1 \) while in a model with additive ability second-period effort depends on \( \Delta x_1 \) and the posterior of \( \Delta a \) given \( \Delta x_1 \). Qualitatively this means that nothing changes when we move from a model without ability to a model with additive ability. However, the quantitative effects of a full-feedback policy are more pronounced in a model with additive ability than in a model without ability since the ability difference and the first-period output

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7In the macroeconomics literature there is an interesting analogue of the fact that the third derivative of the cost function plays a role in determining the relationship between the expected effort under the two possible feedback policies. In that literature, the combination of a positive third derivative of the utility function and uncertainty about future income reduces current consumption, and thus raises saving. This is known as *precautionary saving* (Leland 1968). Similarly, in the interim evaluation setting the agent will exert *precautionary effort* in the second period if the marginal cost function is concave.
difference are positively correlated. In particular, we have

$$\text{cov}(\Delta a, \Delta x_1) = 2\text{var}(a^i) > 0.$$  

Not only does a gap in relative first-period performance create an uneven playing field between the contestants as one of the players has to overcome an output deficit of $\Delta x_1 > 0$, but given symmetric first-period effort choices the ‘interim loser’ also expects to be disadvantaged with respect to ability in the second period. Furthermore, when effort costs are quadratic the expected (second-period) effort levels will be identical when comparing two tournaments that have the same amount of aggregate uncertainty about the exogenous noise in output $\Delta \varepsilon_i$ and the persistent ability levels $a^i$ but differ in how much uncertainty there is in each of those two components. However, actual second-period effort under a full-feedback policy will respond more strongly to the first-period output difference in the tournament that has more uncertainty about $a^i$ and less uncertainty about $\Delta \varepsilon_i$.

The predictions of our baseline model change slightly when some of the more restrictive assumptions about commitment on behalf of the principal or the set of admissible feedback policies are changed. First, if the principal is able to costlessly manipulate the interim performance measure $\Delta x_1$ and report whichever outcome he desires, then the effort levels chosen by the contestants will be the same under no- and full-feedback policies. This is because the principal has an incentive to report the first-period output difference that maximizes the second-period efforts of the contestants in the second period regardless of the actual first-period output realization. Since the optimal message does not depend on the actual realization only a babbling equilibrium can exist.\footnote{For a detailed discussion of this point see Ederer and Fehr (2007).} Second, if the principal is only able to selectively disclose interim information, i.e., he can freely choose after the conclusion of the first period whether to announce or to withhold $\Delta x_1$, there will be full information unraveling (Grossman, 1981; Milgrom, 1981). Thus, in equilibrium, all information will be revealed and the contestants will choose the same effort levels as under a full-feedback policy.\footnote{The full unraveling result crucially rests on the assumption that the informed party has perfect information concerning the payoff-relevant state, so that the pair of strategies in which the informed party announces the most favourable report consistent with the true state and the recipient of the report “assumes the worst”, given an announcement, constitutes an equilibrium. Jung and Kwon (1988) and Shin (1994) point out that if there is some positive probability that a sender is unable to make a disclosure, either from prohibitively high}
even if the principal is able to commit to a partial disclosure policy at the beginning of the relationship, Aoyagi (2007) shows that hybrid policies that reveal the output difference $\Delta x_1$ only for a range of values but not for others, are never optimal as long as the marginal cost of efforts function is either convex or concave.\(^\text{10}\) Finally, the choice between a full- and a no-feedback policy is unchanged when I relax the assumption that the principal observes and reports the first-period output difference $\Delta x_1$ rather than the first-period outputs $x_1^A$ and $x_1^B$. Just as in the present case where $\Delta x_1$ is revealed, when the agents receive information about the first period in the form of $x_1^A$ and $x_1^B$ they will adjust their second-period effort choice to reflect this information. Thus, the second-period effort choices of a full-feedback policy are ex-ante stochastic while the effort levels of a no-feedback policy are constant. As a result, the same argument based on Jensen's inequality will apply. However, as I shall demonstrate, the finding that the advantages of revealing information depend entirely on the sign of the third derivative of the cost function, no longer applies when learning about ability impacts effort choices.

### 4.4 Interim Performance Evaluation with the Motivation Effect

To analyze the effects of motivation I employ a different formulation for the agent’s production function which allows for complementarity between effort and ability. The simplest case that incorporates this feature is a situation where the production function takes the multiplicative form, $x'_i = a'e_{i} + \varepsilon'_i$. When receiving interim feedback, as in the previous model, agents also learn about their ability. However, in contrast to the previous model, ability now directly influences the marginal benefit of effort.

The analysis proceeds in two steps. First, I investigate the motivation and signal-jamming effects of a full-feedback policy in isolation by assuming that each period’s exogenous noise difference $\Delta e_t$ is uniformly distributed. As I will argue below, under this distributional as-

\(^\text{10}\)Note that this result is in contrast to Goltsman and Mukherjee (2008) who in a related but slightly different tournament setting find that partial disclosure can be optimal.
sumption the evaluation effect is not present. Second, to illustrate how the lack of competition between the two agents dampens the beneficial effects of a full-feedback policy, I assume that ability and the exogenous noise differences are normally distributed. I will assume that effort cost is quadratic, i.e. \( c(e^i_t) = \frac{k}{2}(e^i_t)^2, k > 0 \). Note that under this assumption expected efforts and outputs are the same under both no-feedback and full-feedback policies in the previous model where no motivation effect was present.

4.4.1 The Uniform Model

I rule out the evaluation effect by assuming that \( \Delta \varepsilon_1 \) is uniformly distributed on the interval \([-d, d]\) and \( \Delta \varepsilon_2 \) is uniformly distributed between \([-m, m]\) where \( m > d \). As a result, the density of the sum of first- and second-period error differences has a trapezoid shape and is symmetric around 0. Furthermore, for technical reasons I assume that \( a^i \) now has limited non-negative support \([0, \bar{a}]\) where \( \bar{a} > 0 \), has a log-concave density and a mean \( \mu \).

No Feedback

As in the previous section the problem faced by the agent in the case of a no-feedback policy of the principal is equivalent to one where the efforts are chosen simultaneously at the beginning of stage 1. Agent A’s maximization problem is

\[
\max_{e^A_i, e^B_i, \Delta \varepsilon_1} E_{a^A, a^B, \Delta \varepsilon_1} \left[ F(a^A e^A_1 + a^A e^A_2 - a^B e^B_1 - a^B e^B_2 + \Delta \varepsilon_1) \right] - c(e^A_1) - c(e^A_2).
\]

Since ability is unknown throughout the two periods and the two agents have the same prior beliefs, by the same arguments as before there is a symmetric equilibrium where \( e^* = e^*_i \) for

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11To see how this distributional assumption eliminates the evaluation effect, consider the case where there is no heterogeneity in ability (i.e., \( \Delta a = 0 \)) and so the interim performance appraisal only contains information about \( \Delta x_1 \). When the noise difference is uniformly distributed, effort is independent of \( \Delta x_1 \) since for a uniform density \( f'(\cdot) = 0 \) within its limited support. Equation (4.2) can be rewritten as

\[ c'(\bar{e}_2) = \frac{1}{2m}. \]
\[ i = A, B \text{ and } t = 1, 2 \text{ now solves} \]

\[ c'(e^*) = E_{a^*, a^t, \Delta e_1} \left[ f \left( 2e^* \Delta a + \Delta e_1 \right) a^t \right] \text{ for } i \neq j. \]

This condition further simplifies once we note that \( f(\cdot) \) is uniform

\[ c'(e^*) = \frac{\mu}{2m}. \tag{4.5} \]

In contrast to the previous models expected ability directly influences the effort choice of players. In this multiplicative output formulation, effort and ability are complements: higher expected ability implies a higher marginal benefit of effort and thus leads to a higher equilibrium effort level.\(^{12}\)

**Feedback**

**Second-period effort**  In the second period agent \( A \) solves

\[
\max_{e_2^A} E_{a^A, a^B} \left[ F(\Delta x_1 + a^A e_2^A - a^B e_2^B) \mid \Delta x_1 \right] - c(e_2^A).
\]

The first order condition for second period effort is

\[ c'(e_2^A) = E_{a^A, a^B} \left[ f(\Delta x_1 + a^A e_2^A - a^B e_2^B)a^A \mid \Delta x_1 \right]. \]

Noting that the difference in noise is uniform, I obtain the first order conditions for both agents which are given by

\[
c' \left( e_2^A (\Delta x_1) \right) = \frac{1}{2m} E \left[ a^A \mid \Delta x_1 \right] \tag{4.6a}
\]
\[
c' \left( e_2^B (\Delta x_1) \right) = \frac{1}{2m} E \left[ a^B \mid \Delta x_1 \right]. \tag{4.6b}
\]

\(^{12}\)Note that throughout this section I focus exclusively on interior solutions for reasons of expositional clarity. In Appendix 4.A.2 I derive sufficient conditions for the existence of interior solutions. These conditions require the cost function to be sufficiently convex and \( m \) to be sufficiently large relative to \( \bar{a} \) and to the bounded support of \( \Delta e_1 \).
The equilibrium effort in the second period is a function of \( \Delta x_1 \) and differs across agents. In particular, we have \( \bar{e}_2^A \neq \bar{e}_2^B \) as long as \( \Delta x_1 \neq 0 \). This asymmetry in effort levels arises because the expected marginal benefit of effort will differ between the agents whenever the first-period output difference is unbalanced. Expected marginal benefit is higher for ‘winners’ of the first-period contest (players for which \( \Delta x_1 \) is biased in their favour) and lower for first-period ‘losers’. As a result, revelation of interim information will drive a wedge between the second-period equilibrium efforts of the two agents. I term this effect the *motivation effect* of a full-feedback policy.

**First-period effort**  In the first period, agent A’s problem is

\[
\max_{e_1^A} E_{a^A,a^B,\Delta \varepsilon_1} \left[ F(a^A e_1^A + a^A \tilde{e}_2^A - a^B e_1^B - a^B \tilde{e}_2^B + \Delta \varepsilon_1) \right] - c(e_1^A) - E_{\varepsilon_1^A,\varepsilon_1^B} \left[ c(\bar{e}_2^A) \right].
\]

To obtain the first order condition I differentiate the above expression with respect to \( e_1^A \). As before the first order condition has three terms and is given by

\[
c'(e_1^A) = E_{a^A,a^B,\Delta \varepsilon_1} \left[ f \left( a^A e_1^A + a^A \tilde{e}_2^A - a^B e_1^B - a^B \tilde{e}_2^B + \Delta \varepsilon_1 \right) a^A \right] + E_{a^A,a^B,\Delta \varepsilon_1} \left[ \{ f \left( a^A e_1^A + a^A \tilde{e}_2^A - a^B e_1^B - a^B \tilde{e}_2^B + \Delta \varepsilon_1 \right) a^A - c' \left( \bar{e}_2^A \right) \} \frac{d\bar{e}_2^A}{de_1^A} \right] - E_{a^A,a^B,\Delta \varepsilon_1} \left[ f \left( a^A e_1^A + a^A \tilde{e}_2^A - a^B e_1^B - a^B \tilde{e}_2^B + \Delta \varepsilon_1 \right) a^B \frac{d\bar{e}_2^B}{de_1^A} \right].
\]

Using the same line of reasoning as before I show that the second line of the above equation is equal to zero by the envelope condition.

**Lemma 2** The first-order condition for first-period effort under a feedback policy is given by

\[
c'(\bar{e}_1) = \frac{1}{2m} \left\{ \mu - E_{a^A,a^B,\Delta \varepsilon_1} \left[ a^B \frac{d\bar{e}_2^B}{de_1^A} (\Delta x_1) \right] \right\}. \tag{4.8}
\]

**Proof.** See appendix. □

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Comparison and Discussion

**Proposition 7** If the distribution of the noise difference is uniform, then the first-period efforts and expected outputs are higher under a feedback policy than under a no-feedback policy.

**Proof.** Comparing equations (4.5) and (4.8) immediately shows that they differ by the strategic effect that an increase in first-period effort of agent \(i\) has on the optimal second-period effort choice of agent \(j\). To show that this strategic effect provides additional incentives for effort, I rewrite the second expression in the curly brackets of equation (4.8) in the following way

\[
E_{a^A,a^B,A\Delta e_1} \left[ a^B \frac{d\tilde{c}_2^B(\Delta x_1)}{dA} \right] = \frac{1}{2m} E_{a^A,a^B,A\Delta e_1} \left[ a^A a^B \frac{d}{d\Delta x_1} \left( (c')^{-1} \left(E \left[ a^B | \Delta x_1 \right] \right) \right) \right]
\]

From the assumptions about the ability distribution I know that all realizations of ability will be non-negative. Furthermore, since the cost function is convex marginal cost is increasing. Hence, the derivative of the inverse of the marginal cost function is positive. Since all expressions on the right-hand side are always non-negative with the exception of the derivative of the conditional expectation I only need to show that this derivative is non-positive.

Efron (1965) has shown that \(E[\theta(X_1,\ldots,X_n) | \sum X_i = w]\) is increasing in \(w\) for any increasing function \(\theta\) when the \(X_i\) are independently distributed with log-concave densities. A special case of Efron’s result is that \(E \left[ a^B | \tilde{c}_1 a^A - \tilde{c}_1 a^B + \Delta \varepsilon_1 = \Delta x_1 \right]\) is decreasing in \(\Delta x_1\) whenever \(\tilde{c}_1\) is a constant and \(a^A, a^B\) and \(\Delta \varepsilon_1\) are independently distributed with log-concave densities. Therefore, \(\frac{d}{d\Delta x_1} \left( E \left[ a^B | \Delta x_1 \right] \right) \leq 0\) and so \(\tilde{c}_1 \geq c^*\).

As a result expected combined first-period output is also higher under a feedback policy since

\[
E_{a^A,a^B,A\Delta e_1} \left[ \tilde{x}_1^A + \tilde{x}_1^B \right] = 2\mu\tilde{e}_1 \geq 2\mu c^* = E_{a^A,a^B,A\Delta e_1} \left[ x_1^A + x_1^B \right]
\]

\(^{13}\text{Jewitt (1985) provides a discussion and generalisation of Efron’s (1965) result.}\)
where the inequality follows from $\tilde{e}_1 \geq e^*$. ■

The result that effort is higher when feedback is provided is driven by the presence of implicit incentives that are similar in spirit to Holmstrom (1982a) and Fudenberg and Tirole (1986) and which are absent when no feedback is given to the agents. I call this the signal-jamming or strategic effect of a full-feedback policy since it creates implicit incentives prior to the revelation of information to the agents. As discussed in the analysis of the effort choice in the second period, agents need to make conjectures about first-period effort choice of their opponent to update expectations of their own and their opponent’s ability. As long as ability is unknown each agent has an additional incentive to supply effort for any given conjecture of their opponent about first-period effort choice. By increasing effort, each agent can potentially bias the process of inference of his opponent in his favour. When player $i$ increases his supply of effort, the first-period output difference will tend to move in $i$’s favour which in turn will lead to a more pessimistic perception by agent $j$ of his own ability at the start of period 2. Since effort and expected ability are complements, agent $j$ will reduce his second-period effort, thereby increasing player $i$’s probability of winning the tournament. Of course, in equilibrium neither agent will be able to fool his counterpart because the agents will know what effort levels to expect in equilibrium and adjust their beliefs accordingly.

**Proposition 8** In equilibrium, the expected effort in the second period is the same in both full-feedback and no-feedback scenarios if the distribution of the noise difference is uniform and the cost function is quadratic. The expected sum of second-period outputs of the two agents is higher when information is revealed than under a no-feedback policy.

**Proof.** I rewrite equation (4.5) for quadratic effort cost and use the law of iterated expectations and equations (4.6a) and (4.6b)

$$e^* = \frac{\mu}{2mk} = E_{\Delta x_1} \frac{1}{2mk} E \left[ a^i \mid \Delta x_1 \right] = E_{\Delta x_1} \left[ \bar{c}_2 \left( \Delta x_1 \right) \right].$$

which shows that the expected second-period effort levels under both policies are equal.

The expected second-period output under a no-feedback policy is

$$E[x_2^A + x_2^B] = E[a^A e^* + \varepsilon_2^A + a^B e^* + \varepsilon_2^B] = \frac{\mu^2}{mk}.$$
The expected second-period output when information is revealed is

$$E[\tilde{x}_2^A + \tilde{x}_2^B] = E[a^Ae_2^A + \varepsilon_2^A + a^Be_2^B + \varepsilon_2^B] = \frac{S}{2mk}$$

where the term $S$ is given by

$$S = E[a^AE[a^A | \Delta x_1] + a^BE[a^B | \Delta x_1]]$$

$$= E_{\Delta x_1}E[a^AE[a^A | \Delta x_1] | \Delta x_1] + E_{\Delta x_1}E[a^BE[a^B | \Delta x_1] | \Delta x_1].$$

Jensen’s inequality implies

$$E_{\Delta x_1} (E[a^A | \Delta x_1])^2 + E_{\Delta x_1} (E[a^B | \Delta x_1])^2 \geq (E_{\Delta x_1} E[a^A | \Delta x_1])^2 + (E_{\Delta x_1} E[a^B | \Delta x_1])^2$$

$$\Leftrightarrow$$

$$S \geq 2\mu^2.$$

Therefore we have $E[\tilde{x}_2^A + \tilde{x}_2^B] \geq E[x_2^{*A} + x_2^{*B}]$.  

Under a full-feedback policy more able players will, on average, receive good news in the form of a first-period output difference that is tipped in their favour, thus leading them to put in higher second-period effort than if they had relied upon their prior expectation of ability. Less able players on the other hand will tend to put in lower second-period effort, balancing out the increase of their more able competitors. If the cost function is quadratic these two effects will exactly cancel out each other as shown in the analysis of the previous section.

The beneficial results of a full-feedback policy on second-period output are a consequence of the motivation effect. This might seem slightly paradoxical since expected effort is the same under no- and full-feedback scenarios if the cost function is quadratic. However, although expected effort does not differ across the two scenarios, actual second-period effort will differ. The key insight is that a full-feedback policy has a beneficial sorting effect since, on average, it raises the second-period effort of more able agents while reducing the effort of less able contestants. Given the complementary form of the production function this leads to higher
expected output than if both able and unable agents supply the same amount of effort as is the case under a no-feedback policy.

**Corollary 1** If the distribution of the noise difference is uniform and the cost function is quadratic, a full-feedback policy leads to higher expected overall output than a no-feedback policy.

**Proof.** The corollary is a straightforward result of Propositions 7 and 8. Since expected output in both periods is higher under a feedback policy, expected overall output must be higher under such a policy. ■

The superiority of a full-feedback policy is caused by the implicit incentives that exist in the first period as well as the sorting induced by the motivation effect of the second period. The combination of these effects guarantees that a principal solely interested in output maximization will choose to implement an interim performance evaluation.

The most important difference that the complementarity between effort and ability generates is the asymmetric effect that feedback has for the second-period effort choice of the two agents. When effort and ability are complementary, ‘winners’ of the first period will choose higher levels than ‘losers’ because their expected marginal benefits of effort are no longer the same. ‘Winners’ are more motivated and have more confidence in their own ability, that is to say they hold higher expectations about their own ability. Of course, this motivation effect is a double-edged sword since it also breaks bad news to some workers and depresses their morale and effort levels. However, by motivating and demotivating the right kinds of contestants a full-feedback policy effectively sorts the workers. Proposition 8 shows that because, on average, a full-feedback policy transmits good news to more able and bad news to less able individuals, expected output is higher under a full-feedback policy than under a no-feedback rule.

It is straightforward to show that the advantages of this sorting effect are higher the stronger the agents’ beliefs about ability respond to the first-period output difference. This can be seen from the difference in second-period output between the two feedback policies which is given by

$$E[\tilde{x}_2^A + \tilde{x}_2^B] - E[x_2^A + x_2^B] = \frac{1}{2mk} \text{var} \left( E \left[ a^i \mid \Delta x_1 \right] \right)$$
where the variance is taken over all values of $\Delta x_1$. Hence, the more variable is the agents’ posterior of ability following the revelation of $\Delta x_1$, the larger is the difference in output between the two policies. In the no-feedback scenario workers will still choose the same effort levels regardless of their actual abilities as effort choice only depends on expected ability. Under a full-feedback policy agents choose asymmetric effort levels in the second period as they tailor their effort choice to their posterior about their ability level so that on average output will be higher. The favourable outcomes of this sorting effect will also be larger when the principal only cares about the effort of the most able individuals or when it is important to select the most able individual for promotion. This may be particularly important in industries where only a few select, highly able individuals advance up the corporate ladder. For example, professional service firms companies must pay particular attention to the quality of the few analysts who are promoted to the partner level (Levin and Tadelis 2004), and indeed frequent and highly institutionalized interim performance appraisals are a common feature in such firms.

The asymmetries that arise from the motivation effect are also the source of the implicit incentives that are present in the first period of the full-feedback scenario. As before, if ability is uncertain, each agent puts some weight on $\Delta x_1$ when revisiting his beliefs about ability. If ability is multiplicative, an imbalance in the first-period output difference has direct repercussions on the second-period effort choice regardless of the opponent’s reaction in the second period. Observing an unfavorable realization of $\Delta x_1$ leads to a lower effort choice because the agent has less confidence in his ability, and to a lower equilibrium effort choice because the second-period tournament is unequal. Whereas the second effect is also present in a model with no heterogeneity in ability or additive ability, the first effect is only a feature of the multiplicative ability model. Thus, both contestants have an incentive to influence their respective opponent’s perceptions about ability by exerting additional effort that shifts $\Delta x_1$ in their favour. However, if ability levels are commonly known, there are no returns to influencing output and the implicit incentives vanish.

$^{14}$Note that this signal-jamming effect is similar to the career concerns in Holmstrom’s (1982a) model where implicit incentives are provided because the agent has an incentive to bias the market’s assessment of his ability by supplying additional effort.
I conclude this section with a note of caution. The derivation of the results of Section 4.4.1 relied on the assumption that the noise difference is uniformly distributed. This assumption eliminates the \textit{evaluation effect}. As discussed in Section 4.3 this evaluation effect causes equilibrium effort levels to change with the closeness of competition between the two agents. The effect is absent in the uniform model as the density function and hence the marginal benefit of effort do not vary with the difference in first-period output since for a uniform density $f'(\cdot) = 0$ within its limited supports. Therefore, in the uniform model with multiplicative ability the asymmetries created by a full-feedback policy do not have any adverse effects on effort provision. Hence, while it would be tempting to conclude that within an exogenously given incentive scheme the principal will favour the use of interim performance evaluation, such a conclusion would be premature. In the next section I analyze how the use of a different distribution for the noise difference that allows for the presence of the evaluation effect weakens the argument for full-feedback policies.

### 4.4.2 The Normal Model

I now assume that the noise difference $\Delta \varepsilon_t$ is normally rather than uniformly distributed. This serves to illustrate the evaluation effect that will tend to weaken the results found in previous sections. In order to ensure expositional clarity, I assume that the cost function is quadratic and that all random variables are normally distributed. Let the prior joint distribution of random variables therefore be given by

$$
\begin{pmatrix}
    a^A \\
    a^B \\
    \Delta \varepsilon_1 \\
    \Delta \varepsilon_2
\end{pmatrix}
\sim N
\begin{bmatrix}
    \mu \\
    \mu \\
    0 \\
    0
\end{bmatrix},

\begin{pmatrix}
    \sigma^2 & 0 & 0 & 0 \\
    0 & \sigma^2 & 0 & 0 \\
    0 & 0 & 2\tau^2 & 0 \\
    0 & 0 & 0 & 2\tau^2
\end{pmatrix}.
$$

Rather than providing a complete comparison of both full-feedback and no-feedback scenarios I limit our attention to showing how the evaluation effect undermines the beneficial consequences of a full-feedback policy since, even with these simplifying distributional assumptions, the solutions are too algebraically complex to solve explicitly for effort levels.
However, the distributional assumptions allow us to illustrate the trade-off between the evaluation and the motivation effect. Moreover, I am able to choose parameter values for which the maximization problems of the agents are concave and I can numerically solve for (unique) equilibria in pure strategies. This enables us to contrast the effects on effort and output of the two different feedback policies as well as analyze the effect of changes in the parameter values on the relative strengths of the evaluation and the motivation effect as well as the sorting that the latter induces. Most importantly, the re-introduction of the evaluation effect and its interaction with the motivation effect destroys the optimality of a full-feedback policy that I obtained in the previous section. For different parameter values one or the other feedback policy may dominate.

No Feedback

Given the joint normality of all variables, agent A’s probability of winning the contest is

\[
\Pr(\Delta x_1 + \Delta x_2 > 0) = \Phi(z^A)
\]

where \( z^A = \frac{E[\Delta x_1 + \Delta x_2]}{\sqrt{\text{var}(\Delta x_1 + \Delta x_2)}} \) and \( \Phi \) denotes the standard normal cumulative distribution function. The first order condition is given by

\[
\phi(z^A) \frac{\partial z^A}{\partial e^A} = ke^A.
\]

Again I note that equilibrium effort levels are the same for both agents in both periods, i.e. \( e^*_i = e^* \) for all \( i = A, B \) and \( t = 1, 2 \). The first order condition therefore reduces to

\[
ke^* = \frac{\phi(0)}{\sqrt{\text{var}(\Delta x_1 + \Delta x_2)}} \mu
\]  

(4.9)

where \( \phi \) is the standard normal probability density function. This solution has all the obvious interpretations of tournament models. Equilibrium effort is increasing in the expected level of ability \( \mu \) and the degree of competition in the tournament \( \phi(0) \) which is at its optimum at 0. Equilibrium effort is decreasing in the overall uncertainty of the contest given by \( \text{var}(\Delta x_1 + \Delta x_2) \) which is increasing in the variance of ability and exogenous noise.
Feedback

Given a first-period output difference $\Delta x_1$, agent $A$’s probability of winning the contest is given by

$$\Pr(\Delta x_1 + \Delta x_2 > 0 \mid \Delta x_1) = \Phi(y^A_2)$$

where $y^A_2 = \frac{\Delta x_1 + E[\Delta x_2 | \Delta x_1]}{\sqrt{\text{var}(\Delta x_2 | \Delta x_1)}}$. The first order conditions for the two players yield

$$\phi(y_2) \frac{\partial y^A_2}{\partial e^A_2} = ke^A_2$$

$$\phi(y_2) \frac{\partial y^B_2}{\partial e^B_2} = ke^B_2$$

since $y^A_2 = -y^B_2$ and hence $\phi(y_2) \equiv \phi(y^i_2)$ for $i = A, B$. These first order conditions lead to asymmetric effort choices and their explicit form is derived in Appendix 4.A.4. From the previous analysis I know that there is a symmetric first-period equilibrium where the two ex-ante symmetric players choose the same effort levels, i.e. $\bar{\epsilon}_i \equiv \bar{\epsilon}_1^i$ for $i = A, B$. Using the distributional assumptions I find that the first order conditions are

$$ke^A_2 = \frac{\phi(y_2)}{\sqrt{\text{var}(\Delta x_2 | \Delta x_1)}} \left\{ \mu + \frac{\sigma^2 e_1}{\text{var}(\Delta x_1)} \Delta x_1 - \frac{\sigma^2 \left[ e^A_2 - \frac{\text{cov}(\Delta x_1, \Delta x_2)}{\text{var}(\Delta x_1)} e_1 \right]}{\text{var}(\Delta x_2 | \Delta x_1)} T \right\} (4.10a)$$

$$ke^B_2 = \frac{\phi(y_2)}{\sqrt{\text{var}(\Delta x_2 | \Delta x_1)}} \left\{ \mu - \frac{\sigma^2 e_1}{\text{var}(\Delta x_1)} \Delta x_1 + \frac{\sigma^2 \left[ e^B_2 - \frac{\text{cov}(\Delta x_1, \Delta x_2)}{\text{var}(\Delta x_1)} e_1 \right]}{\text{var}(\Delta x_2 | \Delta x_1)} T \right\} (4.10b)$$

where $T = \Delta x_1 + E(\Delta x_2 | \Delta x_1)$.

From equations (4.10a) and (4.10b) one can immediately see that the asymmetry in effort levels is created by the interplay of two different factors: imbalances in the first-period output difference $\Delta x_1$ and variance in ability $\sigma^2$. These correspond to the evaluation and the motivation effect. First, note that when $\Delta x_1 = 0$, the effort choice of the agents is symmetric for any $\sigma^2$, i.e., $\bar{\epsilon}^A_2 = \bar{\epsilon}^B_2$ and the above equations reduce to

$$ke_2(\Delta x_1) = \frac{\phi(0)}{\sqrt{\text{var}(\Delta x_2 | \Delta x_1)}} \mu.$$
Second, when \( \sigma^2 = 0 \), the model reduces to the case where there is no motivation effect and the symmetric equilibrium effort level which is decreasing in \( \Delta x_1 \) is given by

\[
k \tilde{c}_2(\Delta x_1) = \frac{\phi \left( \frac{\Delta x_1}{\sqrt{\text{var}(\Delta x_2|\Delta x_1)}} \right)}{\sqrt{\text{var}(\Delta x_2|\Delta x_1)}} \mu.
\]

Figure 4-1 illustrates how the motivation effect increases the asymmetry of second-period effort choices. For the chosen parameter values the maximization problems for the two agents are concave and I can numerically compute their best response functions for different realizations of \( \Delta x_1 \). The best response functions when \( \sigma^2 = 1 \) are shown in Figure 4-1 for three different values of \( \Delta x_1 \). Note, in particular, that equilibrium effort choices are no longer symmetric as soon as \( \Delta x_1 \neq 0 \) which can be most clearly seen from the different unique intersection points of the best responses for \( \Delta x_1 = 40 \) (point B) and \( \Delta x_1 = -40 \) (point C).

Holding the overall noise in the tournament constant, i.e., \( \text{var}(\Delta x_1 + \Delta x_2) \) is held constant so that the effort \( e^* \) under a no-feedback policy would be unchanged, I can also compute and plot the second-period equilibrium effort choices \( \tilde{c}_2^A(\Delta x_1) \) of agent A for given values of \( \Delta x_1 \) for different values of \( \sigma^2 \) which are shown in Figure 4-2. The equilibrium effort choices are entirely symmetric around 0 when \( \sigma^2 = 0 \), but they become more asymmetric as \( \sigma^2 \) increases (and exogenous noise \( \tau^2 \) decreases). For example, for \( \sigma^2 = 1 \) agent A chooses \( \tilde{c}_2(\Delta x_1 = 40) \approx 12 \) which is more than twice as large as \( \tilde{c}_2(\Delta x_1 = -40) \approx 5 \). As argued before, this asymmetry is a result of the motivation effect since agent A (correctly) believes that he has a higher marginal benefit of effort when he is given favourable information than when he receives the corresponding negative information.

**Comparison and Discussion**

I decompose equations (4.10a) and (4.10b) into several parts and compare them with equation (4.9).

The first term on the right-hand outside the brackets resembles the first term on the

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15The MATLAB programs used for the numerical analysis are available as a web appendix at http://www.mit.edu/~ederer/feedback/web_app.zip.
Figure 4-1: This figure plots the second-period best response functions for the two players under a full feedback policy as a function of the effort choice of the other contestant for different levels of the first-period output difference $\Delta x_1$. The parameter values are $\mu = 1$, $\sigma^2 = 1$, $\tau^2 = 400$ and $k = 0.00027$. 
Figure 4-2: This figure plots the second-period equilibrium effort choice $\tilde{e}_2^A(\Delta x_1)$ of player $A$ as a function of the first-period output difference $\Delta x_1$ under a full feedback policy for different values of the variance of ability $\sigma^2$ while holding $\text{var}(\Delta x_1 + \Delta x_2)$ constant. The other parameter values are $\mu = 1$ and $k = 0.00027$. 
right-hand side of equation (4.9) and captures the evaluation and risk reduction effects. The numerator $\phi(y_2)$ shows that the expected marginal benefit of second-period effort is higher the closer the contest is. When $\Delta x_1 = 0$, the second-period tournament is symmetric and $y_2 = 0$ so that $\phi(y_2)$ reaches its maximum. However, whenever the first-period output difference is biased in favour of one of the agents, i.e. $\Delta x_1 \neq 0$, $y_2$ will be different from zero and $\phi(y_2) < \phi(0)$. The denominator is a measure of the noise of the second period. Information revelation reduces the amount of noise as can be seen from the relation $\text{var}(\Delta x_2 | \Delta x_1) < \text{var}(\Delta x_1 + \Delta x_2)$ and therefore increases incentives for effort.

Just as in the previous models, second-period effort is increasing in the prior expected ability of the agent. This can be seen from the first term inside the brackets on the right-hand side of (4.10a) and (4.10b). The second term inside the curly brackets of equation (4.10a) and (4.10b) captures the motivation effect. An observation of the first-period output difference that is favourable to player $A$, i.e. $\Delta x_1 > 0$, increases the effort supplied by agent $A$ and decreases that of agent $B$ by the same amount since $\frac{\sigma^2 \epsilon_1}{\text{var}(\Delta x_1)} > 0$.

However, the asymmetry in second-period effort choices that is created by a realization of the first-period output difference other than zero through the third term which captures the interaction of motivation and evaluation effect. When the output difference $\Delta x_1$ is positive, agent $A$ realizes that on average he is more able than agent $B$ and that he can therefore produce the same amount of output as his opponent even when he exerts less effort. It is indeed possible that for some values of $\Delta x_1 > 0$ agent $A$ actually exerts less effort in equilibrium than agent $B$. In such a situation, the beneficial sorting role of the motivation effect is actually reversed as less able agents exert more effort at least for some realizations of $\Delta x_1$.

Furthermore, the numerical analysis where I solve for the equilibrium first- and second-period effort levels under both feedback policies reveals that there is no longer an unambiguous ranking of feedback policies. It is now possible that either feedback policy may dominate the other. For example, for the different parameter values chosen for the numerical analysis in Figure 1, for $\sigma^2 = 1$ a full-feedback policy leads to lower expected second-period effort (evaluation effect) but higher first-period effort (signal-jamming effect) and higher expected second-period output (motivation and sorting effect) and therefore higher aggregate output.
than a no-feedback policy. On the other hand, for $\sigma^2 = 0.5$ both expected aggregate effort and output are lower under a full-feedback policy. Since I chose quadratic effort costs, the two policies are obviously identical when $\sigma^2 = 0$. Moreover, it is not true that a larger variance $\sigma^2$ generally favours a full-feedback policy since the asymmetries in second-period effort may become too large.

The analysis makes clear that in a setting where workers are ex-ante identical, the asymmetries created by a full-feedback policy have disadvantageous consequences for effort provision when one considers distribution functions for the noise difference other than the uniform distribution. An immediate consequence of this argument is that for motivational purposes it is not always optimal to give workers full information about what the firm thinks of their performance. It is therefore not surprising that an important strand of research in organizational behavior argues that encouraging managers to be more open about performance information can be counterproductive (Meyer, Kay and French 1965) especially when such information leads them to think that they are not close to the margin between winning and losing a promotion contest (Gibbs 1991). Furthermore, some researchers advocate a system in which managers are not too open with employees, but actively use information to manage employee perceptions of performance and therefore motivation (Beer 1987, Murphy and Cleveland 1995).

My analysis suggests a fundamental trade-off that firms face when deciding whether or not to give feedback to their employees. On the one hand, giving feedback gives the firm the opportunity to motivate workers and to allow them to make more informed decision about how much effort to exert. Such a revelation policy also creates implicit incentives for agents to supply effort. On the other hand, performance appraisals create an uneven playing field between the agents that may lead to a lack of competition. This suggests a distinction between two types of information which are important in interim performance appraisals. The first is information about how the employee can improve performance and develop skill, whereas the second is information about a worker’s future prospects. This distinction corresponds to two personnel objectives that, according to the human resource management literature, are often in conflict: ‘training and development’ on the one hand and ‘evaluation’ on the other.
In terms of the model I proposed, the first kind of information is information that helps the agent in tailoring effort to his correct ability level and the second is information about how likely an agent is to win tournament. Clearly, the first type of information has positive consequences for total output. In contrast, information of the second type creates an uneven playing field between the agents and is therefore unlikely to have favourable implications for effort choice. In theory, if an organization can separate these two forms of information, it will want to give the employee as much as possible of the former kind, while suppressing the latter kind. In practice, however, they are hard to separate, creating a tension that has received much attention in the organizational behavior literature. Beer (1987) notes that the two overall goals of ‘coaching and development’ and ‘evaluation’ are generally in conflict, and that a firm’s approach to performance appraisal involves a balance of this tension. Gibbs (1991) documents that organizations make deliberate attempts to mitigate the conflict between evaluation and development. Some firms have separate appraisals at different times of the year, one for evaluation and one for development. In addition, many organizations explicitly state on assessment forms that they are not for the purpose of evaluation. For example, consulting firms perform periodic formal performance assessments in which entry-level analysts appraise the performance of the consultants and partners they work with and while helpful for the recipients in terms of development, these appraisals have little impact on their evaluation.

4.5 Concluding Remarks

This chapter studied the role of organizational feedback mechanisms. Its main contribution is the consideration of heterogeneity among the agents, a generalization that opens the way for the analysis of learning on behalf of the agents as well as of motivational measures taken by the firm. In models in which ability plays no role or enters additively, the latter aspect is absent and so the choice between a no-feedback and a full-feedback policy is shown to depend on the third derivative of the disutility of effort in a way that is reminiscent of the macroeconomic phenomenon of precautionary saving. However, the analysis becomes much richer in content once one considers a situation in which beliefs about ability directly
impact each workers’ effort choice. In such a setting, interim performance evaluations are not merely a mechanism by which information about past performance is transmitted to workers: They also represent an intentional attempt by organizations to influence the morale of their workers. I discuss several consequences of interim performance evaluations such as the signal-jamming and the motivation effect (as well as the efficient sorting of workers that the latter induces) that have not been analyzed in previous economic models, but are key to our understanding of performance appraisal processes in organizations.

However, because organizations are faced with several countervailing incentives, the model presented in this chapter does not provide an unequivocal endorsement of interim performance evaluations. Interim performance evaluations motivate some employees, but at the same time the information they convey will demotivate other workers and may also reduce equilibrium effort of all workers, in particular, when this information creates a very uneven playing field between the contestants in future periods. Not only does this suggest a fundamental trade-off with respect to performance appraisals that is in accordance with the organizational behavior literature, but it also indicates that there might be cross-industry variation in the prevalence of organizational feedback mechanisms. In particular, I would expect to find a higher percentage of organizations conducting interim performance evaluations in industries in which the motivation and sorting effects of such evaluations are particularly important. As pointed out in Section 4.4.1, this prediction matches the widespread use of interim performance appraisals in the professional service industries.

While shedding a first light on the previously uncharted territory of motivation my analysis can be extended in numerous ways. For example, contrary to my assumptions, interim performance appraisals sometimes take the form of private communication. Furthermore, there is ample evidence that interim performance appraisals are not always truthful, but are in fact manipulated by superiors to increase worker performance. Finally, my analysis focuses exclusively on maximizing output under the two scenarios when the incentive scheme is exogenously given, but I do not allow the principal to choose the incentive scheme optimally in the two scenarios.
4.A Omitted Proofs and Calculations

4.A.1 Proof of Lemma 1

**Proof.** The second line of (4.3) is zero by the envelope theorem. Rewriting and using the law of iterated expectations yields

\[ E_{\Delta x_1} E_{a^A, a^B, \Delta e_1} \left\{ f(\Delta x_1 + \Delta a) - c'(\tilde{e}_2^A(\Delta x_1)) \right\} \frac{de_A^A(\Delta x_1)}{de_1^A} | \Delta x_1 \]

\[ = E_{\Delta x_1} \frac{de_A^A(\Delta x_1)}{de_1^A} E_{a^A, a^B, \Delta e_1} \left\{ f(\Delta x_1 + \Delta a) - c'(\tilde{e}_2^A(\Delta x_1)) \right\} | \Delta x_1 \]

\[ = E_{\Delta x_1} \frac{de_A^A(\Delta x_1)}{de_1^A} E_{a^A, a^B} \left\{ f(\Delta x_1 + \Delta a) - c'(\tilde{e}_2^A(\Delta x_1)) \right\} | \Delta x_1 \]

\[ = 0 \]

by the first order conditions of the second period.

I now show that in the additive ability model the strategic effect given by the third line of (4.3) is zero as well. First, I note that because the agents are ex-ante symmetric both in terms of production functions as well as beliefs, there is a symmetric first-period equilibrium, i.e. \( \tilde{e}_1^A = \tilde{e}_1^B \equiv \tilde{e}_1 \). Hence I can rewrite the third line to read

\[ E_{a^A, a^B, \Delta e_1} \left\{ f(\Delta x_1 + \Delta a) \frac{d\tilde{e}_2^B(\Delta x_1)}{de_1^A} \right\} = E_{\Delta x_1} E_{a^A, a^B, \Delta e_1} \left\{ f(\Delta x_1 + \Delta a) \frac{d\tilde{e}_2^B(\Delta x_1)}{de_1^A} \right\} | \Delta x_1 \]

\[ = E_{\Delta x_1} E_{a^A, a^B} \left\{ f(\Delta x_1 + \Delta a) \frac{d\tilde{e}_2^B(\Delta x_1)}{de_1^A} \right\} | \Delta x_1 \]

\[ = E_{\Delta x_1} \frac{d\tilde{e}_2^B(\Delta x_1)}{de_1^A} E_{a^A, a^B} \left\{ f(\Delta x_1 + \Delta a) | \Delta x_1 \right\}. \]

Substituting from (4.2) one obtains

\[ E_{\Delta x_1} \left\{ \frac{d\tilde{e}_2^B(\Delta x_1)}{de_1^A} c'(\tilde{e}_2^A(\Delta x_1)) \right\} = E_{\Delta x_1} \left\{ \frac{d\tilde{e}_2^B(\Delta x_1)}{d\Delta x_1} c'(\tilde{e}_2^A(\Delta x_1)) \right\} \]

\[ = 0 \]

since \( c'(\tilde{e}_2^A(\Delta x_1)) \) and \( \frac{d\tilde{e}_2^B(\Delta x_1)}{d\Delta x_1} \) are symmetric in \( \Delta x_1 \) around 0 because of the symmetry properties of \( \tilde{e}_2^A(\Delta x_1) \) and \( \tilde{e}_2^B(\Delta x_1) \).

Noting the symmetry of first- and second-period efforts the first order condition therefore simplifies to

\[ E_{a^A, a^B, \Delta e_1} \left\{ f(2\Delta a + \Delta e_1) \right\} = c'(\tilde{e}_1). \]
4.A.2 Sufficient Conditions for Interior Solutions

In Section 4.4.1 I assume that the noise difference is uniformly distributed. Since this means that the noise difference has limited support one must pay particular attention to corner solutions. In what follows I derive sufficient conditions for there to be no corner solutions.

No Feedback

Under a no-feedback policy the first order condition is given by

\[
c'(e^*) = E_{\alpha^*, \alpha^1, \Delta \alpha^1} \left[ f(2e^* \Delta a + \Delta \alpha^1) a^1 \right].
\]

If I assume that

\[-m \leq 2e^* \Delta a + \Delta \alpha^1 \leq m \] 

holds for all possible realizations of \( \Delta a \) and \( \Delta \alpha^1 \), I can rewrite the first order condition in this way

\[
\frac{\mu}{2m} = c'(e^*)
\]

as I have done in the exposition of the uniform model in Section 4.4.1. Equation (1.A.1) holds if

\[2e^* \hat{a} + 2d \leq m.
\]

Here, I have substituted the most extreme realizations of \( \Delta a \) and \( \Delta \alpha^1 \). Finally, substituting in for \( e^* \) I have

\[2\hat{a} \left( \frac{\mu}{2mk} \right) + 2d \leq m
\]

which holds if the noise in period 2, \( m \), and/or the scale of the marginal cost of effort \( k \) are sufficiently large.

Feedback

Following the same procedure as before, we now have to ensure that the following condition holds:

\[-m \leq \bar{e}_1 \Delta a + a^A \bar{e}_{2A}^A (\Delta x_1) - a^B \bar{e}_{2B}^B (\Delta x_1) + \Delta \alpha^1 \leq m.
\]

Substituting the most extreme values for \( a^i \) and \( \Delta \alpha^1 \), as well as \( \bar{e}_{2A}^A \), I obtain

\[
\bar{a} \left\{ \bar{e}_1 + \frac{1}{2mk} E \left[ a^A \mid \Delta x_1 \right] \right\} + 2d \leq m
\]
where \( \bar{e}_1 = \frac{1}{2mk} \left\{ \mu - E_{a^A, a^B, \Delta \varepsilon_1} \left[ a^B \frac{de^B_2(\Delta x_1)}{de^A_1} \right] \right\} \). Again, this inequality holds if \( m \) and/or the scale of the marginal cost of effort \( k \) are sufficiently large.

Comparing the conditions for the no-feedback and full-feedback case shows that because of the asymmetries of the full-feedback scenario the sufficient conditions derived for the revelation case are stricter. I therefore assume that throughout the analysis these conditions hold, an assumption which allows us to rule out unwanted corner solutions.

### 4.A.3 Proof of Lemma 2

**Proof.** The second line of (4.7) is zero by the envelope theorem. Using the law of iterated expectations yields

\[
E_{a^A, a^B, \Delta \varepsilon_1} \left[ \{ f \left( \Delta x_1 + a^A \bar{e}^A_2(\Delta x_1) - a^B \bar{e}^B_2(\Delta x_1) \right) a^A - c' \left( \bar{e}^A_2(\Delta x_1) \right) \} \frac{de^A_2(\Delta x_1)}{de^A_1} \mid \Delta x_1 \right] = 0
\]

where the last equality again follows from the first order condition of the second period.

Since the agents are ex-ante identical in terms of production function and beliefs there is a symmetric equilibrium of the first period where \( \bar{e}^A_1 = \bar{e}^B_1 = \bar{e}_1 \) so that the first-order conditions simplify to

\[
E_{a^A, a^B, \Delta \varepsilon_1} \left[ f \left( \bar{e}^A_1 + a^A \bar{e}^A_2(\Delta x_1) - a^B \bar{e}^B_2(\Delta x_1) \right) a^A - c' \left( \bar{e}^A_2(\Delta x_1) \right) \right] = c' \left( \bar{e}_1 \right).
\]

Using the assumptions about the density function I obtain the more tractable condition

\[
\frac{1}{2m} \left\{ \mu - E_{a^A, a^B, \Delta \varepsilon_1} \left[ a^B \frac{de^B_2(\Delta x_1)}{de^A_1} \right] \right\} = c' \left( \bar{e}_1 \right).
\]

\[\blacksquare\]

### 4.A.4 Calculations for the Normal Model

**No Feedback**

The first order conditions under a no-feedback policy are given by

\[
\phi(z^A) \frac{\partial z^A}{\partial e^A} = ke^A.
\]
Furthermore, I have

$$\Delta x_1 + \Delta x_2 \sim N \left( \mu (e_1^A - e_1^B + e_2^A - e_2^B), \sigma^2 \left[ (e_1^A + e_2^A)^2 + (e_1^B + e_2^B)^2 \right] + 4\tau^2 \right)$$

The second part of the left-hand side of the first order condition therefore yields

$$\frac{\partial z^A}{\partial e^A} = \frac{1}{\sqrt{\text{var}(\Delta x_1 + \Delta x_2)}} \left[ \mu - \frac{\mu (e_1^A - e_1^B + e_2^A - e_2^B) \sigma^2 (e_1^A + e_2^A)}{\text{var}(\Delta x_1 + \Delta x_2)} \right]$$

so that at the symmetric equilibrium the first order condition reduces to

$$ke^* = \frac{\phi(0)}{\sqrt{\text{var}(\Delta x_1 + \Delta x_2)}} = \frac{\mu}{\sqrt{\text{var}(\Delta x_1 + \Delta x_2)}}\mu.$$  

Feedback

The first order conditions for the two players yield

$$\phi(y_2) \frac{\partial y_2^A}{\partial e^A} = ke^A_2$$
$$\phi(y_2) \frac{\partial y_2^B}{\partial e^B} = ke^B_2.$$  

Noting that $\Delta x_t$ is normally distributed for given levels of $e_t$ allows us to write

$$\text{var}(\Delta x_1) = \left[ (e_1^A)^2 + (e_1^B)^2 \right] \sigma^2 + 2\tau^2$$
$$\text{var}(\Delta x_2) = \left[ (e_2^A)^2 + (e_2^B)^2 \right] \sigma^2 + 2\tau^2$$
$$\text{cov}(\Delta x_1, \Delta x_2) = (e_1^A e_2^A + e_1^B e_2^B) \sigma^2$$
$$\text{E}(\Delta x_2 | \Delta x_1) = \mu (e_2^A - e_2^B) + \frac{\text{cov}(\Delta x_1, \Delta x_2)}{\text{var}(\Delta x_1)} [\Delta x_1 - \text{E}(\Delta x_1)]$$
$$\text{var}(\Delta x_2 | \Delta x_1) = \text{var}(\Delta x_2) \left[ 1 - \frac{\left( \text{cov}(\Delta x_1, \Delta x_2) \right)^2}{\text{var}(\Delta x_1) \text{var}(\Delta x_2)} \right].$$

Since the contestants are ex ante identical and the first-period equilibrium is symmetric I know that $\text{E}(\Delta x_1) = 0$.

Hence the first order conditions are given by

$$ke^A_2 = \frac{\phi(y_2)}{\sqrt{\text{var}(\Delta x_2 | \Delta x_1)}} \left\{ \mu + \frac{\sigma^2 e_1}{\text{var}(\Delta x_1)} \Delta x_1 - \frac{\sigma^2 e_2}{\text{var}(\Delta x_2 | \Delta x_1)} \Delta x_2 \right\}$$
$$ke^B_2 = \frac{\phi(y_2)}{\sqrt{\text{var}(\Delta x_2 | \Delta x_1)}} \left\{ \mu - \frac{\sigma^2 e_1}{\text{var}(\Delta x_1)} \Delta x_1 + \frac{\sigma^2 e_2}{\text{var}(\Delta x_2 | \Delta x_1)} \Delta x_2 \right\}.$$
where $T = \Delta x_1 + E (\Delta x_2 | \Delta x_1)$. 
Bibliography


