Joint Discussion Paper Series in Economics

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

No. 20-2016

Matthias Verbeck and Elisabeth Schulte

Contracting with Researchers

Coordination: Bernd Hayo • Philipps-University Marburg
School of Business and Economics • Universitätsstraße 24, D-35032 Marburg
Tel: +49-6421-2823091, Fax: +49-6421-2823088, e-mail: hayo@wiwi.uni-marburg.de

MACIE PAPER SERIES

Marburg Centre for Institutional Economics

MACIE

Nr. 2016/7

Contracting with Researchers

Matthias Verbeck and Elisabeth Schulte

MACIE, Philipps-Universität Marburg

Marburg Centre for Institutional Economics • Coordination: Prof. Dr. Elisabeth Schulte
c/o Research Group Institutional Economics • Barfuessertor 2 • D-35037 Marburg

Phone: +49 (0) 6421-28-23196 • Fax: +49 (0) 6421-28-24858 •
www.uni-marburg.de/fb02/MACIE • macie@wiwi.uni-marburg.de

Philipps Universität Marburg

Contracting with Researchers *

Matthias Verbeck †
University of Marburg

Elisabeth Schulte
University of Marburg

April 13, 2016

Abstract

We study a setting in which one or two agents conduct research on behalf of a principal. The agents' success depends on effort and the choice of a research technology that is uncertain with respect to its quality. A single agent has no incentive to deviate from the principal's preferred technology choice. In the multiagent-setting researchers pursue individual rather than overall success which yields a preference for the most promising technology. We show that a mechanism that deters this *bias towards mainstream research* always entails an efficiency loss if researchers are risk-averse. Our results suggest that there is too little diversity in delegated research.

JEL codes: D82, D83, D86

Keywords: Moral hazard, Hidden action, Incentives in teams, Delegated research, Academic organization, Diversity in research

*For very helpful comments and suggestions we thank the participants of the 2015 annual meeting of the Verein für Socialpolitik, the participants of the Economics department's internal research seminar of Philipps-Universität Marburg, and the participants of the 2015 MAGKS research seminar in Rauischholzhausen.

†Corresponding author: matthias.verbeck@wiwi.uni-marburg.de

1 Introduction

The job of a researcher -both in academia and in the industry- is unique in many ways. One of its most striking characteristics is the high degree of uncertainty any researcher faces when trying to answer a specific research question. Despite hard work, success is by no means certain. Max Weber was certainly right when he wrote nearly 100 years ago

"Yet it is a fact that no amount of such enthusiasm, however sincere and profound it may be, can compel a problem to yield scientific results" (Weber 1946 [1917], p.135).

Effort on the part of the researcher is a necessary but not a sufficient condition for success. In fact, the *technology* that the researcher uses to address the research question is another important determinant of the probability of finding an answer. If a researcher backs the wrong horse, i.e., he or she employs a method or technology that turns out to be a dead end, all efforts are in vain. Hence, the choice of research technology is a risky bet from any researcher's perspective. In our model of research activities, we therefore separate a researcher's actions into "effort choice“ and "technology choice“. Two motivating examples will illustrate this issue:

Example 1: Oil drilling
An oil company hires one or more experts (say geologists), to conduct exploratory drillings with the aim of finding a new oil spring. There are two possible locations for test drillings available. If an expert chooses a location that does not contain oil, he or she will not be able to yield a success, independent of the chosen effort level.

Example 2: Cancer research
A national health agency is interested in a cure for lung cancer. Academic researchers can now choose from several methods to accomplish this goal.

They could, for example, test different possible active ingredients to determine whether or not they could improve existing chemotherapies. Again, only if the selected approach is suitable will a higher effort level increases the chance for success.

A second striking characteristic of research is its "winner-takes-all-structure". The marginal value of a second successful researcher who replicates the discovery of one of his colleagues is (close to) zero. In the words of Dasgupta and Maskin:

"There is no value added when the same discovery is made a second, third, or fourth time. To put it sharply [...], the winning research unit is the sole contributor to social surplus." (Dasgupta and Maskin 1987, p.583).

Such "multiples" are likely to occur whenever researchers independently try to answer similar questions (Merton 1963). From a social perspective, it is neither interesting how many researchers found the answer to any solved research question, nor which specific approach yielded the answer (abstracting from ethical considerations).[1] What *is* crucial is that there is a cure for lung cancer, not *how* it was found. From an ex ante perspective however, facing uncertainty about any available research technology, a principal or social planner might find it optimal to diversify the technological risk by employing more than one approach to maximize the overall probability of success. Our contract-theoretical analysis of this problem shows that this goal might conflict with the researchers' vested interests of maximizing their individual probability of success. Hence, whenever technology choice is not observable, a *moral hazard* problem arises because selfish researchers choose research portfolios that exhibit too little diversity from an efficiency perspective. Al-

[1] If there is no definite answer to the research question yet, the number of researchers promoting a preliminary answer may still be informative. We focus on research questions for which only a definite answer is valuable.

though diversity of research is often optimal from a social point of view, it is not rational from a researcher's perspective to engage in less promising technologies. Whether or not the assumption of an unobservable technology is reasonable, depends on the characteristics of the specific research question. For example, a non-expert principal might have no problem in observing the spot of an oil spring (example 1), but cannot observe the technology behind an effective anti-cancer drug (example 2). We will capture both cases in our analysis.

The remainder of the paper is organized as follows: Section 2 provides the reader with literature related to our research. Section 3 first analyzes the case of a single researcher. Here the interests of principal and agent regarding the technology choice are perfectly aligned. Subsequently we will analyze the multiagent-case that -for many parameter realizations- gives rise to a distortion of optimal technology choice when the principal cannot observe the selected technology. For such cases we will show that the incentivization of the principal's preferred technology choice comes at a cost for the principal, such that there is an overall loss of efficiency. Section 4 discusses critical assumptions and limitations of our model, and Section 5 concludes. Detailed derivations of the presented results are collected in Appendix A. Detailed proofs can be found in Appendix B.

2 Related Literature

Our research contributes to three branches of the economic literature. First and foremost it is related to the literature on incentives and incentives in teams. In the classic papers of Holmström (1979; 1982) the effort level is unobservable, leaving the principal with lower expected return compared to the first-best solution. In our model we extend the agent's strategy space and make the technology choice an (unobservable) part of any agent's strategy. Moreover our research is related to Mookherjee (1984) and Itoh (1991) who both study compensation schemes for multiple agents and find that optimal individual remuneration should also depend on the other agents' performance to filter out common uncertainty. Legros and Matsushima (1991) suggest a compensation scheme that deters free-riding by making use of different performance distributions of heterogeneous agents. Although free-riding is excluded in our model by the assumption of individually observable output, our model features similar characteristics, since differences in output distributions are harnessed to deter undesired actions by the agents.

Second, our research is related to the literature on the Economics of R&D. Here, our results are linked to models that show an unduly amount of aggregated research efforts in equilibrium, like Loury (1979) or Dasgupta and Stiglitz (1980). More specifically, our research is connected to models of optimal research portfolios, e.g., Bhattacharya and Mookherjee (1986) or Dasgupta and Maskin (1987). The latter -similar to our model- shows that independent researchers choose research projects that are overly correlated from a social planner's perspective. In a model of Fershtman and Rubinstein (1997), two researchers independently conduct research at one of multiple sites to find a hidden treasure. In equilibrium, there is an efficiency loss due to a coordination failure which implies a wasteful duplication of research efforts. Moreover, recent contributions to the theory of contests also show similarities to our model, e.g., the work of Erat and Krishnan (2012), and Konrad (2014). Our own contribution differs from the aforementioned models in a number of ways. First, and most importantly, the driving force for the wasteful duplication of research efforts in our model is the non-observability of research technologies. Moreover, and unlike in most of the models mentioned before, we explicitly assume *delegated* research, instead of independent research. Hence, our model aims to capture research activities within a firm instead of research activities between (competing) firms. What is more, our model sheds light on how the prospects of different technologies explicitly influences the agent's optimal effort choice.

Third, in a wider context, our research is also related to the "Economics of Science" literature (Stephan 1996), which analyzes the plethora of issues related to the creation and the transfer of (academic) knowledge. Works cited here are only exemplary and incomplete. Frey (2003), Starbuck (2005) and Grey (2010) criticize the prevailing system of academic peer-reviewed publication as unreliable, opaque, and discouraging to innovative research. Ioannidis (2005) points to a publication bias towards false results. Kieser (2010) criticizes performance related pay in academic research. Felgenhauer and Schulte (2014) show that an information loss between researcher and scientific community is implied when the researcher strives for publishing his/her research.

None of the contributions that we know however, deal with the issue of duplicated research efforts from an agency-perspective. Therefore, our research is new to the best of our knowledge.

3 The Model

3.1 Assumptions and Main Setting

A risk-neutral (female) principal is interested in a conclusive research outcome to a specified research question.[2] Her utility from a research project is given by

$$V(q, w) = q - E[W] \tag{1}$$

where $q \in \{0, 1\}$ denotes the stochastic output of the research project, which can be either a failure or a success. $W = \sum_{i=1}^{n} w_i$ denotes the overall compensation of the employed agent(s), w_i denotes agent i's private compensation,

[2] You can think of the principal as a social planner who wishes to maximize society's benefits from research, but she could just as well be a firm owner who wants to maximize gains from a company's R&D-department.

and n (the number of agents) is either one or two.

Each employed agent chooses exactly one research technology $j \in \{m, o\}$, where technology m is labelled as "mainstream-technology" and technology o is labelled as "outsider-technology". Furthermore, each agent chooses a costly research effort level $e_i \in \mathbb{R}_0^+$ that determines the probability of individual success. An agent's strategy can therefore be fully described as $(e_i, j) \in \mathbb{R}_0^+ \times \{m, o\}$ and his overall utility equals

$$U_i = u_i(w_i) - e_i. \tag{2}$$

As standard in the literature, we assume that

$$u'(\cdot) > 0, \quad u''(\cdot) \leq 0.$$

The agents' reservation utility level is zero.

Any agent's individual output depends on the selected research technology, which can either be "good" or "bad", denoted by $\omega_j \in \{g, b\}$. We let $\pi_j = P(\omega_j = g)$ denote the common prior probability that technology j is good and make the assumption that technologies are *independent*, i.e., knowing the quality of technology m is not informative about the quality of technology o.[3] Furthermore, we assume that $\pi_m \geq \pi_o$, i.e., the mainstream-technology appears at least as promising as the outsider-technology.

Let q_i denote the event that agent i's research yields a success. We impose:

$$P(q_i = 1 \mid e_i \times j) = \begin{cases} \rho(e_i), \text{ if } \omega_j = g \\ 0, \text{ else.} \end{cases} \tag{3}$$

A success is only possible if the agent has chosen a good technology; otherwise, all his efforts are in vain. But even when a good technology has been

[3]The independence-assumption restricts the generality of our model, but simplifies the analysis. It is reasonable when technologies are sufficiently distinct from each other.

chosen, success is not guaranteed and depends on the agent's effort. Here, $\rho(e_i)$ defines the probability of agent i's success, given that technology j is a good technology. As is standard in the literature, we assume that

$$\rho'(\cdot) > 0, \quad \rho''(\cdot) \leq 0.$$

We add the following technical assumptions that guarantee an interior solution:

$$\rho'(0) \cdot \pi_j > 1, \quad \rho(0) = 0, \quad \rho(\infty) = 1.$$

An agent's overall probability of success, provided the usage of technology j and effort e_i, is given as

$$P(q_i = 1 \mid e_i \times j) = \rho(e_i) \cdot \pi_j. \tag{4}$$

The principal offers a contract to the agent(s) so as to maximize (1), anticipating that agent i chooses his actions as to maximize (2). We assume that all of the above (number of agents, cost functions, utility functions, state probabilities) is common knowledge.

The course of action is as follows:

1. Nature chooses ω_j according to π_j.
2. The principal offers a take-it-or-leave-it-contract to the agent(s) which the agents either accept or reject.
3. If an agent accepts the contract, he chooses a technology and an effort level that maximizes his utility given the conditions of the contract. If the contract is rejected, the game ends.
4. Nature draws q_i according to (3) and each party obtains remuneration according to the specified conditions.

3.2 Contracting with a Single Researcher

In this section, we derive the optimal contract with a single researcher, $n = 1$. As there is no ambiguity, we omit subscripts referring to the agent. Let $\overline{w}$ indicate the wage level that is paid to the agent if his research yields a success, and let $\underline{w}$ denote the wage level in the event of fruitless research.

3.2.1 Symmetric Information

As a benchmark, we start with the case of symmetric information. Using the Lagrangian to solve the principal's problem, we obtain the optimal co-insurance conditions (Borch 1962) between principal and agent which yield

$$\overline{w} = \underline{w} = w. \tag{5}$$

The optimal effort and wage levels for a given technology are implicitly defined by

$$\rho'(e_j) \cdot \pi_j = \frac{1}{u'(w)} \tag{6}$$

and

$$w = u^{-1}(e). \tag{7}$$

The left-hand side of (6) equals the marginal product of effort and the right-hand side equals the marginal cost of effort, both seen from the principal's perspective. It is evident (and in accordance with intuition) that the optimal effort e and optimal wage w rise in π_j. As usual, under symmetric information, the risk-neutral principal completely insures the risk-averse agent against the risk of failure by paying a wage that is not conditioned on the agent's success.

Regarding the technology choice, we obtain the intuitive result, that choosing the more promising technology is optimal from the principals perspective:

Proposition 1. *For n=1 and symmetric information, technology m is the principal's optimal technology choice.*

Proof. Suppose it is true that the principal's payoff is higher when the agent chooses the outsider-technology, so that $\rho(e) \cdot \pi_o - w(e,j) > \rho(e) \cdot \pi_m - w(e,j) \Leftrightarrow \pi_o > \pi_m$. This contradicts our assumption that $\pi_m \geq \pi_o$. □

As the principal can perfectly observe the agent's actions, she could induce the optimal choice of technology by inflicting (arbitrary) punishments on the agent for using the wrong technology. In the current setting, this is not necessary, as a rational agent does not profit from departing from the principal's optimal technology choice. He receives a fixed wage in any case. Hence, the agent will always act in the best interest of the principal.

3.2.2 Asymmetric Information

In the case of unobservable actions, the agent's incentive constraint becomes a part of the principal's optimization problem. In order to satisfy the agent's participation constraint and the incentive compatibility constraint, it must be that

$$\overline{w} > \underline{w}. \tag{8}$$

We therefore obtain the typical result that a success is rewarded, and fruitless effort ($q = 0$) is punished. As usual, we see that the non-contractability of e entails an efficiency loss since

$$\begin{aligned} \pi_j \cdot \rho(e) \cdot u(\overline{w}) + (1 - \pi_j \cdot \rho(e)) \cdot u(\underline{w}) = e < \\ u(\pi_j \cdot \rho(e) \cdot \overline{w} + (1 - \pi_j \cdot \rho(e)) \cdot \underline{w}) \\ \Leftrightarrow u^{-1}(e) < \pi_j \cdot \rho(e) \cdot \overline{w} + (1 - \pi_j \cdot \rho(e)) \cdot \underline{w}, \end{aligned} \tag{9}$$

where the right-hand side is due to Jensen's inequality. The expected wage to induce a given effort level is thus larger under asymmetric information than under symmetric information.

Next, we extend the degree of asymmetric information and assume that the agent's technology choice is also not observable (or verifiable in court) by the principal. We will refer to the case of unobservable effort and observable technology as “Moral Hazard I”and unobservable effort and unobservable technology choice as “Moral Hazard II”. The assumption of unobservable technology choice is -at least for many research settings- plausible, as any (non-expert) principal will find it difficult to observe the techniques and methods the agent has applied.

Recall from Proposition 1 that it is optimal to choose the mainstream-technology, from the principal's standpoint. It is easy to see that a rational agent will choose the same technology.

Proposition 2. *For n=1 and asymmetric information, technology m is the agent's optimal technology choice.*

Proof. Consider any (possibly suboptimal) effort choice by the agent. The agent's expected gain when employing the mainstream-technology equals $\rho(e) \cdot \pi_m \cdot u(\overline{w}) + (1 - \rho(e) \cdot \pi_m) \cdot u(\underline{w}) - e$. If we replace π_m with π_o, the expected gains are strictly lower as $u(\overline{w}) > u(\underline{w})$ and the higher utility level $u(\overline{w})$ obtains a lower weight. Hence, the agent prefers technology m for any effort choice. □

The agent's and the principal's interests regarding technology choice are completely aligned, and the optimal contract does not have to condition on technology choice.

3.3 Contracting with two Researchers

We now turn to the case where the principal can employ a second agent. The structure is similar to the one-agent case. Each agent is assigned to a specific technology and exerts research effort. The principal can choose to employ both agents who either both use the same technology or, use different technologies. We will refer to the former option as “concentrated efforts”and the latter as “diversified efforts”. We make the important assumption that *individual output* of agents is always observable, effectively excluding free-riding problems from our setting. In addition, we assume that contracting *between agents* is impossible (no side contacting) and that researcher's probabilities of success are *independent* of each other and, thus, only depend on every researcher's own effort level and technology choice.

Let $\overline{\overline{w}}_i$ ($\overline{w}_i$) denotes agent i's wage level when both agents (only agent i) have been successful, and let $\underline{\underline{w}}_i$ ($\underline{w}_i$) denote the wage level for the case that both agents (only agent i) fail.

3.3.1 Symmetric Information

Again, we start with an analysis of the case of symmetric information. For both settings, concentrated efforts and diversified efforts, we once more obtain the result that the agents' wage only conditions on effort and not on performance:

$$\overline{\overline{w}}_i = \overline{w}_i = \underline{w}_i = \underline{\underline{w}}_i = w_i. \tag{10}$$

Case 1 : Concentrated Efforts:
We postpone the optimal choice of technologies and take it as given for determining the optimal effort and wage levels for each agent. Plugging the uniform wage into the optimization problem, we yield optimal effort and wage levels for agent 1 (likewise for agent 2) by solving

$$\rho'(e_1) \cdot \pi_j \cdot (1 - \rho(e_2)) = \frac{1}{u'(w_1)} \tag{11}$$

and

$$w_i = u^{-1}(e_i). \tag{12}$$

As can be seen from equation (11), the optimal effort also depends on the probability of success of the other agent. We can show that identical effort levels for both agents are optimal.

Proposition 3. *Symmetric effort, i.e., $e_1 = e_2 = e_i$, is optimal when two agents use the same technology.*

Proof. See Appendix.

The intuition for the proof is that due to the increasing cost of inducing higher effort, any probability of success can be obtained in a cost-minimizing manner by equalizing the effort requirements. As a useful corollary we obtain the result, that employing two agents endowed with a certain technology yields higher expected returns than employing a single agent, using that technology:

Corollary 1. *Contracting with two agents, both using technology j, yields a strictly higher expected return than contracting with a single agent using technology j.*

Proof. Any return that is generated by offering the optimal effort-wage-combination to a single agent, can be replicated by offering the same conditions to only one of two agents while the remaining agent receives a zero-wage. However in this case, efforts would be asymmetric, a contradiction to Proposition 3. □

Plugging the result from Proposition 3 into (11), optimal effort and wage levels are defined by

$$\rho'(e_i) \cdot \pi_j \cdot (1 - \rho(e_i)) = \frac{1}{u'(w_i)} \tag{13}$$

and (12). We can easily see that in the two-agent case a lower effort level per agent is optimal, since the left-hand side of (13) is smaller than the left-hand side of (6).

Case 2: Diversified efforts
In the following we assume that agent 1 uses technology m and agent 2 uses technology o. Plugging the uniform wage ino the optimization problem, the optimal effort and wage levels solve

$$\pi_m \cdot \rho'(e_1) \cdot (1 - \pi_o \cdot \rho(e_2)) = \frac{1}{u'(w_1)} \tag{14}$$

for agent 1 and

$$\pi_o \cdot \rho'(e_2) \cdot (1 - \pi_m \cdot \rho(e_1)) = \frac{1}{u'(w_2)} \tag{15}$$

for agent 2 and (12) for both agents. From the previous two equations we can conclude that agent 1, who uses the mainstream-technology exerts a higher effort level than agent 2, who uses the outsider-technology.[4]

Having derived optimal effort-wage-combinations for diversified and concentrated efforts, we can now turn to the question of which of the two options is optimal. The principal has three possible options:

(i) Both agents are assigned to technology m (Concentrated Efforts I).

(ii) Both agents are assigned to technology o (Concentrated Efforts II).

(iii) Agents are assigned to alternate technologies (Diversified Efforts).

Following the reasoning of Proposition 1, assigning both agents to the inferior technology cannot be optimal. Consequently, only the two remaining alternatives (concentrated efforts while using the mainstream-technology and diversified efforts) have to be compared to determine the optimal strategy. Diversifying efforts is optimal when

$$E(V_{mo}(\cdot)) > E(V_{mm}(\cdot)), \tag{16}$$

where V_{mo} (V_{mm}) denotes the principal's payoff function for diversified efforts (concentrated efforts). We can show that there is a set of combinations of π_m and π_o for which it is optimal to assign one agent to the outsider-technology.

[4]For the edge case of $\pi_m = \pi_o$, effort levels would be identical.

Proposition 4. *For $n = 2$ with symmetric information, a threshold $\tilde{\pi}_o = \frac{\pi_m \cdot (\rho(e_1) \cdot (2 - \rho(e_1)) - \rho(e_1')) - 2 \cdot w_1 + w_1' + w_2'}{\rho(e_2') \cdot (1 - \pi_m \cdot \rho(e_1'))} < \pi_m$ determines the optimal allocation of agents, where $\tilde{\pi}_o < \pi_m$ whenever $0 < \pi_m < 1$. When $\pi_o \leq \tilde{\pi}_o$, concentrated efforts with technology m are optimal; otherwise, diversified efforts are optimal.*

Proof. See Appendix.

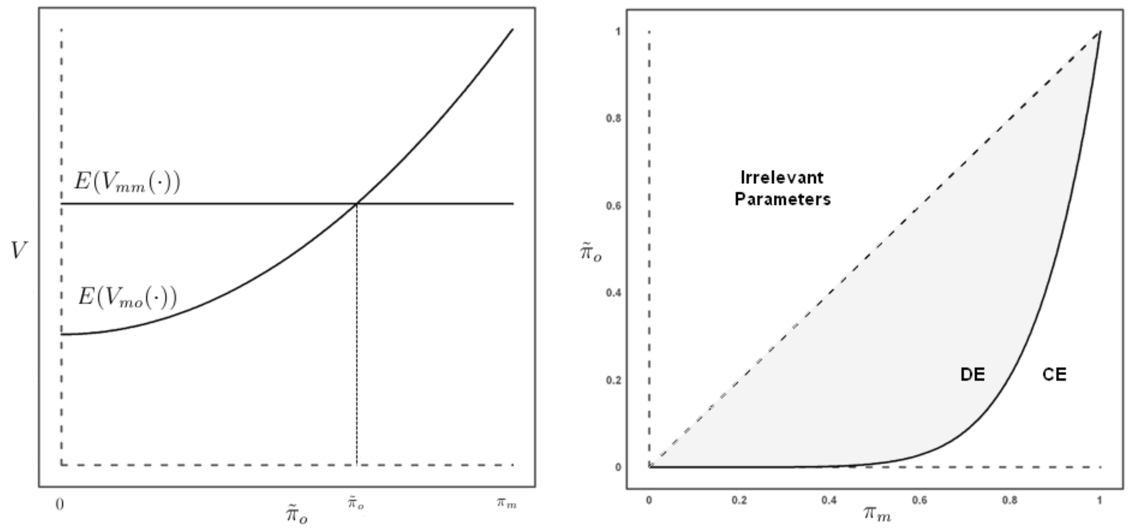

Figure 1:
a) The principals payoff under symmetric information, when choosing concentrated efforts (mm), and diversified efforts (mo).
b) The optimal research portfolio for different parameter constellations (π_m, π_o). CE: concentrated efforts, DE: diversified efforts.

The intuition for the proof is as follows: We know from Corollary 1 that if $\pi_o = 0$, concentrated efforts are better than diversified efforts. Next, we verify that for $\pi_o = \pi_m$ diversified efforts are strictly better than concentrated efforts. Finally, the fact that the principal's payoff from diversifying effort strictly increases in π_o, whereas her payoff from concentrated efforts is constant, yields a unique value for $\pi_o \in (0, \pi_m)$ where her payoffs are equal. Figure 1a) illustrates the proof of Proposition 4 by showing the necessity of a unique intersection of $E(V_{mo}(\cdot))$ and $E(V_{mm}(\cdot))$ as a function of π_o. Figure 1b) illustrates the optimal research portfolio for different parameter constellations of π_m and π_o, where "DE" and "CE" represent "diversified efforts" and "concentrated efforts" respectively.

Note that the implementation of the optimal research agenda is again no problem in the symmetric information setting since the uniform wage makes any agent indifferent between both technologies. Therefore no agent wishes to deviate from the principal's optimal choice.

3.3.2 Asymmetric Information

Let us now assume that the principal cannot observe the agents' actions, i.e., effort level and technology choice. We start with the analysis of observable technology choice and unobservable effort (Moral Hazard I).

Case 1: Concentrated efforts
When effort is unobservable we have to add incentive compatibility constraints to the principal's maximization problems when contracting with agent 1 and agent 2 respectively.

Applying the first-order approach and then constructing the Lagrangian yields

$$\frac{1}{u'(\overline{\overline{w}}_i)} = \frac{1}{u'(\overline{w}_i)} = \lambda_i + \mu_i \cdot \frac{\rho'(e_i)}{\rho(e_i)}, \tag{17}$$

and

$$\frac{1}{u'(\underline{w}_i)} = \lambda_i - \mu_i \cdot \frac{\rho'(e_i)}{1 - \rho(e_i)}, \tag{18}$$

and, by taking into account that $e_1 = e_2 = e_i$,

$$\frac{1}{u'(\underline{\underline{w}}_i)} = \lambda_i - \mu_i \cdot \frac{\pi_m \cdot \rho'(e_i) \cdot (1 - \rho(e_i))}{\pi_m \cdot (1 - \rho(e_i)) \cdot (1 - \rho(e_i)) + (1 - \pi_m)}, \tag{19}$$

where λ_i and μ_i are Lagrange multipliers.

From equations (17) to (19) we can derive the structure of optimal wages for concentrated efforts. Letting $\overline{\overline{w}}_i^{SB1}, \overline{w}_i^{SB1}, \underline{w}_i^{SB1}$, and $\underline{\underline{w}}_i^{SB1}$ denote the optimal wages for agent i for different output distributions (analogous to the case of symmetric information), we obtain the following result:

Lemma 1. For $n = 2$ with unobservable effort and observable technology choice, the structure of optimal wages when efforts are concentrated is $\overline{\overline{w}}_i^{SB1} = \overline{w}_i^{SB1} > \underline{\underline{w}}_i^{SB1} \geq \underline{w}_i^{SB1}$.

Proof. $\overline{\overline{w}}_i^{SB1} = \overline{w}_i^{SB1}$ follows directly from (17). $\overline{\overline{w}}_i^{SB1} > \underline{\underline{w}}_i^{SB1}$ must be true, because the right-hand side of equation (17) is strictly larger than the right-hand side of equation (19). Furthermore, $\underline{\underline{w}}_i^{SB1} \geq \underline{w}_i^{SB1}$ follows from comparing (18) to (19), where the inequalities are identical except for the term $(1 - \pi_m)$ that is added to the right-hand side denominator of (19), such that we have a strict inequality whenever $\pi_m < 1$. □

If an agent fails to produce a positive output, his wage also depends on the performance of the other agent. This is the case because the other agent's output is informative about the technology's quality and individual performance alone is not a sufficient statistic for any agent's effort level (Mookherjee 1984). By incorporating into the contract any signal that is informative with respect to individual effort choice (Holmström 1979), a more advantageous trade-off between effort provision and insurance is created for the principal.

Case 2: Diversified efforts

As in the case of concentrated efforts, we have to add the agents' incentive constraints to the original problem. This yields

$$\frac{1}{u'(\overline{\overline{w}}_i)} = \frac{1}{u'(\overline{w}_i)} = \lambda_i + \mu_i \cdot \frac{\rho'(e_i)}{\rho(e_i)}, \tag{20}$$

$$\frac{1}{u'(\underline{w}_1)} = \frac{1}{u'(\underline{\underline{w}}_1)} = \lambda_1 - \mu_1 \cdot \frac{\pi_m \cdot \rho'(e_1)}{1 - \ \pi_m \cdot \rho(e_1)} \tag{21}$$

as well as

$$\frac{1}{u'(\underline{w}_2)} = \frac{1}{u'(\underline{\underline{w}}_2)} = \lambda_2 - \mu_2 \cdot \frac{\pi_o \cdot \rho'(e_2)}{1 - \ \pi_o \cdot \rho(e_2)}. \tag{22}$$

From the previous equations we can derive the wage structure for diversified efforts:

Lemma 2. For $n = 2$ with unobservable effort and observable technology choice, the structure of optimal wages when efforts are diversified is $\overline{\overline{w}}_i'^{SB1} = \overline{w}_i'^{SB1} > \underline{w}_i'^{SB1} = \underline{\underline{w}}_i'^{SB1}$.

Proof. $\overline{\overline{w}}_i'^{SB1} = \overline{w}_i'^{SB1}$ follows directly from (20). $\overline{w}_i'^{SB1} > \underline{w}_i'^{SB1}$ must be true, because the right-hand side of equations (21) and (22) is strictly larger than the right-hand side of equation (20). $\underline{w}_i'^{SB1} = \underline{\underline{w}}_i'^{SB1}$ follows directly from (21) and (22). □

Due to the technological independence, the performance of agent 1 is not a signal for the effort level of agent 2 and vice versa. Hence, when efforts are diversified, individual performance alone determines the wage level for any agent. This independence will facilitate the analysis of Moral Hazard II drastically.

In both cases -concentrated and diversified efforts- under asymmetric information, the expected wage for any agent needed to induce the first-best effort level is higher than under symmetric information. The reasoning is similar to the one-agent setting, such that we abstain from formally stating the argument again here. What is more interesting is the change in the optimal research portfolio generated by the non-observability of effort. We obtain the intuitive result that concentrated efforts (i.e., research with the more promising technology) is optimal for more parameter constellations of π_m and π_o as compared to the first-best solution.

Proposition 5. *For $n = 2$ and unobservable effort ("Moral Hazard I"), $\tilde{\pi}_o^{SB1} = \frac{\pi_m \cdot (\rho(e_1^{SB1}) \cdot (2 - \rho(e_1^{SB1})) - \rho(e_1'^{SB1})) - 2 \cdot E(W_1^{SB1}) + E(W_1'^{SB1}) + E(W_2'^{SB1})}{\rho(e_2'^{SB1}) \cdot (1 - \pi_m \cdot \rho(e_1'^{SB1}))}$ determines the optimal allocation of agents, where $\tilde{\pi}_o < \tilde{\pi}_o^{SB1} < \pi_m$ whenever $0 < \pi_m < 1$. When $\pi_o \leq \tilde{\pi}_o^{SB1}$, concentrated efforts with technology m are optimal, otherwise diversified efforts are optimal.*

Proof. See Appendix.

The intuition for the proof of the uniqueness of the threshold is similar to that of the proof of Proposition 4. The proof that $\tilde{\pi}_o^{SB1} > \tilde{\pi}_o$ takes three steps. First, it relies on the fact that for either option of the technology choice, the principal's payoff is lower when she cannot observe the agents' efforts. Second, showing that for $\pi_o = 0$ the difference between payoffs is larger for diversified efforts than for concentrated efforts and, third, acknowledging that for diversified efforts she gains more from a marginal increase of π_o when she can observe the agents' efforts, implies that the intersection between her payoffs when choosing diversified and concentrated efforts, respectively, occurs for a larger value of π_o if she cannot observe agents' efforts. Figure 2 illustrates the argument. Due to the agents' risk-aversion, it is more costly for the principal to induce effort for low success probabilities. Hence the principal finds it optimal to concentrate efforts on the mainstream-technology for a larger parameter range. A deviation from the assigned technology can easily be deterred by the principal, as she can observe the technology choice.

This is no longer the case in the problem of "Moral Hazard II", when technology choice is also unobservable. Following the reasoning of Proposition

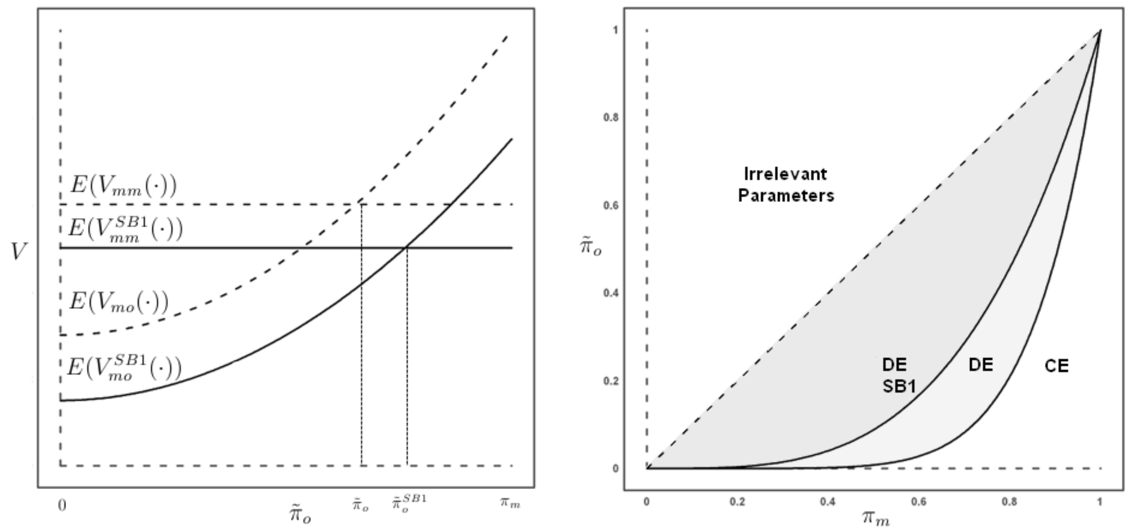

Figure 2:

a) The principals payoff under symmetric information (dashed), and under Moral Hazard I (solid), when choosing concentrated efforts (mm), and diversified efforts (mo).

b) The optimal research portfolio for different parameter constellations (π_m, π_o). CE: concentrated efforts, DE: diversified efforts. In the setting Moral Hazard I, the set of parameters for which DE is optimal shrinks (DE SB1).

2, any agent prefers to use the mainstream technology. Hence, an explicit incentivization for choosing the mainstream-technology is not necessary and asymmetric information with respect to technology choice does not harm the principal when the parameter constellation is such that she prefers concentrated efforts. Whenever diversified efforts are optimal, however, the wage scheme derived for the previous problem is no longer optimal. In fact, under that wage scheme, agent 2 will deviate from the principal's desired behavior and switch to the mainstream-technology, since choosing the mainstream-technology increases the probability of individual success for any given effort level.

Proposition 6. *For n=2 with unobservable effort and unobservable technology choice ("Moral Hazard II"), every agent will choose the mainstream-technology under the optimal wage scheme for "Moral Hazard I".*

Proof. See Appendix.

The unobservability of the agent's technology choice requires a mechanism that incentivizes the principal's preferred technology choice. Hence we have to add another incentive compatibility constraint for the second agent (see Appendix). The incorporation of the additional constraint into the principal's problem yields a new wage scheme that rewards or punishes the second agent according to his own performance *and* the performance of agent 1.

Lemma 3. For agent 2, the structure of wages for diversified unobservable efforts and unobservable technology choice is $\overline{w}_2^{SB2} > \overline{\overline{w}}_2^{SB2}$ and $\underline{w}_2^{SB2} > \underline{\underline{w}}_2^{SB2}$.

Proof. See Appendix.

The resulting wage scheme rewards agent 2 according to the distribution of outcomes. If he is the sole agent to succeed, his earnings are higher compared to the outcome where both agents are successful. Moreover, his punishment is more severe when both agents fail as compared to the case where he, alone, fails. This new wage structure is optimal because output distributions are informative about agent 2's compliance with the principal's desired actions. A single success and a single failure are more likely to occur in situations where the agent complied with the principal's wishes. A double-success and a double-failure, however, are signals for deviant behavior. Our wage scheme is therefore similar to the one suggested by Legros and Matsushima (1991), who use heterogeneity in agents' characteristics to deter free-riding in team-production.

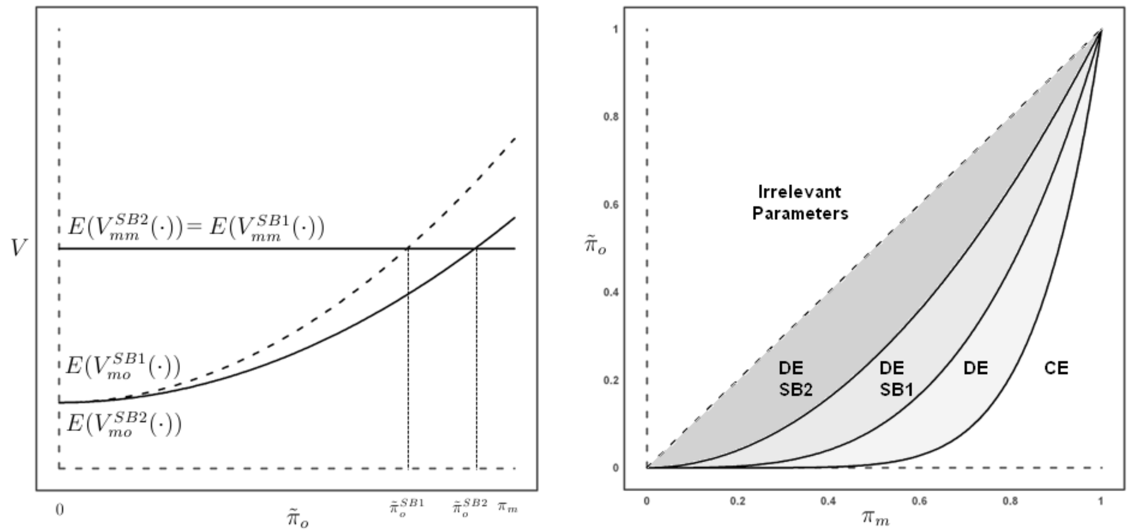

Figure 3:
a) The principals payoff under Moral Hazard I (dashed), and under Moral Hazard II (solid), when choosing concentrated efforts (mm), and diversified efforts (mo).
b) The optimal research portfolio for different parameter constellations (π_m, π_o). CE: concentrated efforts, DE: diversified efforts. In the setting Moral Hazard II, the set of parameters for which DE is optimal shrinks (DE SB2).

The incentivization of her preferred technology choice comes at a cost for the principal because of the agent's risk aversion. For both performance levels of agent 2, his respective wage also depends on the performance of agent 1. Hence, he faces a lottery in both respective cases. Agent 2 prefers pairwise sure outcomes over respective lotteries with identical expected value. Therefore, an additional risk-premium is necessary to induce any given effort level, which entails a cost for the principal.

Proposition 7. *The principal's expected payoff is lower for diversified efforts, when the technology choice is not observable:* $E(V_{mo}^{SB1}(\cdot)) > E(V_{mo}^{SB2}(\cdot))$

Proof. See Appendix.

Since diversified efforts are more costly compared to Moral Hazard I, the set of parameter constellations for which diversified efforts are optimal shrinks once more, and we define a new threshold.

Proposition 8. *For $n = 2$ with unobservable effort and unobservable technology choice ("Moral Hazard II"), $\tilde{\pi}_o^{SB2} = \frac{\pi_m \cdot (\rho(e_1^{SB2}) \cdot (2 - \rho(e_1^{SB2})) - \rho(e_1'^{SB2})) - 2 \cdot E(W_1^{SB2}) + E(W_1'^{SB2}) + E(W_2'^{SB2})}{\rho(e_2'^{SB2}) \cdot (1 - \pi_m \cdot \rho(e_1'^{SB2}))}$ determines the optimal allocation of agents, where $\tilde{\pi}_o^{SB1} < \tilde{\pi}_o^{SB2} < \pi_m$ whenever $0 < \pi_m < 1$. When $\pi_o \leq \tilde{\pi}_o^{SB2}$, concentrated efforts with technology m are optimal, otherwise diversified efforts are optimal.*

Proof. See Appendix.

Again we have a non-empty set of parameter-constellations for which it is optimal to diversify, although this set must be smaller than under "Moral Hazard I". Figure 3 illustrates Proposition 8.

4 Discussion

Our results suggest that -for the case of two researchers- the individual optimal research portfolio choice does not necessarily have to coincide with the social optimum, when asymmetric information between principal and agents is involved. First, when effort is unobservable but technology choice is observable, the adjusted optimal research portfolio shifts towards the mainstream-technology for a larger set of parameter realizations compared to the first-best solution (Moral Hazard I). Second, the wage scheme developed for Moral Hazard I, is not optimal any longer, when the principal wants to induce a multiplicity of research approaches and technology choice is also unobservable for the principal. Without modifications of the wage-structure, only the mainstream-approach would be used by both agents. The optimal wage-scheme for Moral Hazard II takes into account that an agent who is supposed to use the inferior technology has to be additionally incentivized to do so. However this adjustment of payments comes at a cost for the principal, shifting the optimal research portfolio towards mainstream research for more parameter constellations once more. Hence, the bias towards mainstream-technology becomes more pronounced in Moral Hazard II. Unlike in related models like Dasgupta and Maskin (1987) and Fershtman and Rubinstein (1997), the misdirection of research effort is completely due to the information asymmetry between principal and agents.

Admittedly our model is quite stylized, and does not cover important aspects of reality. First and foremost, the resulting bias towards mainstream research is (partly) driven by the assumptions that all players have a common prior about success probabilities, identical cost functions for both technologies, and decide simultaneously, which technology to chose. Changes in these assumptions might yield results that resolve or mitigate the resulting bias. Furthermore we exclude important aspects like economies of scale[5] or closely related technologies, where our independence assumption is violated. Furthermore one might criticize the resulting optimal wage scheme as too complicated or unrealistic.

As valid as all these points may be, our model helps to understand why research diversity is nothing that is achieved easily or follows naturally from a researcher's own interest. In fact, without well-designed incentives, a beneficial multiplicity of research approaches is not likely to occur.

5 Conclusion

We have derived optimal contracts for a setting of delegated research in which the agents' action space encompasses an effort level and the choice between two research technologies. For a single agent, the optimal second-best con-

[5]For example, success probabilities might disproportionally increase when more than one agent uses a certain technology, due to knowledge spillovers.

tract is simple and is characterized by an effort level that is higher the more promising the superior technology. Optimal technology choice follows from the agent's self-interest and does not have to be incentivized by the contract. Hence, the non-observability of effort reduces the principal's expected income, whereas the non-observability of technology choice does not.

For two agents, depending on the respective realizations of parameter values, either (i) concentrating efforts on the mainstream-technology or (ii) diversifying efforts on both technologies can be optimal. Given technological independence, the optimal second-best contract conditions on the other agent's performance level only when efforts are concentrated. Unobservable effort shifts the optimal allocation of researchers towards the mainstream-technology for a larger range of parameter values compared to the first-best solution. When the principal intends to induce diversified efforts and technology choice cannot be observed, the original second-best wage scheme fails, since employing the mainstream-technology always yields the agent a higher expected payoff. The desired choice of technology can be induced by an adjusted payoff scheme that harnesses differences in outcome distributions. The distortion due to the additional information asymmetry lowers the principal's expected payoff and leads to a further enlargement of the set of parameters for which concentrated efforts are optimal. Our model suggests that there is a socially suboptimal level of diversity in research when multiple researchers work on an identical research goal.

References

Bhattacharya, S. and D. Mookherjee (1986). Portfolio choice in research and development. *The RAND Journal of Economics 17*(4), 594–605.

Borch, K. (1962). Equilibrium in a reinsurance market. *Econometrica 30*(3), 424–444.

Dasgupta, P. and E. Maskin (1987). The simple economics of research portfolios. *Economic Journal 97*(387), 581–595.

Dasgupta, P. and J. Stiglitz (1980). Industrial structure and the nature of industrial activity. *The Economic Journal 90*(358), 266–293.

Erat, S. and V. Krishnan (2012). Managing delegated search over design spaces. *Management Science 58*(3), 606–623.

Felgenhauer, M. and E. Schulte (2014). Strategic private experimentation. *American Economic Journal: Microeconomics 6*(4), 74–105.

Fershtman, C. and A. Rubinstein (1997). A simple model of equilibrium in search procedures. *Journal of Economic Theory 72*(2), 432–441.

Frey, B. (2003). Publishing as prostitution - choosing between one's one ideas and academic success. *Public Choice 116*(1), 205–223.

Grey, C. (2010). Organizing studies: Publications, politics and polemic. *Organization Studies 31*(6), 677–694.

Holmström, B. (1979). Moral hazard and observability. *Bell Journal of Economics 10*(2), 324–340.

Holmström, B. (1982). Moral hazard in teams. *Bell Journal of Economics 13*(1), 74–91.

Ioannidis, J. (2005). Why most published research findings are false. *PLoS 2*(8), e124.

Itoh, H. (1991). Incentives to help in multi-agent situations. *Econometrica 59*(3), 611–636.

Kieser, A. (2010). Unternehmen Wissenschaft. *Leviathan 38*(3), 347–367.

Konrad, K. (2014). Search duplication in research and design spaces - Exploring the role of local competition. *International Journal of Industrial Organization 37*, 222–228.

Legros, P. and H. Matsushima (1991). Efficiency in partnerships. *Journal of Economic Theory 55*(2), 296–322.

Loury, G. (1979). Market structure and innovation. *The Quarterly Journal of Economics 93*(3), 395–410.

Merton, R. (1963). Resistance to the systematic study of multiple discoveries in science. *European Journal of Sociology 4*(2), 239–249.

Mookherjee, D. (1984). Optimal incentive schemes with many agents. *Review of Economic Studies 51*(3), 433–446.

Starbuck, W. (2005). How much better are the most prestigious journals? The statistics of academic publication. *Organization Science 16*(2), 180–200.

Stephan, P. (1996). The economics of science. *Journal of Economic Literature 34*(3), 1199–1235.

Weber, M. (1946). Chapter Science as a vocation, pp. 129–156. Oxford University Press.

Appendix A: Details to the Optimization Problems

Symmetric Information, n=1

Postponing the choice of j, we obtain the following program

$$E(V_j(\cdot)) = \max_{j,e,\underline{w},\overline{w}} \pi_j \cdot [\rho(e) \cdot (1-\overline{w}) + (1-\rho(e)) \cdot (-\underline{w})] \\ +(1-\pi_j) \cdot (-\underline{w}), \tag{P I: FB}$$

subject to

$$\pi_j \cdot [\rho(e) \cdot u(\overline{w}) + (1-\rho(e)) \cdot u(\underline{w})] + \\ (1-\pi_j) \cdot u(\underline{w}) - e \geq 0. \tag{IR I: FB}$$

We obtain the Lagrangian

$$\mathcal{L} = \begin{array}{c} \rho(e) \cdot \pi_j \cdot (1-\overline{w}) + (1-\rho(e) \cdot \pi_j) \cdot (-\underline{w}) + \\ \lambda \cdot [\rho(e) \cdot \pi_j \cdot u(\overline{w}) + (1-\rho(e) \cdot \pi_j) \cdot u(\underline{w}) - e] = 0. \end{array} \tag{23}$$

Taking the first-order-conditions yields

$$\frac{\partial \mathcal{L}}{\partial e} = \begin{array}{c} \rho'(e) \cdot \pi_j \cdot (1-\overline{w}+\underline{w}) + \\ \lambda \cdot [(\rho'(e) \cdot \pi_j \cdot (u(\overline{w}) - u(\underline{w})) - 1] = 0, \end{array} \tag{24}$$

$$\frac{\partial \mathcal{L}}{\partial \overline{w}} = \rho(e) \cdot \pi_j \cdot (-1) + \lambda \cdot [\rho(e) \cdot \pi_j \cdot u'(\overline{w})] = 0, \tag{25}$$

$$\frac{\partial \mathcal{L}}{\partial \underline{w}} = \begin{array}{c} (1-\rho(e) \cdot \pi_j) \cdot (-1) + \\ \lambda \cdot [(1-\rho(e) \cdot \pi_j) \cdot u'(\underline{w})] = 0. \end{array} \tag{26}$$

From (25) and (26) we can easily obtain the optimal co-insurance conditions and yield

$$\frac{1}{u'(\overline{w})} = \frac{1}{u'(\underline{w})} \Leftrightarrow u'(\overline{w}) = u'(\underline{w}) \Leftrightarrow \overline{w} = \underline{w}. \tag{27}$$

Plugging the uniform wage w into (24) we yield

$$\frac{1}{u'(w)} = \lambda = \frac{\rho'(e) \cdot \pi_j \cdot (1 - w + w)}{1 - \underbrace{\rho'(e) \cdot \pi_j \cdot (u(w) - u(w))}_{0}} \tag{28}$$

which can be rearranged to (6).

Asymmetric Information, n=1

We obtain the following program

$$\begin{aligned} E(V_j^{SB}(\cdot)) = \underset{j,e,\underline{w},\overline{w}}{max} \pi_j \cdot [\rho(e) \cdot (1 - \overline{w}) + (1 - \rho(e)) \cdot (-\underline{w})] \\ +(1 - \pi_j) \cdot (-\underline{w}), \end{aligned} \tag{P I: SB}$$

subject to

$$\begin{aligned} \pi_j \cdot [\rho(e) \cdot u(\overline{w}) + (1 - \rho(e)) \cdot u(\underline{w})] + \\ (1 - \pi_j) \cdot u(\underline{w}) - e \geq 0 \end{aligned} \tag{IR I: SB}$$

and

$$\begin{aligned} e_j \in argmax_{\hat{e}} \pi_j \cdot [\rho(\hat{e}) \cdot u(\overline{w}) + (1 - \rho(\hat{e})) \cdot u(\underline{w})] + \\ (1 - \pi_j) \cdot u(\underline{w}) - \hat{e}. \end{aligned} \tag{IC I: SB}$$

To solve this problem we can use the common first-order-condition approach (Holmström 1979), given our assumptions on $\rho(\cdot)$, $u(\cdot)$, and π_j. Thus, the agent's original incentive constraint is replaced by

$$\rho'(e) \cdot \pi_j \cdot [u(\overline{w}) - u(\underline{w})] = 1. \tag{29}$$

We obtain the Lagrangian

$$\begin{aligned} & \rho(e) \cdot \pi_j \cdot (1 - \overline{w}) + (1 - \rho(e) \cdot \pi_j) \cdot (-\underline{w}) + \\ \mathcal{L} = \; & \lambda \cdot [\rho(e) \cdot \pi_j \cdot u(\overline{w}) + (1 - \rho(e) \cdot \pi_j) \cdot u(\underline{w}) - e] + \\ & \mu \cdot [\rho'(e) \cdot \pi_j \cdot [u(\overline{w}) - u(\underline{w})] - 1] = 0. \end{aligned} \tag{30}$$

Taking derivatives with respect to $\overline{w}$ and $\underline{w}$ yields

$$\frac{1}{u'(\overline{w})} = \lambda + \mu \cdot \frac{\rho'(e)}{\rho(e)} \tag{31}$$

and

$$\frac{1}{u'(\underline{w})} = \lambda - \mu \cdot \frac{\rho'(e) \cdot \pi_j}{1 - \rho(e) \cdot \pi_j}. \tag{32}$$

Equations (31) and (32) imply that $\overline{w} > \underline{w}$.

Symmetric Information, n=2

Concentrated efforts:

If both agents use technology j, the principal's maximization problem is

$$E(V_{jj}(\cdot)) = \max_{e_1,e_2,j,\overline{\overline{w}}_1,\overline{\overline{w}}_2,\overline{w}_1,\overline{w}_2,\underline{w}_1,\underline{w}_2,\underline{\underline{w}}_1,\underline{\underline{w}}_2} =$$

$$\begin{aligned} \pi_j \cdot [\rho(e_1) \cdot \rho(e_2) \cdot (1 - \overline{\overline{w}}_1 - \overline{\overline{w}}_2) + \\ \rho(e_1) \cdot (1 - \rho(e_2)) \cdot (1 - \overline{w}_1 - \underline{w}_2) + \\ (1 - \rho(e_1)) \cdot \rho(e_2) \cdot (1 - \underline{w}_1 - \overline{w}_2) + \\ (1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)] + \\ (1 - \pi_j) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2). \end{aligned} \tag{P II: FB CE}$$

The problem is subject to the individual rationality constraints of the agents (here presented only for agent 1, analogously for agent 2):

$$\begin{aligned} \pi_j \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_1) + \\ \rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\overline{w}_1) + \\ (1 - \rho(e_1)) \cdot \rho(e_2) \cdot u(\underline{w}_1) + \\ (1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\ (1 - \pi_j) \cdot u(\underline{\underline{w}}_1) - e_1 \geq 0. \end{aligned} \tag{IR II: FB CE}$$

We obtain the Lagrangian

$$
\begin{aligned}
\mathcal{L} = \pi_j \cdot [\rho(e_1) \cdot \rho(e_2) \cdot (1 - \overline{\overline{w}}_1 - \overline{\overline{w}}_2) + \\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot (1 - \overline{w}_1 - \underline{w}_2) + \\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot (1 - \underline{w}_1 - \overline{w}_2) + \\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)] + \\
(1 - \pi_j) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)) + \\
\lambda_1 \cdot [\pi_j \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_1) + \\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\overline{w}_1) + \\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot u(\underline{w}_1) + \\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\
(1 - \pi_j) \cdot u(\underline{\underline{w}}_1) - e_1] + \\
\lambda_2 \cdot [\pi_j \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_2) + \\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\underline{w}_2) + \\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot u(\overline{w}_1) + \\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\
(1 - \pi_j) \cdot u(\underline{\underline{w}}_2) - e_2] = 0.
\end{aligned}
\tag{33}
$$

Taking derivatives with respect to the different wage levels for agent 1 (likewise for agent 2) yields

$$
\begin{aligned}
& \pi_j \cdot \rho(e_1) \cdot \rho(e_2) \cdot (-1) + \\
\frac{\partial \mathcal{L}}{\partial \overline{\overline{w}}_1} = \; & \lambda_1 \cdot [\pi_j \cdot \rho(e_1) \cdot \rho(e_2) \cdot u'(\overline{\overline{w}}_1)] = 0 \\
& \Leftrightarrow \frac{1}{u'(\overline{\overline{w}}_1)} = \lambda_1,
\end{aligned}
\tag{34}
$$

$$
\begin{aligned}
& \pi_j \cdot \rho(e_1) \cdot (1 - \rho(e_2)) \cdot (-1) + \\
\frac{\partial \mathcal{L}}{\partial \overline{w}_1} = \; & \lambda_1 \cdot [\pi_j \cdot \rho(e_1) \cdot (1 - \rho(e_2)) \cdot u'(\overline{w}_1)] = 0 \\
& \Leftrightarrow \frac{1}{u'(\overline{w}_1)} = \lambda_1,
\end{aligned}
\tag{35}
$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \underline{w}_1} = \quad & \pi_j \cdot (1-\rho(e_{1j})) \cdot \rho(e_2) \cdot (-1) + \\ & \lambda_1 \cdot [\pi_j \cdot (1-\rho(e_1)) \cdot \rho(e_2) \cdot u'(\underline{w}_1)] = 0 \\ & \Leftrightarrow \frac{1}{u'(\underline{w}_1)} = \lambda_1,\end{aligned} \tag{36}$$

and

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \underline{\underline{w}}_1} = \quad & \pi_j \cdot (1-\rho(e_1)) \cdot (1-\rho(e_2)) \cdot (-1) + \\ & (1-\pi_j) \cdot (-1) + \\ & \lambda_1 \cdot [\pi_j \cdot (1-\rho(e_1)) \cdot (1-\rho(e_2)) \cdot u'(\underline{\underline{w}}_1) + \\ & (1-\pi_j) \cdot u'(\underline{\underline{w}}_1)] = 0 \\ & \Leftrightarrow \frac{1}{u'(\underline{\underline{w}}_1)} = \lambda_1.\end{aligned} \tag{37}$$

From the previous four equations we obtain that

$$\begin{aligned}\frac{1}{u'(\overline{\overline{w}}_i)} = \frac{1}{u'(\overline{w}_i)} = \frac{1}{u'(\underline{w}_i)} = \frac{1}{u'(\underline{\underline{w}}_i)} \\ \Leftrightarrow \overline{\overline{w}}_i = \overline{w}_i = \underline{w}_i = \underline{\underline{w}}_i = w_i.\end{aligned} \tag{38}$$

Making use of (38), we take the derivative with respect to e_1:

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial e_1} = \quad & \pi_j \cdot (\rho'(e_1) - \rho'(e_1) \cdot \rho(e_2)) + \\ & \lambda_1 \cdot [-1] = 0 \\ & \Leftrightarrow \rho'(e_1) \cdot \pi_j \cdot (1-\rho(e_2)) = \lambda_1.\end{aligned} \tag{39}$$

The same can be done for e_2. From equations (34) to (37) and (39) one can easily obtain

$$\rho'(e_1) \cdot \pi_j \cdot (1-\rho(e_2)) = \frac{1}{u'(w_1)} \tag{40}$$

and

$$w_i = u^{-1}(e_i). \tag{41}$$

Diversified efforts:
If the agents use one technology each (agent 1 uses m and agent 2 uses o), the principal's problem becomes

$$E(V_{mo}(\cdot)) = \max_{e_1, e_2, \overline{\overline{w}}_1, \overline{\overline{w}}_2, \overline{w}_1, \overline{w}_2, \underline{w}_1, \underline{w}_2, \underline{\underline{w}}_1, \underline{\underline{w}}_2} =$$

$$\begin{aligned}
(\pi_m \cdot \pi_o) \cdot [\rho(e_1) \cdot \rho(e_2) \cdot (1 - \overline{\overline{w}}_1 - \overline{\overline{w}}_2) +& \\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot (1 - \overline{w}_1 - \underline{w}_2) +& \\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot (1 - \underline{w}_1 - \overline{w}_2) +& \\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)] +& \\
(\pi_m \cdot (1 - \pi_o)) \cdot [\rho(e_1) \cdot (1 - \overline{w}_1 - \underline{w}_2) +& \\
(1 - \rho(e_1)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)] +& \\
((1 - \pi_m) \cdot \pi_o) \cdot [\rho(e_2) \cdot (1 - \underline{w}_1 - \overline{w}_2) +& \\
(1 - \rho(e_2)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)] +& \\
((1 - \pi_m) \cdot (1 - \pi_o)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2),&
\end{aligned} \tag{P II: FB DE}$$

subject to agent 1's participation constraint (likewise for agent 2)

$$\begin{aligned}
(\pi_m \cdot \pi_o) \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_1) +& \\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\overline{w}_1) +& \\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot u(\underline{w}_1) +& \\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] +& \\
(\pi_m \cdot (1 - \pi_o)) \cdot [\rho(e_1) \cdot u(\overline{w}_1) + (1 - \rho(e_1)) \cdot u(\underline{\underline{w}}_1)] +& \\
((1 - \pi_m) \cdot \pi_o) \cdot [\rho(e_2) \cdot u(\underline{w}_1) + (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] +& \\
((1 - \pi_m) \cdot (1 - \pi_o)) \cdot u(\underline{\underline{w}}_1) - e_1 \geq 0.&
\end{aligned} \tag{IR II: FB DE}$$

We obtain the Lagrangian

$$
\begin{aligned}
\mathcal{L} = \pi_m \cdot \pi_o \cdot [\rho(e_1) \cdot \rho(e_2) \cdot (1 - \overline{\overline{w}}_1 - \overline{\overline{w}}_2) + \\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot (1 - \overline{w}_1 - \underline{w}_2) + \\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot (1 - \underline{w}_1 - \overline{w}_2) + \\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)] + \\
\pi_m \cdot (1 - \pi_o) \cdot [\rho(e_1) \cdot (1 - \overline{w}_1 - \underline{w}_2) + (1 - \rho(e_1)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)] + \\
(1 - \pi_m) \cdot \pi_o \cdot [\rho(e_2) \cdot (1 - \underline{w}_1 - \overline{w}_2) + (1 - \rho(e_2)) \cdot (-\underline{\underline{w}}_1 - \underline{\underline{w}}_2)] + \\
(1 - \pi_m) \cdot (1 - \pi_o) \cdot [-\underline{\underline{w}}_1 - \underline{\underline{w}}_2] + \\
\lambda_1 \cdot [\pi_m \cdot \pi_o \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_1) + \\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\overline{w}_1) + \\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot u(\underline{w}_1) + \\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\
\pi_m \cdot (1 - \pi_o) \cdot [\rho(e_1) \cdot u(\overline{w}_1) + (1 - \rho(e_1)) \cdot u(\underline{\underline{w}}_1)] + \\
(1 - \pi_m) \cdot \pi_o \cdot [\rho(e_2) \cdot u(\underline{w}_1) + (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\
(1 - \pi_m) \cdot (1 - \pi_o) \cdot [u(\underline{\underline{w}}_1)] - e_1] + \\
\lambda_2 \cdot [\pi_m \cdot \pi_o \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_2) + \\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\underline{w}_2) + \\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot u(\overline{w}_2) + \\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_2)] + \\
\pi_m \cdot (1 - \pi_o) \cdot [\rho(e_1) \cdot u(\underline{w}_2) + (1 - \rho(e_1)) \cdot u(\underline{\underline{w}}_2)] + \\
(1 - \pi_m) \cdot (\pi_o) \cdot [\rho(e_2) \cdot u(\overline{w}_2) + (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_2)] + \\
(1 - \pi_m) \cdot (1 - \pi_o) \cdot [u(\underline{\underline{w}}_2)] - e_2] = 0.
\end{aligned}
\tag{42}
$$

Taking derivatives with respect to the different wage levels for agent 1 yields

$$\frac{\partial \mathcal{L}}{\partial \overline{\overline{w}}_1} = \begin{aligned} \pi_m \cdot \pi_o \cdot \rho(e_1) \cdot \rho(e_2) \cdot (-1) + \\ \lambda_1 \cdot [\pi_m \cdot \pi_o \cdot \rho(e_1) \cdot \rho(e_2) \cdot u'(\overline{\overline{w}}_1)] = 0 \\ \Leftrightarrow \frac{1}{u'(\overline{\overline{w}}_1)} = \lambda_1, \end{aligned} \tag{43}$$

$$\frac{\partial \mathcal{L}}{\partial \overline{w}_1} = \begin{aligned} (\pi_m \cdot \pi_o \cdot \rho(e_1) \cdot (1 - \rho(e_2)) + \pi_m \cdot (1 - \pi_o) \cdot \rho(e_1)) \cdot (-1) + \\ \lambda_1 \cdot [(\pi_m \cdot \pi_o \cdot \rho(e_1) \cdot (1 - \rho(e_2)) + \\ \pi_m \cdot (1 - \pi_o) \cdot \rho(e_1)) \cdot u'(\overline{w}_1)] = 0 \\ \Leftrightarrow \frac{1}{u'(\overline{w}_1)} = \lambda_1, \end{aligned} \tag{44}$$

$$\frac{\partial \mathcal{L}}{\partial \underline{w}_1} = \begin{aligned} (\pi_m \cdot \pi_o \cdot (1 - \rho(e_{1r})) \cdot \rho(e_{2l}) + (1 - \pi_m) \cdot \pi_o \cdot \rho(e_{2l})) \cdot (-1) + \\ \lambda_1 \cdot [(\pi_m \cdot \pi_o \cdot (1 - \rho(e_1)) \cdot \rho(e_2) + \\ +(1 - \pi_m) \cdot \pi_o \cdot \rho(e_2)) \cdot u'(\underline{w}_1)] = 0 \\ \Leftrightarrow \frac{1}{u'(\underline{w}_1)} = \lambda_1, \end{aligned} \tag{45}$$

and

$$\frac{\partial \mathcal{L}}{\partial \underline{\underline{w}}_1} = \begin{aligned} (\pi_m \cdot \pi_o \cdot (1 - \rho(e_1)) \cdot (1 - \rho(e_2)) + \\ \pi_m \cdot (1 - \pi_o) \cdot (1 - \rho(e_1)) + \\ (1 - \pi_m) \cdot \pi_o \cdot (1 - \rho(e_2)) + \\ (1 - \pi_m) \cdot (1 - \pi_o)) \cdot (-1) + \\ \lambda_1 \cdot [(\pi_m \cdot \pi_o \cdot (1 - \rho(e_1)) \cdot (1 - \rho(e_2)) + \\ \pi_m \cdot (1 - \pi_o) \cdot (1 - \rho(e_1)) + \\ (1 - \pi_m) \cdot \pi_o \cdot (1 - \rho(e_2)) + \\ (1 - \pi_m) \cdot (1 - \pi_o)) \cdot (u'(\underline{\underline{w}}_1))] = 0 \\ \Leftrightarrow \frac{1}{u'(\underline{\underline{w}}_1)} = \lambda_1. \end{aligned} \tag{46}$$

The previous four equations are equivalent to (38). The optimal wage levels for agent 2 can be derived in a similar way.

Taking the derivative with respect to e_1 results in

$$\frac{\partial \mathcal{L}}{\partial e_1} = \begin{aligned} &\pi_m \cdot \rho'(e_1) \cdot (\pi_o \cdot (1-\rho(e_2)) + (1-\pi_o)) + \lambda_1 \cdot [-1] = 0 \\ &\Leftrightarrow \pi_m \cdot \rho'(e_1) \cdot (1 - \pi_o \cdot \rho(e_2)) = \lambda_1. \end{aligned} \tag{47}$$

From equations (43) to (46) and (47) one can easily obtain

$$\pi_m \cdot \rho'(e_1) \cdot (1 - \pi_o \cdot \rho(e_2)) = \frac{1}{u'(w_1)}. \tag{48}$$

The same can be done for e_2, which yields and

$$\pi_o \cdot \rho'(e_2) \cdot (1 - \pi_m \cdot \rho(e_1)) = \frac{1}{u'(w_2)}. \tag{49}$$

Moreover, equation (38) also holds for the case of diversified efforts.

Asymmetric Information, n=2

Concentrated Efforts, Moral Hazard I:

The incentive compatibility constraint for agent 1 (likewise for agent 2) is given as

$$\begin{aligned} e_1 \in argmax_{\hat{e}_1} \pi_m \cdot [\rho(\hat{e}_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_1) + \\ \rho(\hat{e}_1) \cdot (1-\rho(e_2)) \cdot u(\overline{w}_1) + \\ -\rho'(\hat{e}_1) \cdot \rho(e_2) \cdot u(\underline{w}_1) - \\ \rho'(\hat{e}_1) \cdot (1-\rho(e_2)) \cdot u(\underline{\underline{w}}_1)] - 1. \end{aligned} \tag{IC II: SB1 CE}$$

Therefore we add

$$\begin{aligned} \mu_i \cdot [\pi_m \cdot [\rho'(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_1) + \\ \rho'(e_1) \cdot (1-\rho(e_2)) \cdot u(\overline{w}_1) + \\ -\rho'(e_1) \cdot \rho(e_2) \cdot u(\underline{w}_1) - \\ \rho'(e_1) \cdot (1-\rho(e_2)) \cdot u(\underline{\underline{w}}_1)] - 1] \end{aligned} \tag{50}$$

to the left-hand side of the original Lagrange function (33) to obtain the updated Lagrangian. We take derivatives with respect to the different wage levels of agent 1 (likewise for agent 2):

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \overline{\overline{w}}_1} = \quad & \pi_m \cdot \rho(e_1) \cdot \rho(e_2) \cdot (-1) + \\
& \lambda_1 \cdot [\pi_m \cdot \rho(e_1) \cdot \rho(e_2) \cdot u'(\overline{\overline{w}}_1)] + \\
& \mu_1 \cdot [\pi_m \cdot \rho'(e_1) \cdot \rho(e_2) \cdot u'(\overline{\overline{w}}_1)] = 0 \\
& \Leftrightarrow \frac{1}{u'(\overline{\overline{w}}_1)} = \lambda_1 + \mu_1 \cdot \frac{\rho'(e_1)}{\rho(e_1)},
\end{aligned}
\tag{51}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \overline{w}_1} = \quad & \pi_m \cdot \rho(e_1) \cdot (1 - \rho(e_2)) \cdot (-1) + \\
& \lambda_1 \cdot [\pi_m \cdot \rho(e_1) \cdot (1 - \rho(e_2)) \cdot u'(\overline{w}_1)] + \\
& \mu_i \cdot [\pi_m \cdot \rho'(e_1) \cdot (1 - \rho(e_2)) \cdot u'(\overline{w}_1)] = 0 \\
& \Leftrightarrow \frac{1}{u'(\overline{w}_1)} = \lambda_1 + \mu_1 \cdot \frac{\rho'(e_1)}{\rho(e_1)},
\end{aligned}
\tag{52}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \underline{w}_1} = \quad & \pi_m \cdot (1 - \rho(e_1)) \cdot \rho(e_2) \cdot (-1) + \\
& \lambda_1 \cdot [\pi_m \cdot (1 - \rho(e_1)) \cdot \rho(e_2) \cdot u'(\underline{w}_1)] + \\
& \mu_1 \cdot [\pi_m \cdot (-\rho'(e_1)) \cdot \rho(e_2) \cdot u'(\underline{w}_1)] = 0 \\
& \Leftrightarrow \frac{1}{u'(\underline{w}_1)} = \lambda_1 - \mu_1 \cdot \frac{\rho'(e_1)}{1 - \rho(e_2)},
\end{aligned}
\tag{53}
$$

and

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \underline{\underline{w}}_1} = \quad & (\pi_m \cdot (1 - \rho(e_1)) \cdot (1 - \rho(e_2)) + (1 - \pi_m)) \cdot (-1) + \\
& \lambda_1 \cdot [(\pi_m \cdot (1 - \rho(e_1)) \cdot (1 - \rho(e_2)) + (1 - \pi_j)) \cdot u'(\underline{\underline{w}}_1)] + \\
& \mu_i \cdot [\pi_m \cdot (-\rho'(e_1)) \cdot (1 - \rho(e_2)) \cdot u'(\underline{\underline{w}}_1)] \\
& \Leftrightarrow \frac{1}{u'(\underline{\underline{w}}_1)} = \lambda_1 - \mu_1 \cdot \frac{\pi_m \cdot \rho'(e_1) \cdot (1 - \rho(e_2))}{\pi_m \cdot (1 - \rho(e_1)) \cdot (1 - \rho(e_2)) + (1 - \pi_m)}.
\end{aligned}
\tag{54}
$$

Diversified Efforts, Moral Hazard I:
The incentive compatibility constraint for agent 1 (likewise for agent 2) is given as

$$\begin{aligned} e_1 \in argmax_{\hat{e}_1} \pi_m \cdot \pi_o \cdot [\rho(\hat{e}_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_1) + \\ \rho(\hat{e}_1) \cdot (1 - \rho(e_2)) \cdot u(\overline{w}_1) + \\ (1 - \rho(\hat{e}_1)) \cdot \rho(e_2) \cdot u(\underline{w}_1) + \\ (1 - \rho(\hat{e}_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\ (\pi_m \cdot (1 - \pi_o) \cdot [\rho(\hat{e}_1) \cdot u(\overline{w}_1) + (1 - \rho(\hat{e}_1)) \cdot u(\underline{\underline{w}}_1)] + \\ (1 - \pi_m) \cdot \pi_o \cdot [\rho(e_2) \cdot u(\underline{w}_1) + (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\ (1 - \pi_m) \cdot (1 - \pi_o) \cdot [u(\underline{\underline{w}}_1)] - \hat{e}_1. \end{aligned} \quad \text{(IC II: SB1 DE)}$$

We add

$$\begin{aligned} \mu_i \cdot [\pi_m \cdot \pi_o \cdot [\rho'(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_1) + \\ \rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\overline{w}_1) + \\ (1 - \rho(\hat{e}_1)) \cdot \rho(e_2) \cdot u(\underline{w}_1) + \\ (1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\ (\pi_m \cdot (1 - \pi_o) \cdot [\rho(e_1) \cdot u(\overline{w}_1) + (1 - \rho(e_1)) \cdot u(\underline{\underline{w}}_1)] + \\ (1 - \pi_m) \cdot \pi_o \cdot [\rho(e_2) \cdot u(\underline{w}_1) + (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_1)] + \\ (1 - \pi_m) \cdot (1 - \pi_o) \cdot [u(\underline{\underline{w}}_1)] - e] \end{aligned} \quad (55)$$

to the left-hand side of equation (42) to obtain an updated Lagrangian. We once more take derivatives with respect to the different wage levels of agent 1 (likewise for agent 2):

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial \overline{\overline{w}}_1} = \begin{array}{r} \pi_m \cdot \pi_o \cdot \rho(e_1) \cdot \rho(e_2) \cdot (-1) + \\ \lambda_1 \cdot [\pi_m \cdot \pi_o \cdot \rho(e_1) \cdot \rho(e_2) \cdot u'(\overline{\overline{w}}_1)] + \\ \mu_1 \cdot [\pi_m \cdot \pi_o \cdot \rho'(e_1) \cdot \rho(e_2) \cdot u'(\overline{\overline{w}}_1)] = 0 \\ \Leftrightarrow \frac{1}{u'(\overline{\overline{w}}_1)} = \lambda_1 + \mu_1 \cdot \frac{\rho'(e_1)}{\rho(e_1}, \end{array} \end{aligned} \quad (56)$$

$$\frac{\partial \mathcal{L}}{\partial \overline{w}_1} = \begin{aligned}[t] &\pi_m \cdot \rho(e_1) \cdot (\pi_o \cdot (1-\rho(e_2)) + (1-\pi_o)) \cdot (-1) + \\ &\lambda_1 \cdot [\pi_m \cdot \rho(e_1) \cdot (\pi_o \cdot (1-\rho(e_2)) + (1-\pi_o)) \cdot u'(\overline{w}_1)] + \\ &\mu_1 \cdot [\pi_m \cdot \rho'(e_1) \cdot (\pi_o \cdot (1-\rho(e_2)) + (1-\pi_o)) \cdot u'(\overline{w}_1)] = 0 \\ &\Leftrightarrow \frac{1}{u'(\overline{w}_1)} = \lambda_1 + \mu_1 \cdot \frac{\rho'(e_1)}{\rho(e_1)}, \end{aligned} \tag{57}$$

$$\frac{\partial \mathcal{L}}{\partial \underline{w}_1} = \begin{aligned}[t] &(\pi_m \cdot (1-\rho(e_1)) + (1-\pi_m)) \cdot \pi_o \cdot \rho(e_2) \cdot (-1) + \\ &\lambda_1 \cdot [(\pi_m \cdot (1-\rho(e_1)) + (1-\pi_m)) \cdot \pi_o \cdot \rho(e_2) \cdot u'(\underline{w}_1)] + \\ &\mu_1 \cdot [\pi_m \cdot \pi_o \cdot (-\rho'(e_1)) \cdot \rho(e_2) \cdot u'(\underline{w}_1)] = 0 \\ &\Leftrightarrow \frac{1}{u'(\underline{w}_1)} = \lambda_1 - \mu_1 \cdot \frac{\pi_m \cdot \rho'(e_1)}{1-\pi_m \cdot \rho(e_1)}, \end{aligned} \tag{58}$$

and

$$\frac{\partial \mathcal{L}}{\partial \underline{\underline{w}}_1} = \begin{aligned}[t] &(1-\pi_m \cdot \rho(e_1)) \cdot (1-\pi_o \cdot \rho(e_2)) \cdot (-1) + \\ &\lambda_1 \cdot [(1-\pi_m \cdot \rho(e_1)) \cdot (1-\pi_o \cdot \rho(e_2)) \cdot u'(\underline{\underline{w}}_1)] + \\ &\mu_1 \cdot [\pi_m \cdot (-\rho'(e_1)) \cdot (1-\pi_o \cdot \rho(e_2)) \cdot u'(\underline{\underline{w}}_1)] = 0 \\ &\Leftrightarrow \frac{1}{u'(\underline{\underline{w}}_1)} = \lambda_1 - \mu_1 \cdot \frac{\pi_m \cdot \rho'(e_1)}{1-\pi_m \cdot \rho(e_1)}. \end{aligned} \tag{59}$$

Diversified efforts, Moral Hazard II:

The additional incentive compatibility constraint that is needed to insure agent 2's usage of the outsider-technology is

$$
\begin{aligned}
(\pi_m \cdot \pi_o) \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_2) +\\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\underline{w}_2) +\\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot u(\overline{w}_2) +\\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_2)] +\\
(\pi_m \cdot (1 - \pi_o)) \cdot [\rho(e_1) \cdot u(\underline{w}_2) + (1 - \rho(e_1)) \cdot u(\underline{\underline{w}}_2)] +\\
((1 - \pi_m) \cdot \pi_o) \cdot [\rho(e_2) \cdot u(\overline{w}_2) + (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_2)] +\\
((1 - \pi_m) \cdot (1 - \pi_o)) \cdot u(\underline{\underline{w}}_2) - e_2 \geq\\
\pi_m \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_2) +\\
\rho(e_1) \cdot (1 - \rho(e_2)) \cdot u(\underline{w}_2) +\\
(1 - \rho(e_1)) \cdot \rho(e_2) \cdot u(\overline{w}_2) +\\
(1 - \rho(e_1)) \cdot (1 - \rho(e_2)) \cdot u(\underline{\underline{w}}_2)] +\\
(1 - \pi_m) \cdot u(\underline{\underline{w}}_2) - e_2.
\end{aligned}
\tag{IC2 II: SB2 DE}
$$

Since this conditionmust hold with equality (otherwise the principal would give away utility for free), we can incorporate the former constraint into the Lagrange-function and add

We add

$$
\begin{aligned}
\nu \cdot [(\pi_m \cdot \pi_o) \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_2) +\\
\rho(e_1) \cdot (1-\rho(e_2)) \cdot u(\underline{w}_2) +\\
(1-\rho(e_1)) \cdot \rho(e_2) \cdot u(\overline{w}_2) +\\
(1-\rho(e_1)) \cdot (1-\rho(e_2)) \cdot u(\underline{\underline{w}}_2)] +\\
(\pi_m \cdot (1-\pi_o)) \cdot [\rho(e_1) \cdot u(\underline{w}_2) + (1-\rho(e_1)) \cdot u(\underline{\underline{w}}_2)] +\\
((1-\pi_m) \cdot \pi_o) \cdot [\rho(e_2) \cdot u(\overline{w}_2) + (1-\rho(e_2)) \cdot u(\underline{\underline{w}}_2)] +\\
((1-\pi_m) \cdot (1-\pi_o)) \cdot u(\underline{\underline{w}}_2) -\\
(\pi_m \cdot [\rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_2) +\\
\rho(e_1) \cdot (1-\rho(e_2)) \cdot u(\underline{w}_2) +\\
(1-\rho(e_1)) \cdot \rho(e_2) \cdot u(\overline{w}_2) +\\
(1-\rho(e_1)) \cdot (1-\rho(e_2)) \cdot u(\underline{\underline{w}}_2)] +\\
(1-\pi_m) \cdot u(\underline{\underline{w}}_2))]
\end{aligned}
\tag{60}
$$

to the left-hand side of the former Lagrange function (equations (42) and (55)) and take derivatives with respect to the different wage levels of agent 2.

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \overline{\overline{w}}_2} = \quad & \pi_m \cdot \pi_o \cdot \rho(e_1) \cdot \rho(e_2) \cdot (-1) +\\
& \lambda_2 \cdot [\pi_m \cdot \pi_o \cdot \rho(e_1) \cdot \rho(e_2) \cdot u'(\overline{\overline{w}}_2)] +\\
& \mu_2 \cdot [\pi_m \cdot \pi_o \cdot \rho(e_1) \cdot \rho'(e_2) \cdot u'(\overline{\overline{w}}_2)] +\\
& \nu \cdot [\pi_m \cdot (\pi_o - 1) \cdot \rho(e_1) \cdot \rho(e_2) \cdot u'(\overline{\overline{w}}_2)] = 0\\
& \Leftrightarrow \frac{1}{u'(\overline{\overline{w}}_2)} = \lambda_2 + \mu_2 \cdot \frac{\rho'(e_2)}{\rho(e_2)} + \nu_2 \cdot \frac{\pi_o - 1}{\pi_o},
\end{aligned}
\tag{61}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \overline{w}_2} = \quad & \pi_o \cdot \rho(e_2) \cdot (\pi_m \cdot (1 - \rho(e_1)) + (1 - \pi_m)) \cdot (-1) + \\
& \lambda_2 \cdot [\pi_o \cdot \rho(e_2) \cdot (\pi_m \cdot (1 - \rho(e_1)) + (1 - \pi_m)) \cdot u'(\overline{w}_2)] + \\
& \mu_1 \cdot [\pi_o \cdot \rho'(e_2) \cdot (\pi_m \cdot (1 - \rho(e_1)) + (1 - \pi_m)) \cdot u'(\overline{w}_2)] + \\
& \nu \cdot [\rho(e_2) \cdot (\pi_m \cdot (\rho(e_1) \cdot (1 - \pi_o) - 1) + \pi_o) \cdot u'(\overline{w}_2)] = 0 \\
\Leftrightarrow \frac{1}{u'(\overline{w}_2)} = \lambda_2 + \mu_2 \cdot \frac{\rho'(e_2)}{\rho(e_2)} + \nu_2 \cdot & \frac{\pi_m \cdot (\rho(e_1) \cdot (1 - \pi_o) - 1) + \pi_o}{\pi_o \cdot (1 - \pi_m \cdot \rho(e_1))},
\end{aligned}
\tag{62}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \underline{w}_2} = \quad & (\pi_o \cdot (1 - \rho(e_2)) + (1 - \pi_o)) \cdot \pi_m \cdot \rho(e_1) \cdot (-1) + \\
& \lambda_2 \cdot [(\pi_o \cdot (1 - \rho(e_2)) + (1 - \pi_o)) \cdot \pi_m \cdot \rho(e_1) \cdot u'(\underline{w}_2)] + \\
& \mu_1 \cdot [\pi_o \cdot \pi_m \cdot \rho(e_1) \cdot (-\rho'(e_2)) \cdot u'(\underline{w}_2)] + \\
& \nu \cdot [(1 - \pi_o) \cdot \pi_m \cdot \rho(e_1) \cdot \rho(e_2) \cdot u'(\underline{w}_2)] = 0 \\
\Leftrightarrow \frac{1}{u'(\underline{w}_2)} = \lambda_1 - \mu_1 \cdot & \frac{\pi_o \cdot \rho'(e_2)}{1 - \pi_o \cdot \rho(e_2)} + \nu_2 \cdot \frac{\rho(e_2) \cdot (1 - \pi_o)}{1 - \pi_o \cdot \rho(e_2)},
\end{aligned}
\tag{63}
$$

and

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \underline{\underline{w}}_2} = \quad & (1 - \pi_m \cdot \rho(e_1)) \cdot (1 - \pi_o \cdot \rho(e_2)) \cdot (-1) + \\
& \lambda_2 \cdot [(1 - \pi_m \cdot \rho(e_1)) \cdot (1 - \pi_o \cdot \rho(e_2)) \cdot u'(\underline{\underline{w}}_2)] + \\
& \mu_2 \cdot [\pi_m \cdot (-\rho'(e_1)) \cdot (1 - \pi_o \cdot \rho(e_2)) \cdot u'(\underline{\underline{w}}_2)] + \\
& \nu_2 \cdot [\rho(e_2) \cdot (\pi_m \cdot (1 - \rho(e_1)) \cdot (1 + \pi_o)) - \pi_o)] = 0 \\
\Leftrightarrow \frac{1}{u'(\underline{\underline{w}}_2)} = \lambda_2 - \mu_2 \cdot \frac{\pi_m \cdot \rho'(e_1)}{1 - \pi_m \cdot \rho(e_1)} + \nu_2 \cdot & \frac{\rho(e_2) \cdot (\pi_m \cdot (1 - \rho(e_1) \cdot (1 - \pi_o)) - \pi_o)}{(1 - \pi_m \cdot \rho(e_1)) \cdot (1 - \pi_o \cdot \rho(e_2))}.
\end{aligned}
\tag{64}
$$

Appendix B: Proofs

Proof of Proposition 3:
From equation (11), we obtain that optimal probabilities are given as

$$\rho(e_1) = 1 - \frac{1}{u'(w_1) \cdot \pi_j \cdot \rho'(e_2)} \tag{65}$$

and

$$\rho(e_2) = 1 - \frac{1}{u'(w_1) \cdot \pi_j \cdot \rho'(e_1)}. \tag{66}$$

Suppose $\rho(e_1) > \rho(e_2) = 0$. Equation (66) implies that $\rho(e_2) = 0$ cannot be an optimum and the left-hand side of $\rho(e_2)$ will increase. This in turn will cause $\rho'(e_2)$ to decrease, making $\rho(e_1)$ also decrease. This process continues until $\rho(e_1) = \rho(e_2) \Leftrightarrow e_1 = e_2$. □

Proof of Proposition 4
Denote with e_i and w_i, the optimal effort and wage levels for concentrated efforts, and with e_i' and w_i', the optimal effort and wage levels for diversified efforts. Condition (16) holds iff

$$\begin{aligned}(\pi_m \cdot \pi_o) \cdot (\rho(e_1') \cdot \rho(e_2') + \rho(e_1') \cdot (1 - \rho(e_2')) + (1 - \rho(e_1')) \cdot \rho(e_2'))+ \\ \pi_m \cdot (1 - \pi_o) \cdot \rho(e_1') + (1 - \pi_m) \cdot \pi_o \cdot \rho(e_2') - w_1' - w_2' > \\ \pi_m \cdot (2 \cdot \rho(e_1) - \rho(e_1)^2) - 2 \cdot w_1 \\ \Leftrightarrow \pi_o > \frac{\pi_m \cdot (\rho(e_1) \cdot (2 - \rho(e_1)) - \rho(e_1')) - 2 \cdot w_1 + w_1' + w_2'}{\rho(e_2') \cdot (1 - \pi_m \cdot \rho(e_1'))},\end{aligned} \tag{67}$$

where we use the fact that $e_1 = e_2$ and $w_1 = w_2$.

Next, we show that for $0 > \pi_m > 1$, $\tilde{\pi}_o$ is strictly larger than 0. We do so by first showing that for $\pi_o = 0$, concentrated efforts are strictly better than diversified efforts. Since $\rho(e_2') = 0$ for $\pi_o = 0$, the expected payoff for diversified efforts equals the expected payoff of a single researcher, using the mainstream-technology. From Corollary 1 we know that every expected return of a single researcher can be obtained more cheaply with two researchers both using the same technology. Hence, $\tilde{\pi}_o$ must be larger than zero.

Second, we show that for $\pi_o = \pi_m$, diversified efforts are strictly better, so that $\tilde{\pi}_o$ is strictly smaller than π_m. We plug in the optimal effort-wage-combination for concentrated efforts into $E(V_{mo}(\cdot))$ and yield

$$\begin{aligned} 1-(1-\pi_m\cdot\rho(e_1))\cdot(1-\pi_m\cdot\rho(e_1))-2\cdot w_1 >\\ \pi_m\cdot(1-(1-\rho(e_1))\cdot(1-\rho(e_1)))-2\cdot w_1\\ \Leftrightarrow \pi_m\cdot\rho(e_1)\cdot(2-\pi_m\cdot\rho(e_1)) > \pi_m\cdot\rho(e_1)\cdot(2-\rho(e_1))\\ \Leftrightarrow 1>\pi_m. \end{aligned} \tag{68}$$

Again, this condition is always satisfied, so that $\tilde{\pi}_o < \pi_m$.

Finally we show that $E(V_{mo}(\cdot))$ is strictly increasing in π_o and $E(V_{mm}(\cdot))$ is not affected by changes of π_o, which implies that a unique intersection of both payoff functions must exist.

If π_o increases, but the effort-wage-combination remains unchanged, $E(V_{mo}(\cdot))$ rises. Hence, increasing the effort when π_o rises must necessarily yield weakly higher returns than keeping the effort level constant, so that $E(V_{mo}(\cdot))$ is strictly increasing in π_o. According to equation (13), $E(V_{mm}(\cdot))$ does not depend on π_o, so that the intersection must be unique. □

Proof of Proposition 5

The existence of a unique threshold $\tilde{\pi}_o^{SB1}$ can be proven with a similar argument used to prove Proposition 4. What remains to be shown is that $\tilde{\pi}_o^{SB1} > \tilde{\pi}_o$. It is sufficient to prove that

$$E(V_{mm}^{SB1}(\cdot)) - E(V_{mo}^{SB1}(\cdot)) > E(V_{mm}(\cdot)) - E(V_{mo}(\cdot)) \tag{69}$$

$\forall\pi_o$. Let $\Delta_{SB1}(\pi_o) = E(V_{mm}^{SB1}(\cdot)) - E(V_{mo}^{SB1}(\cdot))$ denote the difference in expected payoffs between the two options for asymmetric information and let $\Delta(\pi_o) = E(V_{mm}(\cdot)) - E(V_{mo}(\cdot))$ denote the differences for symmetric information. We have $\Delta_{SB1}(0) > \Delta(0)$, because the principal gains more from employing a second agent in the case of Moral Hazard I, as it is more expensive to induce individual effort. Thus, the cost-reduction effect of reducing individual effort is more pronounced. Furthermore, it must be that $\Delta'_{SB1}(\pi_o) < \Delta'(\pi_o)$, because the principal benefits less from an increase in π_o in Moral Hazard 1, since effort invested in the outsider-technology increases less due to the higher cost of inducing effort. As a consequence we have $\tilde{\pi}_o^{SB1} > \tilde{\pi}_o$ and $\Delta_{SB1}(\tilde{\pi}_o^{SB1}) = 0$. □

Proof of Proposition 6

Since only two wage levels have to be considered (Lemma 2), agent i prefers to choose the mainstream-technology if

$$\begin{aligned} \pi_m \cdot \rho(e_i') \cdot u(\overline{w}_i') + (1 - \pi_m \cdot \rho(e_i')) \cdot u(\underline{w}_i') > \\ \pi_o \cdot \rho(e_i') \cdot u(\overline{w}_i)' + (1 - \pi_o \cdot \rho(e_i')) \cdot u(\underline{w}_i') \\ \Leftrightarrow u(\overline{w}_i') > u(\underline{w}_i'). \end{aligned} \tag{70}$$

Hence agent 2 will always deviate. □

Proof of Lemma 3

For $\overline{w}_2^{SB2} > \overline{\overline{w}}_2^{SB2}$ to be true, equations (61) and (62) imply that it is sufficient to show that

$$\begin{aligned} \frac{\pi_m \cdot (\rho(e_1) \cdot (1 - \pi_o) - 1) + \pi_o}{\pi_o \cdot (1 - \pi_m \cdot \rho(e_1))} > \frac{\pi_o - 1}{\pi_o} \\ \Leftrightarrow 0 > (\pi_o - 1) \cdot (1 - \pi_m \cdot \rho(e_1)) - (\pi_m \cdot (\rho(e_1) \cdot (1 - \pi_o) - 1) + \pi_o) \\ \Leftrightarrow 1 > \pi_m. \end{aligned} \tag{71}$$

Likewise, for $\underline{w}_2^{SB2} > \underline{\underline{w}}_2^{SB2}$ to hold, equations (63) and (64) imply

$$\begin{aligned} \frac{\rho(e_2) \cdot (1 - \pi_o)}{1 - \pi_o \cdot \rho(e_2)} > \frac{\rho(e_2) \cdot (\pi_m \cdot (1 - \rho(e_1) \cdot (1 - \pi_o)) - \pi_o)}{(1 - \pi_m \cdot \rho(e_1)) \cdot (1 - \pi_o \cdot \rho(e_2))} \\ \Leftrightarrow (1 - \pi_o) \cdot (1 - \pi_m \cdot \rho(e_1)) - (\pi_m \cdot (1 - \rho(e_1) \cdot (1 - \pi_o)) - \pi_o) > 0 \\ \Leftrightarrow 1 > \pi_m. \end{aligned} \tag{72}$$

□

Proof of Proposition 7

Since $u(\cdot)$ is concave, it is true that

$$\begin{aligned} \pi_m \cdot \pi_o \cdot \rho(e_1) \cdot \rho(e_2) \cdot u(\overline{\overline{w}}_2) + \\ \pi_m \cdot \rho(e_1) \cdot (1 - \pi_o \cdot \rho(e_2)) \cdot u(\underline{w}_2) + \\ (1 - \pi_m \cdot \rho(e_1)) \cdot \pi_o \cdot \rho(e_2)) \cdot u(\overline{w}_2) + \\ (1 - \pi_m \cdot \rho(e_1)) \cdot (1 - \pi_o \cdot \rho(e_2)) \cdot u(\underline{\underline{w}}_2) = e_2 < \\ \pi_o \cdot \rho(e_2) \cdot u(\pi_m \cdot \rho(e_1) \cdot \overline{\overline{w}}_2 + (1 - \pi_m \cdot \rho(e_1)) \cdot \overline{w}_2) + \\ (1 - \pi_o \cdot \rho(e_2)) \cdot u(\pi_m \cdot \rho(e_1) \cdot \underline{w}_2 + (1 - \pi_m \cdot \rho(e_1)) \cdot \underline{\underline{w}}_2). \end{aligned} \tag{73}$$

If $(\overline{\overline{w}}_2^{SB2}, \overline{w}_2^{SB2}, \underline{w}_2^{SB2}, \underline{\underline{w}}_2^{SB2})$ are the solutions to the principal's optimization problem under Moral Hazard II, the left-hand side of (73) equals e_2, as agent 2's participation constraint is binding. Under Moral Hazard I the principal conditions agent 2's wage only on his own success. Keeping the expected value fixed, the principal can adjust the spread between payments so that the agent is incentivized to provide the same effort. Thus she can achieve the same success probability at a lower cost. □

Proof of Proposition 8

Let e_i^{SB2} and $E(W_i^{SB2})$ denote the optimal effort and expected wage levels for concentrated efforts and let $e_i^{\prime SB2}$ and $E(w_i^{\prime SB2})$ denote the optimal effort and expected wage levels for diversified efforts when the effort level and technology choice are unobservable. Then, a revised form of condition (67) yields

$$\pi_o > \frac{\pi_m \cdot (\rho(e_1^{SB2}) \cdot (2 - \rho(e_1^{SB2})) - \rho(e_1^{\prime SB2})) - 2 \cdot E(W_1^{SB2}) + E(W_1^{\prime SB2}) + E(W_2^{\prime SB2})}{\rho(e_2^{\prime SB2}) \cdot (1 - \pi_m \cdot \rho(e_1^{\prime SB2}))}. \tag{74}$$

Proposition 7 states that $E(V_{mo}^{SB1}(\cdot)) > E(V_{mo}^{SB2}(\cdot))\ \forall \pi_o > 0$. Since $E(V_{mm}^{SB1}(\cdot)) < E(V_{mm}^{SB2}(\cdot))$, an intersection of $E(V_{mo}^{SB2}(\cdot))$ and $E(V_{mm}^{SB2}(\cdot))$ must be to the right of the intersection of $E(V_{mm}^{SB1}(\cdot))$ and $E(V_{mo}^{SB1}(\cdot))$. The existence of such an intersection is guaranteed whenever $\tilde{\pi}_o^{SB2} < \pi_m$. To show that this is true we assume $\pi_o = \pi_m$ and plug in the optimal effort-wage-combination for $E(V_{mm}^{SB2}(\cdot))$ into $E(V_{mo}^{SB2}(\cdot))$ and compare payoffs. We yield a revised form of inequality (68):

$$\begin{aligned}
1-(1-\pi_m\cdot\rho(e_1^{SB2}))\cdot(1-\pi_m\cdot\rho(e_1^{SB2}))-2\cdot E(W_1^{\prime SB2}) > \\
\pi_m\cdot(1-(1-\rho(e_1^{SB2}))\cdot(1-\rho(e_1^{SB2})))-2\cdot E(W_1^{\prime SB2}) \\
\Leftrightarrow \pi_m\cdot\rho(e_1^{SB2})\cdot(2-\pi_m\cdot\rho(e_1^{SB2})) > \pi_m\cdot\rho(e_1^{SB2})\cdot(2-\rho(e_1^{SB2})) \\
\Leftrightarrow 1 > \pi_m.
\end{aligned} \tag{75}$$

□