Communication Costs and Incentives to Acquire Soft and Hard Knowledge

Corresponding author

abennardo@unisa.it

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Adalgiso AMENDOLA, Floro Ernesto CAROLEO, Marcello D’AMATO, Cesare IMBRIANI, Pasquale PERSICO

CELPE - Centro di Ricerca Interdipartimentale di Economia del Lavoro e di Politica Economica
Università degli Studi di Salerno
Via Giovanni Paolo II, 132 - 84084 Fisciano, I- Italy
http://www.celpe.unisa.it
E-mail celpe@unisa.it
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Communication Costs and Incentives to Acquire Soft and Hard Knowledge

Antonio Abatemarco∗  Alberto Bennardo†
University of Salerno  University of Salerno

Abstract

We study a multiple tasking principal-agent model where the agent gathers soft and hard knowledge for operational purposes. Within this set-up, we model communication from the agent to the principal as the process of hardening and transmitting soft knowledge, in the spirit of Dewatripont and Tirole (2005), and we assume that soft information, once hardened, can be used by the principal as a measure of the agent contribution to production (e.g., for incentive purposes). The assumption that hard and soft knowledge are complements in the communication technology, which naturally reflects the non-depletable nature of hard knowledge, leads to the following results. Under full delegation of information gathering choices, the agent’s private incentives to gather hard information fall short of social incentives; therefore, in the second best, the principal imposes the agent to gather more hard information than he would freely do were his decision reflect market prices (e.g., under full delegation).

Keywords: hard knowledge, soft knowledge, communication, agency

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∗Department of Economics and Statistics and CELPE, University of Salerno, Via Giovanni Paolo II, 132 - 84084 - Fisciano (SA), Italy. Email: aabatemarco@unisa.it
†Department of Economics and Statistics, University of Salerno, and CSEF, University of Napoli "Federico II". Email: abennardo@unisa.it (corresponding author).
1 Introduction

Professional workers, managers, executives and white collars as well as entrepreneurs devote most of their working time to gather and exploit information and knowledge for operational purposes. Roughly, these activities can be distinguished into two subsets: acquisition of hard or explicit, transferable knowledge and information, and acquisition of specialized, soft knowledge which resides with the agent, and is difficult to express, formalize and substantiate into transferable signals. Managerial competence, technical and scientific knowledge, or rough data on the economic fundamentals of the environment in which an agent operates, are all common examples of hard information, whereas knowledge obtained by addressing specific problems through trials, learning by doing process, or, informal, not fully articulated, reasoning guided by past experience are examples of soft knowledge.

The key distinction between hard and soft knowledge, which goes back to Hayek (1945) and Polanyi (1966), reflects their codifiability, namely the extent to which knowledge can be formally expressed, classified and coded (see Garicano and Wu (2012) among others): completely soft (tacit) knowledge cannot be codified; at the other extreme, hard knowledge can be perfectly communicated by using standard codes, which are infrastructures that can be repeatedly operated once created (“communication channels” in the terminology coined by Arrow (1974)).

A large literature starting from Crawford and Sobel (1982) studies whether and how agents can transmit soft information; their approach has more recently been adopted in the organization literature (see, for instance, Dessein 2002). Nonetheless, several authors including Hayek (1945), Dewatripont and Tirole (2005), Liberti et al. (2018), Stein (2002) have stressed that most information is neither completely soft nor perfectly hard, “it is in the middle”, and, most importantly, that the degree of softness of soft knowledge is endogenous: soft information can be, at least partially, hardened, by exerting costly communication activities. For example, a formal proof of a math theorem hardens a mathematical conjecture, an information sharing system across banks hardens the knowledge on borrowers indebtedness etc.

This paper makes a step toward being more explicit in modeling the communication technology that agents’ use to harden soft information. A key feature of our analysis is that (previously gathered) hard knowledge is the main asset (infrastructure) that agents use to communicate, i.e. to harden soft knowledge. We explicitly introduce a communication technology with this property within a Principal-Agent multiple-task setting, where the effort exerted by the agent in gathering and using soft information is unobservable to the principal (due to the essential inarticulate nature of soft knowledge), whereas costly activities undertaken to acquire hard knowledge can be made verifiable by the principal, possibly at a positive cost. Within this set-up, we analyze the agent’s private incentives to acquire hard knowledge and
to communicate soft knowledge, as well as the net gains the principal can achieve by delegating (or centralizing) hard knowledge gathering choices to the agent.

Our model sheds some new lights on these organizational and contractual choices, by showing that a natural complementarity between hard and soft knowledge — which is featured by the communication technology and reflects the non-depletable nature of hard knowledge — leads to the following results. Under full delegation of information gathering choices, the agent private incentives to gather hard information fall short of social incentives; consequently, in the second best the principal imposes the agent to gather more hard information than he would freely do were his decision reflect market prices (e.g., under full delegation).

As a matter of fact, the trade-offs underlying these choices shape the organization and the contractual structures of many real life institutions. Most large companies are organized into business units, but differ in the degree of centralization of activities such as product development, accounting and finance that largely rest upon the acquisition and the use of hard knowledge. Similarly, network of firms setting contractual agreement aimed at developing scientific collaboration or information sharing infrastructures, differs in the degree of centralization of hard knowledge and information gathering activities. By the same token, a fundamental difference between standard credit contracts and venture capital credit agreements is that in contrast to banks, contracts between venture capitalists (the principals) and agents typically involve the venture capitalists centralizing important decision concerning the professionalization of the management (the acquisition by the firm of formal knowledge).

Throughout the paper, we shall postulate that hardening soft knowledge requires learning and codification activities, encompassing both the acquisition and the use of explicit knowledge. In other words, explicit knowledge is the key input — the infrastructure — that economic agents use to harden soft knowledge. This is for two reasons.

First, in order to communicate his tacit knowledge an agent needs a codified language, a set of classification protocols and conventions, as well as the formal knowledge embedded in the technology (softwares) he uses to communicate. For instance, the director of a local branch of a bank must learn how to use a grading rules for loans and borrowers (communication protocols), which are often standardized through a proprietary software, in order to pass local information about the riskiness of his clientele through the company’s hierarchy.

Second, in many real life situations the only way an agent can transmit the tacit knowledge that he has obtained through learning by doing, or through intuitive judgements based on past experience, is to acquire the cognitive ability to make “formal statements” replacing his heuristics. For this purpose, the agent needs to learn how to use formal knowledge produced
by other agents (theorems, formal logic, causal analysis etc.) to develop this knowledge by himself. For instance, the branch director of a bank or a division manager may have observed some local information (say a signal on the state of demand) that has induced him to update his prior beliefs. Then, knowledge of elementary principles of Bayesian inference enables him to communicate why and how he updated his prior distribution, and to replace somewhat confusing informal statements about his beliefs’ change. Similarly, knowing some econometrics may enable him to provide better evidence and to argue more forcefully on the existence of a causality relationships between observable variables, that he has understood through long periods of field experience.

Within our model, communication activities take place in a multiple tasking set-up where a risk-neutral principal and an agent, whose risk attitude is conventionally described by CARA preferences, interact through several stages. At the initial stage, the principal offers to the agent an exclusive contract that the latter can either accept or refuse; subsequently the agent engages in two costly activities, acquisition and use of specialized human capital (specific knowledge) and acquisition of hard knowledge, which is used subsequently to better evaluate a signal on the state of the world. In an intermediary stage, the agent observes two imperfect signals: one provides information on the true state of nature (for instance a demand or a supply shock that is realized in the final stage); the other signal, which in our setting can be naturally interpreted as an intermediary output (such as, for instance, a prototype resulting from research activity). The quality of the signal on the true state of nature depends on the amount of hard knowledge gathered by the agent, whereas the expected value of the intermediary output is increasing in the amount of specific knowledge.

The agent then uses a communication technology to transmit his information on the value of the intermediary output and on the true state of nature to the principal. The signal on the state of nature is hard information and can be perfectly transmitted, whereas the value of the intermediary output is soft information that needs to be hardened. The hardening process produces a signal whose precision is increasing both in the amount of hard and soft knowledge gathered by the agent. We assume, in the spirit of the literature on certifiable information (Milgrom 1981), that all knowledge that is hardened by the agent is truthfully communicated to the principal, whereas information that remains tacit is not contractually used in the agency relationship.

Finally, the information revealed at the intermediary stage (the signal on the state of nature and the signal on the intermediary output communicated by the agent) is used by the principal in the last stage to choose a monetary investment (for operational purposes), production is realized and the agent receives a payment contingent on the realization of the uncertainty resolved at the intermediary and at the final stage, as well as on the information he
Within this set-up, the paper addresses the following two questions. First, under which conditions is it second best optimal for the principal to let the agent “freely” choose how much hard information to acquire? Second, whenever full delegation is not constraint efficient, do second best arrangements impose the agents to gather more or less hard information than he would freely do under a contract that provides only monetary incentives?

The following assumption of complementarity between soft and hard knowledge in the communication process is imposed in characterizing the second best contract of this problem. The larger the amount of specific tacit knowledge gathered by the agent, the stronger the impact of explicit hard knowledge in reducing the noise in the transmission of information by the agent to the principal. We argue that the very essential feature of formal knowledge, which is its non depletability, generates this complementarity. An agent involved on his core production activity for along time acquires several pieces of soft information, and can use the same formal knowledge (the same “information channel” in the language of Arrow) repeatedly, in order to communicate each of these pieces. More generally, when the amount of specialized knowledge gathered on a specific problem gets larger, *ceteris paribus*, the expected value that an additional “bite” of formal knowledge yielded in the communication process gets larger because of the non depletability of formal knowledge.

Under this assumption, our analysis delivers the following results. In the second best the principal imposes the agent to acquire more hard knowledge than he would freely choose. Moreover, under the second best contract, the shadow price of hard knowledge paid by the agent is lower than the market price. Finally, we study the case in which acquisition of hard information cannot be verified, and show that, under mild convexity assumptions, it is lower than the corresponding second best level.

By acquiring more information than the amount that maximizes his expected utility — given the contractual payments — the agent reduces the variability of signals’ realizations and, hence, the variability of his consumption. This relaxes his incentive constraint with respect to soft knowledge acquisition, e.g., it makes it relatively more valuable to exert effort in that activity. In choosing hard knowledge under full delegation, the agent does not internalize the effect of his choice on this incentive constraint, and, hence, on the amount of insurance that he can obtain from the principal.

These results provide a purely incentive based rationale for why economic institutions, in the presence of endogenous communication costs limiting the transfers of soft information, centralize the functions involving the acquisition of hard information. The same findings suggest that contractual arrangements through which a venture capitalist providing funds “imposes” an entrepreneur to acquire managerial skills and professionalization. This practice can be rationalized as second best devise that the venture capitalist
(the principal) uses in order to facilitate the evaluation of the entrepreneurial activities at intermediary stages and the assessment of firms’ investment opportunities.

2 The Model

We consider a multi-task principal-agent set-up in which a risk-averse agent, after signing a contract with a risk-neutral principal, operates a two stages production technology. In the first stage, he exerts effort to use and develop his specialized knowledge (his idea, project, or specific human capital), and gathers general knowledge (managerial competence, professionalization, or technical and scientific knowledge) as production inputs. General knowledge can be also acquired by the principal through outsourcing, whereas specialized knowledge is exclusively provided by the agent.

These two types of knowledge are then used in the second stage. Specialized knowledge produces an intermediary output, whereas general knowledge provided by the agent has a double role: it allows the agent to communicate (to harden) the soft knowledge that he has gathered as well as to better interpret hard information (information on the state of nature).

In the following we describe first the production and then the communication technology.

Let \( a \in A \) and \( z_A \in Z \), with \( A \) and \( Z \) being compact sets, be the effort exerted by the agent in gathering specialized knowledge and the amount of general knowledge that he acquires in the first stage, respectively; \( a \) is assumed to generate a disutility cost \( \varphi(a) \) while \( z \) is acquired at some monetary cost \( q_A \).

The action \( a \) produces an intermediate random output \( x = h(a) + \varepsilon_x \), where \( h(\cdot) \) is a strictly concave, increasing and twice differentiable function of effort, and where \( \varepsilon_x \) is a random production shock, which is normally distributed with variance \( \sigma^2_x \).

The intermediary output \( x \) together with a monetary investment \( m \in M = [0, +\infty) \) produces a final output whose value depends on the realization of a state of nature \( \omega \in \Omega \) which is normally distributed with mean \( \mu_\omega \) and variance \( \sigma^2_\omega \). Let \( y = g(x + \omega, m) \) be the final value of the output (of second-stage production). We will assume that \( g(\cdot, \cdot) \) is strictly concave and twice differentiable in \((x + \omega)\) and \( m \), respectively.

The true state of nature \( \omega \) is unknown to both the agent and the principal at the second production stage (e.g., when \( m \) is chosen). However, at that stage, the principal can use the general knowledge acquired by the agent, \( z_A \), as well as that obtained through outsourcing, \( z_P \), to interpret a signal \( \theta \in \Theta \) of the true state where \( \Theta \) is a compact set. We assume that \( \theta \) is normally distributed with mean \( \mu_\theta \) and variance \( \sigma^2_\theta(z) \), where \( z = z_A + z_P \).
is the overall amount of general knowledge acquired by the agent $z_A$ and by the principal $z_P$: the larger the general knowledge $z$ acquired in the first stage, the lower the measurement error made by the principal.

The effort $a$ exerted in using and gathering specialized human capital is assumed to be private information of the agent and it is not contractible. In the first part of the paper, we shall assume that $z_A$ is verifiable at zero cost and contractible. Subsequently, we shall also study an alternative regime where $z_A$ is unobservable and, for this reason, the choice of $z_A$ must be fully delegated to the agent.

The signal $\theta$ is observed by the principal, whereas the intermediary output $x$ is soft information observed by the agent only. The realization of this signal can be communicated by the agent to the principal only to the extent that it is hardened by the agent. The outcome of the communication process is a signal $x_c$ whose precision depends upon both the amount of soft and hard information gathered by the agent. More specifically, the signal $x_c = h(a) + \varepsilon_c$ with $\varepsilon_c$ is a normally distributed error with zero mean and variance $\sigma^2_c(a, z_A)$.

The following two assumptions on communication are key for our analysis. First, communication skills of the agent are increasing in knowledge $z_A$, so that, for all $a \in A$ and $z_A' > z_A$, $\sigma^2_c(a, z_A') < \sigma^2_c(a, z_A)$; i.e., the signal $x_c$ received by the principal is more or less noisy depending on knowledge $z_A$ gathered by the agent.

Second, for all $z_A \in Z$ and $a', a \in A$ with $a' > a$, $\partial \sigma^2_c(a', z_A)/\partial z_A < \partial \sigma^2_c(a, z_A)/\partial z_A$, that is, the larger the amount of specific tacit knowledge gathered by the agent, the stronger the impact of explicit hard knowledge in reducing the noise in the transmission of information by the agent to the principal. It is natural to interpret $a$ as a vector of many activities giving to the agent ‘pieces’ of information to be communicated to the principal by using knowledge $z_A$ which acts as a public good, in that the use of knowledge to communicate specialized human capital does not deplete its availability for further communication.

We shall assume that contractual payments can be made contingent all on information that both the agent and the principal can observe and verify: namely $x_c$, $\theta$, $(x + \omega)$, and $y$. However, as $m$ is contractible and $(x + \omega)$ is observed by both parties, $y$ turns out to be a redundant signal.

As conventional in the literature, we shall restrict attention to linear contracts. A contract $\gamma := \{a, z_A, z_P, t, s_c, s_\theta, s_\omega\}$ then specifies a vector of actions $(a, z_A, z_P)$, a fixed payment $t$, and a vector of linear (unitary) payments $s = (s_c, s_\theta, s_\omega)$ contingent on signals $x_c, \theta, (x + \omega)$ respectively.

The agent is assumed to be risk-averse with constant absolute risk aver-
sion (CARA) with preferences represented by the Bernoulli utility

\[ U(w, a, z_A) = -e^{[-\eta(w(\gamma) - \varphi(a) - q_A z_A)]} \]  

(1)

where \( w(\gamma) = t + s_c x_c + s_\theta + s_\omega (x + \omega) \), \( \eta > 0 \) is the coefficient of absolute risk aversion, \( w \in \mathbb{R}_+ \) is the payment defined by the principal, and \( \varphi(\cdot) \) is increasing and strictly convex.

The expected utility of an agent who signs the contract \( \gamma \) and takes actions prescribed by the contract is

\[ E[U(\gamma)] = E[-e^{[-\eta(t + s_c x_c + s_\theta + s_\omega (x + \omega) + s_\omega \mu - \varphi(a) - q_A z_A)]}] \]  

(2)

Merely for simplicity, we shall assume that \( \sigma_{xc} = \sigma_{x\omega} = \sigma_{x\theta} = \sigma_{c\omega} = \sigma_{c\theta} = 0 \). Hence, the certainty equivalent of \( EU(\gamma) \) can be written as

\[ CE(\gamma) = t + h(a)(s_\theta + s_\omega) + (s_\theta + s_\omega) \mu - \varphi(a) - q_A z_A + \frac{1}{2} \eta \left( (s_c + s_\omega)^2 \sigma_x^2 + s_c^2 \sigma_c^2 + s_\omega^2 \sigma_\omega^2 + s_\theta^2 \sigma_\theta^2 + 2s_\theta s_\omega \sigma_{\theta\omega} \right) \]  

(3)

The certainty profit function of the principal is

\[ \Pi(y, w, m, z_P) = y - w - c(m) - q_P z_P \]  

(4)

where \( q_P \) is the market price of general knowledge. The principal expected profit result from a two stage maximization. In the second, last stage the money investment \( m \) is optimally chosen after observing \( x_c \) and \( \theta \). Hence, at that stage the principal chooses \( m \) by solving the following program.

\[ m^*(x_c, \theta, \gamma) = \arg \max_m E[\Pi(m) | x_c, \theta, \gamma] \]

\[ = \int_{0}^{+\infty} \int_{0}^{+\infty} \int_{-\infty}^{+\infty} \left( g(x + \omega, m) - w(\gamma) \right) f(x + \omega | x_c, \theta, \gamma) d(x + \omega) + \]  

(5)

\[ - c(m) - q_P z_P \]

s.t. \( x = h(a) + \varepsilon_x \), \( x_c = h(a) + \varepsilon_{x_c} + \varepsilon_c \)

where \( f(x + \omega | x_c, \theta, \gamma) \) is the posterior density function of \( (x + \omega) \).

Provided that the agent chooses the actions prescribed by the contract \( \gamma \), the expected profit that the principal obtains at the initial stage is then

\[ E[\Pi(\gamma)] = \int_{0}^{+\infty} \int_{0}^{+\infty} \int_{-\infty}^{+\infty} \left( g(x + \omega, m^*(x_c, \theta, \gamma) - w(\gamma) - c(m^*(x_c, \theta, \gamma)) - q_P z_P \right) \]  

(6)

\[ f(x + \omega | x_c, \theta, \gamma) f(x_c, \theta | \gamma) d(x + \omega) dx_c d\theta \]
where \( f(x_c, \theta | \gamma) \) is the joint density function associating a probability to any pair \((x_c, \theta)\) conditional on \((a, z_A, z_P)\).

In the first stage the principal solves the second best program, that is, he maximizes his expected profits under the incentive compatibility constraint, imposing that the agent acquires unobservable soft knowledge as prescribed by the contract, and the participation constraint:

\[
\begin{align*}
\max_{\gamma} & \quad E[\Pi(\gamma)] \\
\text{s.t.} & \quad a = \arg \max_a E[U(\gamma)] \quad (IC_a) \quad (7) \\
& \quad E[U(\gamma)] \geq \bar{U} \quad (PC')
\end{align*}
\]

Later on in the paper, we shall also consider an alternative regime, hereafter full-delegation analysis, where the amount of hard knowledge gathered by the agent, \(z_A\), is not observable by the principal, so that \(z_A\) acquisition decision must be necessarily fully delegated to the agent. The full delegation contract solves the following program.

\[
\begin{align*}
\max_{\gamma'} & \quad E[\Pi(\gamma')] \\
\text{s.t.} & \quad a = \arg \max_a E[U(\gamma')] \quad (IC'_a) \quad (8) \\
& \quad z_A = \arg \max_{z_A} E[U(\gamma')] \quad (IC_z) \\
& \quad E[U(\gamma')] \geq \bar{U} \quad (PC'')
\end{align*}
\]

where the condition \((IC_z)\) imposes that it is rational for the agent to acquire the amount of hard knowledge recommended by the program. In what follows, we indicate by \(\gamma^{FD} = (a^{FD}, z_A^{FD}, z_P^{FD}, t^{FD}, s^{FD})\) the solutions to the full delegation program \((8)\), whereas \(\gamma^{SB} = (a^{SB}, z_A^{SB}, z_P^{SB}, t^{SB}, s^{SB})\) are the solutions of the second best program \((7)\).

### 2.1 Second-best knowledge and decentralization

This section addresses the following two questions. First, under which conditions is it second best optimal for the principal to let the agent “freely” choose how much hard information to acquire? Second, whenever full delegation is not constraint efficient, do second best arrangements impose the agents to gather more or less hard information than he would freely do under a contract that provides only monetary incentives? Let

\[
\begin{align*}
z_A^s = \arg \max_{z_A} E[U(a^{SB}, z_A, z_P^{SB}, s^{SB})], \quad (9)
\end{align*}
\]

addressing the former of the two questions above amounts to ask whether the second best value \(z_A^{SB}\) is different from \(z_A^s\), or equivalently, whether the
agent and the principal private incentives are aligned with respect to the choice of $z_A$. Addressing the latter of the two questions above amounts to verify whether $z_A^* \geq z_{SB}^A$.

The next two propositions show that the second best incentives of the principal and the agent diverge with respect to the choice of $z_A$, implying that it would be suboptimal for the principal (at least whenever $z_A$ can be monitored at a sufficiently low cost) to delegate the choice of $z_A$ to the agent. Moreover, we will show that $z_A^* < z_{SB}^A$, which is the level of $z_A$ that the agent would prefer to gather, were he free to choose, falls short of the second best value, under the assumption that soft and hard information are complementary inputs in the communication information.

**Proposition 2.1** proves this result restricting attention to the case in which $\frac{\partial E[\Pi(\gamma_{SB})]}{\partial z_P} > 0$, which is the amount of information gathered in the second best is lower than the (first best) profit maximizing level (we shall consider the complementary case later).

**Proposition 2.1.** $z_A^{SB} > z_A^*$ if $z_A^{SB} = z_A^{SB} + z_A^P$ such that $\frac{\partial E[\Pi(\gamma_{SB})]}{\partial z_P} > 0$.

**Proof.** Consider the first-order condition of the second best program w.r.t. $z_A$

$$
\frac{dE[\Pi(\gamma_{SB})]}{dz_A} + \lambda \frac{\partial}{\partial z_A} \left( \frac{dE[U(\gamma_{SB})]}{da} \right) + \mu \frac{dE[U(\gamma_{SB})]}{dz_A} = 0 \quad (10)
$$

Note first that

$$
\frac{dE[U(\gamma_{SB})]}{da} = \frac{\partial E[U(\gamma_{SB})]}{\partial a} \frac{\partial}{\partial z_A} + \frac{\partial E[U(\gamma_{SB})]}{\partial z_A} \quad (11)
$$

Hence, by envelope logic,

$$
\frac{dE[U(\gamma_{SB})]}{dz_A} = \frac{\partial E[U(\gamma_{SB})]}{\partial z_A} \quad (12)
$$

Moreover,

$$
\frac{\partial}{\partial z_A} \left( \frac{dEU(\gamma_{SB})}{da} \right) = \frac{1}{2} \eta s^2 \frac{\partial^2 \sigma_\theta^2(a,z_A)}{\partial a \partial z_A} > 0 \quad (13)
$$

under our complementarity assumption $\left( \frac{\partial^2 \sigma_\theta^2(a,z_A)}{\partial a \partial z_A} < 0 \right)$.

Consider now the first addenda in (10), $\frac{dE[\Pi(\gamma_{SB})]}{dz_A}$. Under the assumption $\frac{\partial E[\Pi(\gamma_{SB})]}{\partial z_P} > 0$, $\frac{dE[\Pi(\gamma_{SB})]}{dz_A}$ is equal to zero. This fact is proved by contradiction. Notice first that an increase in $z_P$ does not affect the incentive constraint $\frac{\partial}{\partial z_A} \left( \frac{dE[U(\gamma_{SB})]}{da} \right) = 0$, and increases the agent’s expected utility by reducing the variability of his consumption, which is

$$
- \frac{1}{2} \eta \left( s^2 \frac{\partial^2 \sigma_\theta^2(z)}{\partial z_P^2} + 2s_\theta s_\omega \frac{\partial \sigma_\theta \omega(z)}{\partial z_P} \right) > 0 \quad (14)
$$

13
Moreover, since \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_P} > 0 \) by assumption, the principal weakly gains by increasing \( z_P \) whenever \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_A} > 0 \). Hence in the second best \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_A} = 0 \). It then follows that optimality of \( z_A \) implies \( \frac{\partial E[U(\gamma^{SB})]}{\partial z_A} < 0 \), which is equivalent to \( z^{SB} > z^* \).

The intuition for this result is as follows. First, starting from \( z_A = z_A^* \), an increase of \( z_A \) allows the agent to provide a less noisy signal of the intermediary output. This reduces the variability of the agent’s consumption and increases his utility. At \( z_A = z_A^* \), however, this effect is exactly offset by the cost of \( z \). Thus, the effect of a small increase in \( z_A \) around \( z_A^* \) on the agent utility is zero at first order. However, when \( z_A \) increases the signal of the agent’s action, \( a \), gets more precise, hence the agent’s marginal gain from increasing \( a \) gets larger, or, equivalently, the incentive constraint gets relaxed. Moreover, an increase of \( z_A \) under the condition \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_P} > 0 \) enhances the expected profit of the principal.

In summary, starting from \( z_A = z_A^* \), an increase of \( z_A \) has a second order effect on the agent’s utility, a positive effect on the principal’s expected profit, and relaxes the incentive constraint. This explains why the principal gains from imposing the agent to gather more information than he would freely do at the second best: \( z^{SB} > z^* \).

Next proposition extends the result of Proposition 2.1 to the complementary case where \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_P} \leq 0 \).

**Proposition 2.2.** \( z_A^{SB} > z_A^* \) if \( z^{SB} = z_A^{SB} + z_P^{SB} \) such that \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_P} \leq 0 \).

**Proof.** The proof proceeds by considering a few steps.

**Step 1.** In the second best \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_A} > 0 \) and \( \frac{\partial E[U(\gamma^{SB})]}{\partial z_A} > 0 \) one cannot have.

Proof. The proof is by contradiction. If \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_A} > 0 \) and \( \frac{\partial E[U(\gamma^{SB})]}{\partial z_A} > 0 \) an increase in \( z_A \) would (i) relax the incentive constraint (since \( \frac{\partial}{\partial z_A} \left( \frac{\partial E[U(\gamma^{SB})]}{\partial a} \right) > 0 \)), (ii) enhance expected profits by construction \( (\partial E[\Pi(\gamma^{SB})])/\partial z_A > 0 \), and (iii) weakly increase the expected utility, which, all-together, would contradict second-best optimality.

**Step 2.** In the second-best, it must be \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_A} \geq 0 \).

Proof. Assume, by contradiction, \( \frac{\partial E[\Pi(\gamma)]}{\partial z_A} < 0 \). Notice that \( \frac{\partial E[\Pi(\gamma)]}{\partial z_A} < \frac{\partial E[\Pi(\gamma)]}{\partial z_P} \) because the principal does not pay for the cost of \( z_A \). Then, one must necessarily have \( \frac{\partial E[\Pi(\gamma^{SB})]}{\partial z_P} < 0 \). But this implies that \( z_P^{SB} \) must necessarily equal zero to be second-best optimal. Moreover, if \( z_P^{SB} = 0 \), then \( \frac{\partial E[\Pi(\gamma)]}{\partial z_A} \geq 0 \).
Step 3. In the second best \( \frac{\partial E[U(\gamma_{SB})]}{\partial z_{A}} < 0 \).

Proof. Once more the proof goes by contradiction. Suppose \( \frac{\partial E[U(\gamma_{SB})]}{\partial z_{A}} > 0 \), then, a small increase of \( z_{SB}^{A} \) would (i) increase the expected utility of the agent by construction, (ii) relax the incentive constraint (since \( \frac{\partial}{\partial z_{A}} \left( \frac{dE[U(\gamma_{SB})]}{da} \right) > 0 \)), and (iii) weakly increase the principal’s profit (since \( \frac{\partial E[\Pi(\gamma_{SB})]}{\partial z_{A}} \geq 0 \)), meaning that, second-best optimality of \( z_{SB}^{A} \) would be contradicted.

The intuition underlying this result is similar to that behind Proposition 2.1. However, Proposition 2.2 extends the analysis to the case in which the amount of information gathered by the principal in the second best is larger or equal than the profit maximizing level. In order to prove that the result of Proposition 2.2 continues to hold true in this case we need to show, as done in Proposition 2.2, that in the second best the marginal impact of \( z_{A} \) on the expected profit is non negative.

2.2 Second-best vs full-delegation knowledge and incentives

The analysis of the previous section has been developed under the assumption of contractibility of \( z_{A} \).

In most real life situations, however, the knowledge gathered by an agent can be verified only when the competences he obtained by acquiring that knowledge can be certified by a third party at a sufficiently low cost. Moreover, the real life cost of certification depends both upon the type of knowledge required to the agent (for instance, the acquisition of scientific knowledge is, in general, easier to certify than the acquisition of knowledge on the specific environment where a firm operates) and on the truthfulness enforcement standards that prevail in the specific institutional context at stake.

For this reason, it becomes of interest, especially from a positive viewpoint, to understand whether the agent gathers more hard knowledge in the case where this knowledge is fully certifiable (e.g., in the second best) or when it is his own private information, respectively (e.g., in the full delegation program).

Next proposition shows that the agent gathers more information in the second best program than in the full delegation program.

Proposition 2.3. The second best value of hard knowledge gathered by the agent, \( z_{SB}^{A} \), is lower than the value of knowledge gathered under full delegation, \( z_{A}^{FD} \).
Proof. Given \( s' = (s^F_D, s^F_D, s^F_D, ds) \), let

\[
\gamma' = (a^{FD}, z^{FD} + dz, z^{FD} + dt, t^{FD} + dt, s')
\]

be a perturbation of the full-delegation contract. Moreover, let \( dIC_a \approx \frac{\partial E[U(\gamma')]}{\partial a} - \frac{\partial E[U(\gamma^{FD})]}{\partial a} \) and \( dU \approx E[U(\gamma')] - E[U(\gamma^{FD})] \) be the first order approximation of the difference between the value of incentive constraint and expected utility evaluated at \( \gamma' \) and \( \gamma^{FD} \) respectively. As an intermediary step we show that there exists a vector \((dz, ds, dt)\) such that \( dIC_a \approx 0 \), \( dU \approx 0, \) and \( E[\Pi(\gamma')] > E[\Pi(\gamma^{FD})] \). Specifically, we show that the above relationships are satisfied for

\[
\begin{align*}
    dt & = - \left( \left( \frac{\partial E[U(\gamma^{FD})]}{\partial s} \right) \left( \frac{1}{2} \eta s^c \sigma^2 \left( \frac{\partial^2 \sigma^2(a, z_A)}{\partial a \partial z_A} \right) \left( \frac{\partial h(a)}{\partial a} \right)^{-1} \right) + \left( \frac{\partial E[U(\gamma^{FD})]}{\partial z_A} \right) \right) dz_A \\
    ds & = - \frac{1}{2} \eta s^c \sigma^2 \left( \frac{\partial h(a)}{\partial a} \right)^{-1} dz_A
\end{align*}
\]

(15)

and for any \( dz_A > 0 \). Totally differentiating \( \frac{\partial E[U(\gamma')]}{\partial a} \) w.r.t. \((ds, dz_A)\) one obtains

\[
\frac{\partial h(a)}{\partial a} ds + \frac{1}{2} \eta s^c \sigma^2 \left( \frac{\partial^2 \sigma^2(a, z_A)}{\partial a \partial z_A} \right) dz_A = 0
\]

(16)

Hence, \((dz, ds, dt)\) satisfies \( dIC_a \approx 0 \) since \( dt \) does not appear in the incentive constraint w.r.t. \( a \). Let

\[
\chi(s, \sigma^2, \sigma^2, \sigma^2, \sigma^2) = - \frac{1}{2} \eta \left( (s_c + s_w)^2 \sigma^2 + s^2 \sigma^2(a, z_A) + s^2 \sigma^2(z) + s^2 \sigma^2 + 2s \eta s_w \sigma^2(z) \right)
\]

(17)

be the variance component in \( CE(\gamma) \). Totally differentiating \( CE(\gamma^{FD}) \) w.r.t. \((ds, dz_A)\) one obtains

\[
(h(a) + \mu_w) ds - q_A dz_A + \frac{\partial \chi(\gamma)}{\partial s} ds + \frac{\partial \chi(\gamma)}{\partial z} dz_A = 0
\]

(18)

Finally, replacing in \( E[\Pi(\gamma^{FD})] \) the values of \( dt \) and \( ds \) from (15), and then totally differentiating \( E[\Pi(\gamma^{FD})] \) w.r.t. \( dz_A \), one obtains

\[
\left( \frac{1}{2} \eta s^c \sigma^2 \left( \frac{\partial^2 \sigma^2(a, z_A)}{\partial a \partial z_A} \right) \left( \frac{\partial h(a)}{\partial a} \right)^{-1} \left( \frac{\partial \chi(\gamma)}{\partial s} \right) + \frac{\partial E[\Pi(\gamma^{FD})]}{\partial z_A} + \frac{\partial E[U(\gamma^{FD})]}{\partial z_A} \right) dz_A
\]

(19)

and one can immediately verify that this is strictly positive for \( ds, dt \) in (15) and \( dz_A > 0 \).
A continuity argument then implies that there is a contract $\gamma''$ that satisfies the participation and incentive constraint w.r.t. $a$, and yields larger expected profit to the principal than in $\gamma^{FD}$.

Now consider the following program

$$\max_{\gamma} E[\Pi(\gamma)] \quad \text{s.t.} \quad IC_\omega(\gamma) = 0; \ E[U(\gamma) = \bar{U}]; \ z_A = \bar{z}_A \quad (20)$$

Let $\hat{\Pi}(\bar{z}_A)$ be the value function associated to this program. The previous result implies that $\frac{\partial \Pi(\bar{z}_A)}{\partial z_A} |_{z_A = z^{FD} > 0}$. The reason is the following. First, $\hat{\Pi}(z^{FD}) = E[\Pi(\gamma^{FD})]$ by construction. Moreover, there is a feasible contract $\gamma''$ imposing $z_A^{FD} + d_z A$ with $d_z A > 0$ yielding a larger profit than $\gamma^{FD}$. Therefore, the value function associated to program (20) must necessarily take a larger value in $z_A^{FD} + d_z A$ than in $z_A^{FD}$. Hence, if the program in (20) has an unique local maximum than $z^{FD} < z^{SB}$. If, instead, the second-best program has several local maxima, there is at least one of them such that $z^{FD} < z^{SB}$. \[\square\]

Roughly, this proposition shows that starting from the full delegation contract, one can always find a contract that satisfies both the participation and the incentive constraint w.r.t. $a$, but not the incentive constraint w.r.t. $z_A$, and increases the expected profit of the principal. The intuition behind this result is as follows.

First, an increase in $z_A$ of size $d_z A$, by reducing the variance of agent’s consumption, would relax the incentive constraint w.r.t. $a$ (i.e. would induce the agent to choose a larger $a$). The principal can then reduce the unitary bonus $s_\omega$ by an amount $d_s_\omega$ and keep incentives to exert $a$ unchanged.

Second, the principal can also vary $t$ by $dt$ so that $(d_s_\omega, dt)$ leaves also the expected utility unchanged. Then, it becomes key to ascertain how the perturbation $(d_z A, dt, d_s_\omega)$ affects the expected profit of the principal; as a matter of fact, $d_z A$ increases the principal profit since $z_A$ has positive operation value. Moreover, as we show, the perturbation $(dt, d_s_\omega)$, that leaves the utility of the agent unaltered, increases the principal’s expected profit. This is because the marginal rates of substitution between $d_s_\omega$ and $dt$ are different for the principal and the agent. Specifically, the latter values relatively more a unitary increase in $t$ than a unitary increase in $s_\omega$, as $s_\omega$ also increases the variability of the consumption.

3 Related Literature

Dewatripont and Tirole (2005), Liberti and Petersen (2018) and Stein (2002) all take the view that the degree of soft information and knowledge is endogenous and depends on costly activities made by the parties in a contractual
relationship. For simplicity, in this paper we focus on costly activities undertaken by the agent and assume that the principal’s knowledge is exogenous. Our analysis hinges on the assumption that in order to make transferable (harden) his soft knowledge, the agent needs to perform costly activities that involve the production and/or the use of hard knowledge.

The seminal article by Holmstrom and Milgrom (1991) provides the technology to investigate incentive issues within a multiple tasking environment. Within this framework a large literature emphasizes the “substitution effect” between costly efforts exerted in different activities. This effect arises because those efforts are seen as homogeneous, depletable inputs. In our paper, we develop a variant of the multi-task model by Holmstrom Milgrom — which is extended by introducing a communication technology between the principal and the agent — in order focus on the case of professional and entrepreneurial activities. Within our set-up, the main inputs supplied by the agent in production are not homogenous effort, but soft and hard knowledge and information. The non depletability of these inputs generates a strategic complementarity in the communication function, which turns out to be the main ingredient of our analysis.

The second best literature on optimal non monetary payments and the public economics literature on incentives (Atkinson and Stiglitz 1976, Benard et al. 2013, Fabbri and Menichini 2010, 2016, Greenwald and Stiglitz 1986, Marino and Zábojník 2008, Rajan and Wulf 2006) has shown that it may be optimal from a second best perspective to induce the agent to over-consume (under-consume) goods or production factors which reduce the marginal disutility of effort or increase the marginal productivity of effort. In this paper we show that the complementarity between soft and hard knowledge in communication, which is due to the non-depletability of the latter, implies that the second best contract imposes the agent to overproduce hard knowledge.

Holmstrom and Milgrom (1991), Rajan and Zingales (1998), and Holmstrom (1999) argue that a firm can regulate (limit) access to some key assets in order to provide better incentives to agents. Within our set-up, the principal “regulates” access to hard knowledge by imposing the agent to acquire more knowledge than he would freely do: extra access is imposed, instead of being forbidden. Our paper is also related with the organization literature focusing on delegation and integration (centralization) decisions within firms (Aghion and Tirole 1997, Dessein 2002, Dessein et al. 2010, Friebel and Raith 2010 among others).\footnote{There also exists a literature starting with the seminal contributions by Marshack and Radner (1972) on optimal teams that studies optimal communication mechanisms within teams. This literature, however abstracts from incentive issues.} In most of those papers, however, monetary incentives are muted by assumption, information resides on the agent (e.g. cannot be hardened) and “exogenous” technological motives (for instance,
gains from specialization) imply that full delegation may not be efficient in the second best. In our paper, contracts are complete and monetary incentives are therefore optimally used, soft information can be hardened, albeit at a cost, and finally, whether delegation is constrained efficient only depends on an incentive trade-off.

From an empirical perspective, the literature on the role of venture capital (Da Rin et al. 2013, Hellman and Puri 2002a, 2002b, Kaplan and Stromberg 2001) shows that venture capitalists provide professionalization and business competence to the firms they fund. Consistently with our results, venture capitalists get decision power within the firms they fund and use this decision power to “impose” the acquisition of those competencies (knowledge). This is broadly in line with the results of our model, once the venture capital and the firm, are seen, as suggested by Kaplan and Stromberg (2001), as the parties of Principal-Agent relationship.

Finally, there exists a relatively large literature investigating agents’ incentives to acquire information before contracting (Bergmann and Välimäki 2003, Crémer et al. 1998, Dasgupta and Stiglitz 1980, Hirshleifer 1971). A result common to most of that literature is that agents acquire “too much” information with respect to the second best, due to a negative information externality. In this paper, we obtain the opposite result: in the presence of full delegation, an agent acquire less information than the second best level.

4 Concluding remarks

A recent strands of papers in the literature on contracts and institutions has investigated whether incentives to gather and communicate information can shape organizational and contractual forms that are commonly observed in the real world.

In this paper, we contribute to this literature by studying a multiple tasking model where a communication technology is introduced that harden and transmit soft information from the agent to the principal. Within this set-up we show that the second best contract entails over acquisition of hard knowledge by the agent, and is precluded by full delegation.

A few simplifying assumptions are introduced to obtain this result in a stark form. In particular, we postulate that acquisition of hard and soft knowledge are the only productive activities undertaken by the agent, and that hard knowledge is the only input of the communication technology. We also assume that only hard information can be communicated to the principal.

In a companion paper (Abatemarco and Bennardo 2019b) we extend the analysis of this paper by considering bilateral communication, and we also derive a few comparative statics results.

We see the results of this paper as a very initial step toward a better
understanding of some important issues concerning the process of hardening soft knowledge and its integration with the analysis of incentives performed within standard principal agent models.
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