

Regulating Trade Among Agents*

by

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1. Introduction

Our purpose is to analyze how a principal would optimally want to regulate the amount and nature of side-trade between his agents – an aspect of the general problem of constructing incentives in a multi-agent organization. By side-trade we mean implicit or explicit exchanges between the agents which the principal cannot control directly, because he cannot observe them. Such side-trades are typically labeled by their social or organizational merits. We speak of collusion when private trades harm the organization and cooperation when they help. Evidently, the labels are intended to invoke the substantial powers of social norms to limit undesirable behavior or encourage desirable behavior.

Notice that very similar trades can be labeled as “cooperation” or “collusion” depending on the context and the intent of the trade. We will attempt to identify in this paper the factors that determine the desirability of agent side-trade in a given situation. What circumstances distinguish cooperation from collusion? And how should the principal regulate the degree of cooperation to limit collusion?

We will analyze these questions in a rather special but quite tractable agency model (HOLMSTRÖM and MILGROM [1987]). In this model optimal sharing rules are linear, which permits us to expand our inquiry into richer organizational territory than is typical. Most importantly, we are able to consider agents that are engaged in multiple tasks. We will find this feature central: it is in large part substitution among activities that will determine the cost of letting agents trade with each other. Substitution will prevent the principal from creating highly varying incentives for the agent's activities, even when such variation in incentives would be desirable for risk sharing purposes. If performance in different tasks is observed with different accuracy, the principal would ideally like to balance risk and incentives separately for each task. The main trade-off is between keeping incentives in balance and minimizing risk exposure.

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The model is described in the next section. Section 3 studies the principal's incentive problem when agents do not cooperate. This is a rich and interesting problem of its own. We will only highlight its main features, since an extensive discussion is contained in a companion paper (HOLMSTRÖM and MILGROM [1989]). Section 4 considers the case of unrestricted side-transfers between agents. This corresponds to the original approach to collusion in TIROLE [1986].¹ We show first that in order for collusion to be of value, agents must share some private information or else side-contracting merely adds constraints to the principal's problem (see also VARIAN [1990]). The simplest case of private information occurs when agents can monitor each others' actions without error and hence cooperatively decide on them. We find that such monitoring paired with unrestricted trade will make the agents behave like a syndicate, that is, they will behave like a single agent, whose risk tolerance is the sum of the risk tolerances of the individual agents. Thus agent monitoring allows the principal to reduce risk without lessening incentives (see also ITOH [1988]). The drawback of collusion is that agents can engage in arbitrage across performance measures, which may make it harder for the principal to control individual behavior. Also, arbitrage prevents the use of relative performance evaluation, which can be quite costly when competition provides accurate information about the circumstances of the performance (see also ARON [1988], and RAMAKRISHNAN and THAKOR [1988]).

Section 5, finally, discusses a principal-supervisor-agent model in the tradition of TIROLE [1986]. The main purpose is to show that restrictions on trade between the supervisor and the agent can be quite valuable. In particular, it will be desirable to ban private monetary transfers between the two and have the supervisor compensate the agent with the principal's money instead. This way, the principal can better control the extent of side-trade between the supervisor and the agent (some of which is desirable, of course) and make better use of his monitoring services.

2. A Model

Our model has a principal P and two agents, labeled A and B. Each agent can engage in several activities, providing inputs into each. For notational convenience we restrict the number of inputs to (at most) two per agent. Let $a = (a_1, a_2)$ be the input vector chosen by agent A and $b = (b_1, b_2)$ the input vector chosen by agent B. Each component of these vectors is a real number. For instance, a_j may denote the time agent A spends on activity j .

The agents bear the cost of supplying inputs. The cost function for agent A is denoted $C^A(a_1, a_2)$ and for agent B, $C^B(b_1, b_2)$; both are assumed strictly

¹ Several other papers have considered side-contracting. See for instance BROWN and WOLFSTETTER [1989], LAFFONT [1988], ITOH [1988] and, in a slightly different context, CREMER and RIORDAN [1987].

convex, but they need not be everywhere increasing nor positive.² Partial derivatives of these cost functions will be indicated by subscripts.

Neither the costs incurred by the agents nor the input levels chosen by them can be directly observed. Instead, what is observed is a set of performance indicators. For illustrative purposes, we will assume there are only two performance indicators. These are assumed to take the specific form:

$$(1) \quad x_i = f_i(a_i, b_i) + \varepsilon_i, \quad i = 1, 2.$$

We interpret x_i as profit from activity i (before wage payments), measured with error ε_i . The error terms are assumed to have a multivariate normal distribution with mean zero and covariance matrix Σ ; (the variance of ε_i is σ_i^2 , the covariance is σ_{12} and the correlation coefficient is $\rho = \sigma_{12}/\sigma_1\sigma_2$). The expected return function $f_i(a_i, b_i)$ is assumed concave in the inputs. Aggregate profits, $x_1 + x_2$, accrue to the principal.³

We will often impose further structure on the technology (1). We will say that production is *technologically separable* if $f_i(a_i, b_i) = f_i^A(a_i) + f_i^B(b_i)$, for $i = 1, 2$, and that it is *technologically independent* if $f_1(a_1, b_1) = f^A(a_1)$ and $f_2(a_2, b_2) = f^B(b_2)$. In a separable technology, inputs do not interact. In an independent technology, each agent affects only his own performance measure. We may also assume that the technology is *stochastically independent*, that is the error terms are independent.

The principal can pay each agent as a function of both performance measures (thus, we assume that both agents can observe the pair (x_1, x_2)). We will restrict these rewards to be *linear* functions. In general such a restriction would be inappropriate, since it is well known that optimal rewards often are non-linear. However, we can appeal to our earlier results on environments where the agent controls the drift rate of a stochastic vector process of performance indicators and can condition his current actions on the observation of the current position of that process. We showed that the optimal solution of such a model coincides with the optimal solution of a reduced form model in which the agent is restricted to pick a constant action and the principal is constrained to pick a linear compensation function. The present restriction to linear compensation functions is justified by the assumption that we are describing the reduced form of such a dynamic model.⁴

² It is a common misunderstanding that agency theory depends on agents disliking work. They could very well like work, but not without limit. As long as effort is productive, efficient contracts will induce an agent to work at a level where marginal cost of effort is constant or increasing, so the decreasing part of the cost curve is rather irrelevant.

³ This information and production structure is much more special than we need to assume. The number of inputs and performance measures can be arbitrary as can the inputs into the production function. The principal's expected profit can be any concave function of the agents' inputs (no particular error distribution need to be specified for profits). The only essential restrictions are that errors enter additively and have a multivariate normal distribution. See HOLMSTRÖM and MILGROM [1989].

⁴ The reader is referred to HOLMSTRÖM and MILGROM [1987], [1989] for further details.

Given this linearity, the reward functions for agent A and B are:

$$R_A(x; \alpha) = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2; \quad R_B(x; \beta) = \beta_0 + \beta_1 x_1 + \beta_2 x_2.$$

Here α_0 and β_0 are the fixed components of compensation and α_i and β_i the incentive shares of profit from activity i . We write $\alpha = (\alpha_0, \alpha_1, \alpha_2)$ and $\beta = (\beta_0, \beta_1, \beta_2)$.

We assume that an agent's preference ordering over monetary lotteries can be represented by an exponential utility function. In addition, we assume that input costs are monetary, or have a monetary equivalent that does not depend on the agent's wealth. Given a linear reward function and measurement errors that are normally distributed, one can then express the agent's preferences in certain equivalent terms. As is well-known, agent A 's certain equivalent given R_A and input choices a, b is:

$$(2) \quad CE_A(a, b; \alpha) = \alpha_0 + \Sigma \alpha_i f_i(a_i, b_i) - C^A(a_1, a_2) - (1/2) r_A [\alpha^T \Sigma \alpha].$$

The certain equivalent for agent B is analogous. In expression (2), r_A is agent A 's coefficient of absolute risk aversion, and

$$(3) \quad \alpha^T \Sigma \alpha = \alpha_1^2 \sigma_1^2 + \alpha_2^2 \sigma_2^2 + 2 \alpha_1 \alpha_2 \sigma_{12},$$

the variance of his compensation, that is, his exposure to risk.

The principal is assumed risk neutral. His certain equivalent net of payments to the agents is:

$$(4) \quad CE_P(a, b; \alpha, \beta) = \Sigma (1 - \alpha_i - \beta_i) f_i(a_i, b_i) - \alpha_0 - \beta_0.$$

We are interested in the principal's problem of designing contracts for the agents under varying assumptions about agent collusion/cooperation. In lieu of a full-fledged repeated game model of tacit collusion, we follow TIROLE [1986] in modelling cooperation as side-contracting between the agents. We will consider three cases: *no side-contracting* (no cooperation), *unregulated side-contracting* (full cooperation) and *regulated side-contracting* (restricted cooperation). We proceed to define the principal's program in each of these cases.

No side-contracting: In this case, agents are assumed to choose their inputs independently of each other and so that the choices form a Nash equilibrium. The principal's optimal program can be stated as:

$$(5a) \quad \text{Maximize } CE_P(a, b; \alpha, \beta), \text{ subject to}$$

$$(5b) \quad CE_A(a, b; \alpha) \geq CE_A(a', b; \alpha), \quad \text{for every } a',$$

$$CE_B(a, b; \beta) \geq CE_B(a, b'; \beta), \quad \text{for every } b',$$

$$(5c) \quad CE_A(a, b; \alpha) \geq 0,$$

$$CE_B(a, b; \beta) \geq 0.$$

As is standard, we view the principal's problem as one of choosing instructions for the agents (a and b) as well as incentive schemes (α and β), subject to the

constraint that the agents wish to follow the specified instructions (5b). In addition, the principal must assure some minimum level of utility for the agents, which we have normalized to zero (5c). In view of (4), with utility specified in certain equivalent terms, this is a model with *transferable utility*. That is, regardless of the other terms of the contract, it is possible to take a dollar of utility from one agent and transfer it to the other agent or to the principal just by transferring a physical dollar. As is well known, when there is transferable utility, any efficient contract must maximize the sum of the individual utilities or what we shall call the *joint surplus*:

$$(5d) \quad CE_P(a, b; \alpha, \beta) + CE_A(a, b; \alpha) + CE_B(a, b; \beta).$$

The joint surplus is independent of the constants α_0 and β_0 , which serve to distribute the surplus among the participants to trace out the full efficient frontier. The solution to problem (5a-c) is therefore determined by maximizing (5d) subject to (5b), and then determining α_0 and β_0 so that (5c) holds. This is the approach to maximization that we will follow.

Unregulated side-contracting: Agents are assumed able to cooperate with each other by writing (binding) side-contracts contingent on their actions. Importantly, side-payments in money can be made. The most general side-contract we consider takes the following form: agent A promises to pay agent B the amount $T(a, b, x)$ if actions a and b are taken and performance is $x = (x_1, x_2)$. However, as we will show, one can restrict attention to the simpler contract form $T(a, b)$, in which payments are not contingent on performance. This means that cooperation amounts to choosing a triplet (a, b, t) , where $t = T(a, b)$. We assume that this triplet is chosen so that it is Pareto optimal from the agents' perspective, given the incentive schemes provided by the principal. In other words, the principal first announces the incentive schemes and then the agents decide what cooperative input pair to provide and what side-payment agent A should make to B . This gives the following program for the principal:

$$(6a) \quad \text{Maximize } CE_P(a, b; \alpha, \beta) + CE_A(a, b; \alpha) + CE_B(a, b; \beta),$$

subject to the subprogram:

$$(6b) \quad (a, b, t) \text{ maximizes } CE_A(a', b'; \alpha) - t', \text{ subject to}$$

$$(6c) \quad CE_B(a', b'; \beta) + t' \geq \bar{B}$$

where \bar{B} is the level of bargaining utility attributed to B in the agreement between the agents. The subprogram (6b-c) says that (a, b, t) is Pareto optimal for the agents. However, because there is transferable utility between the agents, we can replace that constraint by one which specifies that the agents maximize the sum of their utilities:

$$(6d) \quad (a, b) \text{ maximizes } CE_A(a', b'; \alpha) + CE_B(a', b'; \beta).$$

The transfer payment has disappeared, because it determines only the distribution of benefits among the agents and affects neither the utility of the principal nor the joint surplus under the contract.

Regulated side-contracting: There are many ways in which the principal may be able to regulate cooperation. If the principal can observe side-payments but not effort levels, then one simple possibility is that the principal can tax the side-payments. Letting the tax rate be τ , the principal's program can then be stated as:

$$(7a) \quad \text{Maximize } CE_P(a, b; \alpha, \beta) + CE_A(a, b; \alpha) + CE_B(a, b; \beta),$$

subject to the subprogram:

$$(7b) \quad (a, b, t) \text{ maximizes } CE_A(a', b'; \alpha) - (1 + \tau)t', \text{ subject to}$$

$$(7c) \quad CE_B(a', b'; \beta) + t' \geq \bar{B}.$$

The only difference between this program and program (6) is the coefficient $1 + \tau$ in the objective function (7b), due to the fact that the principal will receive τt if the agents transfer an amount t . In this case, utility is no longer freely transferable between the two agents. If we restrict attention to side-contracts that call for a transfer from B to A , then the model again displays transferable utility if B 's utility is measured by CE_B and A 's by $(1 - \tau)CE_A$, so an efficient contract that lies in this class must maximize $CE_B + (1 - \tau)CE_A$. (Note that \bar{B} still does not affect the welfare weights.)

3. No Side-contracting

Multi-agent models have commonly assumed that agents act non-cooperatively, that is without side-contracting. In most of those models, agents also are assumed to control a single input. The case of multiple inputs in conjunction with multiple performance measures raises many interesting new issues. We discuss them in greater depth in our companion paper (HOLMSTRÖM and MILGROM [1989]). Here we only wish to highlight some of the major points and provide a basis for a comparison to side-contracting.

We can write the principal's program (5) in the form:

$$(8a) \quad \text{Maximize } f_1(a_1, b_1) + f_2(a_2, b_2) - C^A(a_1, a_2) - C^B(b_1, b_2) \\ - (1/2)r_A\alpha^T\Sigma\alpha - (1/2)r_B\beta^T\Sigma\beta,$$

subject to:

$$(8b) \quad \alpha_i \partial f_i / \partial a_i - \partial C^A / \partial a_i = 0, \quad \text{for } i = 1, 2.$$

$$(8c) \quad \beta_i \partial f_i / \partial b_i - \partial C^B / \partial b_i = 0, \quad \text{for } i = 1, 2.$$

The objective function is the joint surplus (5d) written out. The constraints are the first-order conditions on the agents' choices of inputs. These are necessary as well as sufficient conditions, since the agents' certain equivalents are strictly concave in the inputs. It is easy enough to characterize the solution to this general program, but it will be more illuminating to single out some special cases. We will focus on four particular aspects: conditions under which the contracts for the agents will be independent of each other, the role of relative performance evaluation, the need to balance incentives for the two activities, and situations in which one of the two activities will be provided no incentives at all.

Proposition 1: Suppose production is technologically separable. Then the optimal incentive scheme for agent A will be independent of the optimal incentive scheme for agent B and conversely (except for the constants α_0 and β_0). Suppose in addition that production is technologically and stochastically independent. Then, agent A 's payment will be independent of what B does and conversely.

Proof: The first assumption implies that program (8) becomes separable, and therefore the designs will be independent, except possibly for the constant payments α_0 and β_0 . The second pair of assumptions imply that risk as well as private costs will be minimized by setting $\alpha_2 = \beta_1 = 0$. Q.E.D.

To illustrate the proposition, and also to show what the solution to the basic single agent case is, consider the simplest separable technology:

$$(9) \quad x_1 = a_1 + b_1 + \varepsilon_1, \quad x_2 \equiv 0,$$

with associated cost functions $C^A(a_1, a_2) = C_A(a_1)$ and $C^B(b_1, b_2) = C_B(b_1)$. Solving program (8) under these assumptions yields the following characterization for (a, α) :

$$(10a) \quad 1 - \alpha_1 = \alpha_1 r_A \sigma_1^2 C_A''$$

$$(10b) \quad \alpha_1 = C_A.$$

A similar pair of equations characterizes the optimal scheme for agent B .

Evidently, agent A 's contract does not depend on B 's contract, except for the constant term α_0 , which will adjust to the choice of b , since what agent A gets paid is influenced by B . Note that joint production does not raise any concerns of free-riding in this separable case, since the principal can fully remove the externality by breaking the budget balancing condition (cf. HOLMSTRÖM [1982]).

The solution in (10) is quite intuitive. Equation (10a) says that the incentive coefficient for the agent will be set below marginal product by an amount that depends positively on the agent's risk aversion, the degree of measurement error (σ_1^2) and the agent's "controllability" of supply (C_A'').

Relative performance evaluation: It is well known that if errors are correlated, incentive costs can be reduced by comparing agents with each other (see e.g. HOLMSTRÖM [1982]). Consider the following technologically independent case, with the cost functions as above:

$$(11a) \quad x_1 = a_1 + \varepsilon_1,$$

$$(11b) \quad x_2 = b_2 + \varepsilon_2.$$

The optimal incentive structure for agent A will be:

$$(12a) \quad 1 - \alpha_1 = \alpha_1 r_A \sigma_1^2 (1 - \rho^2) C_A'',$$

$$(12b) \quad \alpha_2 = -\alpha_1 \rho \sigma_1 / \sigma_2.$$

Notice that since α_2 does not affect incentives, its optimal value (12b) is simply set to minimize the agent's exposure to risk (expression (3)) given α_1 . With correlated error terms ($\rho \neq 0$) some of the risk imposed on A via ε_1 can be filtered out using the information about ε_2 that B's performance provides. Positive correlation implies a negative weight on B's performance and conversely. If errors are perfectly correlated, all randomness can be filtered out and α_1 can be set equal to marginal product. This achieves full efficiency.

We will return to this example in our discussion of the costs of side-contracting.

Balanced incentives: When an agent controls more than one input, the issue arises how to balance the incentives for the different inputs. For instance, LAZEAR [1989] has observed that if an agent can engage in individual work as well as team work, the value of relative performance evaluation is diminished, because it allocates effort away from team work (assuming that error terms are positively correlated). Often the cost of lost team effort will be greater than the benefits of risk reduction.

Let us consider the simplest allocation problem of this kind. Production is given by:

$$(13a) \quad x_1 = a_1,$$

$$(13b) \quad x_2 = a_2 + b_2 + \varepsilon_2.$$

The interpretation is that agent A can allocate his time to improve his own performance (x_1) or to improve group performance (x_2). Individual performance is monitored perfectly, while group performance is monitored with error. Assume for the moment that it is desirable to induce agent A to engage in both activities. It is not difficult then to show (from (8)) that the coefficients in A's optimal incentive scheme should be set to satisfy:⁵

⁵ From Proposition 1 we know that A's and B's incentives will be designed independently of each other. B's design is going to be given by (10) with the requisite letter and subscript substitutions.

$$(14a) \quad 1 - \alpha_1 = \alpha_2 r_A \sigma_2^2 C_{12}^A,$$

$$(14b) \quad 1 - \alpha_2 = \alpha_2 r_A \sigma_2^2 C_{22}^A.$$

The most striking feature of this solution is that despite perfect observability, incentives for individual performance will not be set in the first best way, unless there is technological separability ($C_{12}^A = 0$). Instead, if inputs are substitutes ($C_{12}^A > 0$) input a_1 will be curtailed relative to first-best ($\alpha_1 < 1$).⁶ The logic is important. In setting the incentive for a_1 , the principal must consider the effect this has on the cost of providing incentives for a_2 . Raising the coefficient for individual incentives raises the cost of providing incentives for group performance. This indirect cost is given by the expression on the right hand side of (14a).

The insight here can also be expressed as follows: an alternative way to induce performance in the team activity is to lower its opportunity cost by lowering the incentives on individual performance. Moreover, the harder it is to measure team performance, the more important this alternative becomes. How strong the cross-effect is depends of course on the substitutability of the two inputs. If we divide (14a) by (14b), we are left with the expression: $(1 - \alpha_1) / (1 - \alpha_2) = C_{12}^A / C_{22}^A$. If the two inputs are perfect substitutes (so that cost is a function of the sum of the inputs), the right-hand side of this expression equals unity, implying that $\alpha_1 = \alpha_2$; now there is no opportunity for the principal to let incentives reflect differing measurement errors. Since the opportunity to side-contract will make inputs more substitutable, the costs associated with keeping incentives in balance will increase under agent cooperation.

It has been somewhat of a mystery to organizational observers, why there is so much less reliance on high-powered incentives than basic agency theory would suggest. Our analysis of multiple activities suggests an explanation based on the need to keep allocation of effort in check. We may often observe low-powered incentives in situations that would seem well suited for high-powered incentives (activities easy to measure), simply because important concurrent activities are difficult to measure.⁷

Missing incentives: The externalities mentioned above may often dictate that the agent be provided no incentives at all to undertake an activity, even if the marginal product of that activity exceeds the (direct) marginal cost. For instance, in the preceding example, it is readily seen from (14) that α_1 may be set equal to zero, even though $C_1^A(a_1, a_2) < 1$, because when one factors in the

⁶ GREENWALD and STIGLITZ [1986], among others, have noted the role of incentive externalities in markets. For instance, it is desirable to subsidize fire extinguishers in conjunction with fire insurance.

⁷ WILLIAMSON [1985, 144] makes the same point when arguing that low-powered incentives are likely to attend integration: "Owners will recognize the asset dissipation hazards,..." because contributions to asset value presumably are harder to measure upon integration. For further discussion see HOLMSTRÖM and MILGROM [1989].

opportunity cost of raising α_1 (the right-hand-side of (14 a)), individual work no longer is cost-effective. (By contrast, α_2 will always be positive, since it does not exert any externality on the incentive provision for the first activity.) Thus, one can often expect marginal activities to be excluded, in order to improve the incentives for more important activities. In HOLMSTRÖM and MILGROM [1989] we show that the agent's flexibility will be more restricted the harder it is to evaluate his performance in central activities. This suggests a rudimentary theory of bureaucracy based on the difficulty of measuring performance in large organizations.

The general point of this discussion is that with multiple tasks, there is a conflict between efficient allocation of effort and efficient sharing of risk. The principal would like to set the incentives for individual activities so that they correspond to the varying measurement precisions, but he cannot do so without considering the effects on effort allocation. One advantage of having two agents is that the principal can allocate tasks across the agents so that the tension between risk sharing and incentives can be alleviated. The principal will have the two agents specialize in the level of risk so that one takes charge of all tasks which are relatively easy to measure. (See HOLMSTRÖM and MILGROM [1989] and MINAHAN [1988].) When agents side-contract, this opportunity is lost.

4. Unrestricted Side-contracting

We turn to the optimal design of incentives when agents can cooperate with each other by writing side-contracts. The extent of cooperation, in this view, will depend on what the agents jointly observe, since that determines the form of their side-contract. A general formulation would allow the agents to observe imperfect indicators of their actions as in (1). However, we will restrict attention to three specific information structures: (a) agents observe the same information (x) as the principal; (b) agents observe each others' actions (a and b); and the hybrid case (c), where agents observe both x and (a, b). In the first case, a side contract specifies that agent A pays agent B the amount $T(x)$ if the realized performance is x . In the second and third cases, the transfer payments are $T(a, b)$ and $T(a, b, x)$ respectively.

No private information: Suppose we are in situation (a) above. The principal has offered the agents contracts $R_A(x; \alpha)$ and $R_B(x; \beta)$ and, conditional on these contracts, the agents write an optimal side-contract $T(x)$. This means that there is no other side-contract $T'(x)$ which the agents would find mutually more desirable. Now, suppose the principal instead were to offer the agents the alternative contracts: $R'_A(x; \alpha) = R_A(x; \alpha) - T(x)$ and $R'_B(x; \beta) = R_B(x; \beta) + T(x)$. Since this puts the agents in the same position as they were in the initial scenario (after side-contracting), by revealed preference, the agents will be satisfied not to side-contract under the new scheme. Consequently, the set of

feasible contracts available to the principal is at least as large in the case agents cannot side-contract at all. This proves:

Proposition 2: If the agents only observe public information (i.e. the performance vector x), side-contracting is at best useless.⁸

The point of this simple observation (also found in VARIAN [1990]) is that in order for agent side-contracting to be of value it is necessary that the agents share some information that the principal cannot observe. Otherwise, side-trade will merely add constraints to the principal's program.

Equivalence of information structures (b) and (c): Suppose agents can write side-contracts of the form $T(a, b, x)$. We want to show that this is equivalent to writing side-contracts of the form $T(a, b)$. So assume the agents have the richer option initially. Again we can show that an optimal side-contract is linear, and hence of the form:

$$T(a, b, x) = \sum_i \gamma_i x_i + t(a, b).$$

In this contract, the agents reallocate risk (re-insure) via $\gamma = (\gamma_1, \gamma_2)$ and enforce actions via $t(a, b)$. An optimal side-contract $T(a, b, x)$ for the agents will choose (a, b, t, γ) to:

$$(15a) \quad \text{Maximize } \sum_i (\alpha_i + \beta_i) f_i(a_i, b_i) - C^A(a_1, a_2) - C^B(b_1, b_2) \\ - (1/2) r_A (\alpha - \gamma)^T \Sigma (\alpha - \gamma) - (1/2) r_B (\beta + \gamma)^T \Sigma (\beta + \gamma),$$

subject to:

$$(15b) \quad a \text{ maximizes } \sum_i (\alpha_i - \gamma_i) f_i(a_i, b_i) - C^A(a') - t(a', b),$$

$$(15c) \quad b \text{ maximizes } \sum_i (\beta_i + \gamma_i) f_i(a_i, b_i) - C^B(b') + t(a, b').$$

Constraints (15b) and (15c) assure that (a, b) will be a Nash equilibrium.

Considering the agents' behavior as described by (15), the principal will choose individual contracts so that (a, b, α, β) :

$$(16) \quad \text{Maximizes } \sum_i f_i(a_i, b_i) - C^A(a_1, a_2) - C^B(b_1, b_2) \\ - (1/2) r_A (\alpha - \gamma)^T \Sigma (\alpha - \gamma) - (1/2) r_B (\beta + \gamma)^T \Sigma (\beta + \gamma),$$

subject to:

$$(a, b, \gamma) \text{ is an optimal solution to (15).}$$

The following proposition reveals a very convenient feature of our model formulation. It shows that the principal can deal with the two agents in program (16) as if they were a single syndicate-agent; cf. WILSON [1968].

⁸ As the proof indicates, the conclusion of Proposition 2 in no way relies on our particular model structure.

Proposition 3: If agents can directly contract on actions, that is, can write side-contracts of the form $T(a, b)$, the following are true:

(i) The principal's optimal contract will be the same as when the agents can write side-contracts of the form $T(a, b, x)$.

(ii) The principal's optimal design coincides with that for a *single* agent, who is (a) assigned the tasks of both agents, (b) whose cost function is the sum of the two agents' cost functions: $C(a, b) = C^A(a) + C^B(b)$, and (c) whose utility function is exponential with risk tolerance $v = v_A + v_B$ (risk tolerance is defined as $v_i = 1/r_i$, $i = A, B$).

Proof: We prove (i) first. From (15a), by inspection, the agents' optimal choice of (a, b) depends on $(\alpha + \beta)$ but not on γ , and hence is the same in both the $T(a, b)$ and $T(a, b, x)$ regimes. [The constraints (15b) and (15c) are never binding, because the agents can use a (budget-balancing) forcing contract in their own relationship.] The risk premium term in (15a) (and in the joint surplus maximization problem) is at least as low in the $T(a, b, x)$ regime as in the $T(a, b)$ regime, so we need only prove that the principal can reproduce the same risk premium term in the $T(a, b)$ regime with fixed $\alpha + \beta$. So fix α and β according to some optimal contract for $T(a, b, x)$ and consider the response if the principal were to offer instead the incentive coefficients $\hat{\alpha}_i = \alpha_i - \gamma_i$ and $\hat{\beta}_i = \beta_i + \gamma_i$. Then, by inspection, the optimal choice for the agents would set $\hat{\gamma}_i = 0$, and this would also be an optimal contract. Since this is a feasible contract in the $T(a, b)$ regime, part (i) is proved.

Part (ii) follows from the results of WILSON [1968]. Since γ has no effect on incentives, the agents will choose γ to minimize the cost of risk (given α and β). At the optimal value of γ , the agents' preferences (the objective in (15a)) will coincide with the preferences of the single agent described in part (ii). Q.E.D.

It seems more reasonable to assume that agents can cooperate on actions than to assume that they are able to write full-fledged re-insurance contracts (recall that we have in mind that agreements are enforced implicitly rather than explicitly). On the other hand, if the agents were able to re-insure each other, one might have guessed that this would be quite costly to the principal; as we saw earlier, re-insurance is harmful for the principal if the agents only can observe (x_1, x_2) (Proposition 2). It is rather surprising therefore, that once the agents are able to contract directly on actions, re-insurance becomes inconsequential. It shows that arbitrage in actions rather than arbitrage in state-contingent claims is responsible for the additional constraints that side-contracting imposes on the principal in our particular model.

If one of the agents is a supervisor, Proposition 3 gives a sufficient condition for when the principal may pay the supervisor to contract independently with the agent. The Proposition shows that the supervisor's only role in that case is to share risk.

Value of cooperation: the independent case. That side-contracting can be studied as the problem of motivating a single syndicate-agent, greatly simplifies the analysis. It immediately reveals one reason why cooperation can be of value: as a syndicate, agents can tolerate more risk.⁹

Proposition 4: Assume production is stochastically and technologically independent. Then unrestricted side-trade is always preferred to no side-trade.

Proof: By Proposition 1 we know that agents will act independently of each other in an optimal design without side-transfers. If the principal offers the same contract to a syndicate, as he offers two independent agents, the agents will choose the same actions but the cost of risk bearing will be lower. Q.E.D.

Stressing the risk sharing advantage may be a bit misleading in that it hides what really sets the stage for an increase in value, namely the agents' ability to monitor each other. When agents can monitor each other, aggregate rather than individual incentives count. Thus, even when a given risk is divided between two agents, there is no dilution in incentives.

Proposition 4 suggests that the potential drawback of cooperation has to do with either correlated error terms, or interactions in the production function. We consider each in turn.

Cooperation vs. competition: When measurement errors are correlated, one can reduce risk by using relative performance evaluation. What can one say about the relative merits of risk sharing (side-contracting) vs. relative performance evaluation (no side-contracting)? Assuming that performance measures are technologically independent, the comparison is straightforward.

Go back to the example described by (11). Under no side-contracting, α_1 and β_2 will determine the agents' actions; α_2 and β_1 will merely serve to reduce the agents' risk exposure. The risk minimizing value for α_2 is given in (12b). A similar expression holds for β_1 . Substitute the risk minimizing values for α_2 and β_1 into the expression for total risk cost (see (3)); a similar expression applies to B). The result is:

$$(17) \quad (1/2)r_A[\alpha_1^2\sigma_1^2(1 - \rho^2)] + (1/2)r_B[\beta_2^2\sigma_2^2(1 - \rho^2)].$$

This represents the total risk cost that the agents have to bear if the incentives are α_1 and β_2 .

Next, consider the situation under side-contracting. Let γ_1 and γ_2 be the incentive coefficients chosen by the principal for the syndicate (note that the principal now has only two degrees of freedom instead of four). From Proposition 3 follows that in order to implement the same actions under side-con-

⁹ Results similar to Proposition 4 have been previously proved by RAMAKRISHNAN and THAKOR [1986], KIDRON [1986] and TROH [1988].

tracting as under no side-contracting, the principal must set $\gamma_1 = \alpha_1$ and $\gamma_2 = \beta_2$. This results in a total risk cost of:

$$(18) \quad (1/2)r[\alpha_1^2\sigma_1^2 + \beta_2^2\sigma_2^2 + 2\alpha_1\beta_2\rho\sigma_1\sigma_2].$$

where r is the risk aversion coefficient of the syndicate ($1/r = 1/r_A + 1/r_B$).

The relative cost of implementing a given set of actions in either regime is revealed by comparing (17) and (18). For instance, if expression (17) is larger than expression (18) for the optimal choice of α_1 and β_2 under no side-contracting, then the minimum cost of implementing that optimum is smaller under side-contracting; hence this regime is preferred. By inspection, we see that neither regime dominates uniformly. For $\rho = 0$, (18) is smaller; this is the same result as in Proposition 4. When $\rho = 1$, (17) is zero. Notice also that the cost in (17) is decreasing in ρ , whereas the cost in (18) is increasing in ρ . By revealed preference (or the envelope theorem), we can therefore conclude:¹⁰

Proposition 5: Assume that performance measures are technologically independent. Then there is a cut-off value $\bar{\rho} > 0$ for the correlation coefficient of the error terms, such that unrestricted side-trade is preferred to no side-trade if and only if $\rho < \bar{\rho}$.

In a highly stylized fashion, this proposition points to an important trade-off between competition and cooperation. The choice is between two alternative systems for monitoring agents. Competition provides relative performance information, which in our model is information about the circumstances in which agents perform their duties. Cooperation provides information about agents' actions by utilizing the monitoring capacity of fellow agents. The higher the correlation, the stronger is the information from competition.

An essential feature of our model is that the principal cannot selectively intervene in the form of cooperation between the agents. He cannot encourage agents to compete along some dimensions and cooperate along others. This is the force of Proposition 4 upon assuming that all actions are jointly observed. A richer model of cooperation would be desirable for a better understanding of the levers with which the principal is able to effect cooperation or competition. Clearly, one significant variable is organizational structure, which impacts the amount of information that the agents share. RAMAKRISHNAN and THAKOR [1988] argue that competition will require that agents locate in separate firms, while cooperation will require that they are in the same firm. This is a reasonable first hypothesis, but clearly extreme: there is plenty of cooperation across firms as well as competition within firms.

Proposition 5 is closely related to a result in ARON [1988], regarding the benefits of merger. Like us, she finds a cut-off value for the correlation coefficient

¹⁰ RAMAKRISHNAN and THAKOR [1986] conclude that there will be a cut-off value that determines a preference for integration. Their model is different, but the basic logic appears to be the same.

coefficient (equal $1/2$ in her particular case) such that if ρ is below it, merger is preferred. Her model, which is much richer than ours in many respects, is less articulate in its assumption about how performance information changes when firms merge. In particular, agent monitoring plays no role. One can view our result as rationalizing her informational specification.

The cost of arbitrage: Proposition 5 focuses on differences in risk bearing and the cost of lost hedging opportunities when agents cooperate. Another problem with cooperation is that, since it gives agents wider substitution possibilities, it weakens the principal's ability to control what they do. We will look at two particular examples of this. The first one shows that there are benefits from risk specialization, which are lost when agents cooperate.

Suppose the technology is:

$$(19a) \quad x_1 = a_1 + \varepsilon_1,$$

$$(19b) \quad x_2 = f_2(a_2 + b_2).$$

Let $C^A(a_1, a_2) = C_A(a_1 + a_2)$, and $C^B(b_1, b_2) = C^B(b_2)$ and assume that $C'_A(0) = C'_B(0) = 0$. Furthermore, assume $f'_2(0) < 1$ and $f'_2(b^*) > 0$, where b^* is the efficient level of b_2 given that a_2 is zero. Evidently, agent A should choose $a_2 = 0$, in order not to waste his effort on a less productive activity. If agents are kept separate, the principal will discourage agent A from engaging in the second activity by setting $\alpha_1 > 0$, $\alpha_2 = 0$, $\beta_1 = 0$ and $\beta_2 = 1$. However, when agents are allowed to transact with each other, this arrangement will induce agent A to allocate effort to the second activity provided $\alpha_1 < f'_2(b^*)$. It is easy to see that opening the second activity for agent A in this way may cost the principal more than he gains from improved risk sharing. The rationale is the same as we gave for missing incentives in section 3: under some circumstances it is better not to encourage the syndicate to engage in activity 2, even though marginal benefit exceeds (direct) marginal cost. By assuming that agent B is sufficiently risk averse, the gains from risk sharing can be made as small as we like. The result follows, since from a production point of view it obviously is better to have agent B work on activity 2 than to be idle.

Larger collusion costs are likely to be incurred in settings where one agent costlessly makes decisions that impact the welfare of another agent. The following example illustrates this point:

$$(20a) \quad x_1 = a_1 + f(b_1),$$

$$(20b) \quad x_2 = -b_2 + \varepsilon_2.$$

Let $C^A(a_1, a_2) = C_A(a_1)$ and let the private cost of b_2 be zero (say, b_2 is an input paid with "company money").¹¹ If agents are kept separate, there is a first-best

¹¹ Note that b_2 enters each performance measure.

solution: set $\alpha_1 = 1$, $\alpha_2 = 0$ and $\beta_1 = \beta_2 = 0$. If agents are allowed to "cooperate", one has to prevent them from overexpending on input b_2 . To do so, the principal has to set $\beta_2 > 0$. Since this will incur risk costs, side-trade is not desirable.

The example illustrates the point that it may often be cheaper to control incentives by transferring some decisions to a disinterested party who bears no costs nor receives direct benefits from what is decided provided that collusion can be prevented. Decisions on investment funds (as in HOLMSTRÖM and RICART COSTA [1986]) or on salaries (as in MILGROM AND ROBERTS [1988]) are examples that come readily to mind.

5. Regulated Side-contracting

As the examples above indicate, the cost of cooperation/collusion is that it invites arbitrage, which may undermine the effectiveness of any incentives the principal may try to provide. An extreme case of arbitrage occurs if one agent is a supervisor reporting on another agent's performance, and the two can transfer money between themselves. With private monetary transfers, the supervisor will be tempted to collude with the supervisee (as in TIROLE [1986]), reporting the highest possible performance.

In such a case, the principal is better off if he can limit or control the trade between the agents. The simplest control instrument is to restrict the dimensions in which the agents can trade, for example by prohibiting cash transfers or limiting the supervisor's authority to reward the agent or by assigning activities that benefit the supervisor to other agents. In many cases, regulating trade may be the only instrument available to the principal since, as we said earlier, it is unlikely that the principal can selectively instruct the agents to cooperate on some actions and not to cooperate on others.

To represent these ideas formally, consider a simple model with a principal, a supervisor and an agent. Our purpose is to demonstrate the value of forbidding the supervisor and the agent to exchange money between themselves, at least privately. As well, we will demonstrate that other forms of trade can be beneficial even if they compromise the supervisor's role as an impartial evaluator of agent performance. Thus, shutting down all side-trade may not be desirable.

Let the production technology be $x = e + \varepsilon$, with output x the sum of the agent's effort e and a measurement error ε . (To avoid subscripts, our notation departs slightly from the earlier sections.) We assume that the supervisor and the principal can observe x , while the agent cannot; this is to simplify contracting and make our point in the starkest terms. Now, contracting contingent on profit is only possible between the principal and the supervisor.

For simplicity, we will also assume that the supervisor can observe the agent's choice of effort e . The supervisor reimburses the agent for his efforts using the

principal's money (or equivalently, the principal can observe payments made to the agent). Let t denote the payment to the agent. In addition the agent can provide the supervisor some private services or goods (flattery, help, friendship, etc.). Let z be the amount. We normalize z so that it is expressed in units of benefit to the supervisor. The agent's private cost of delivering z to the supervisor is $D(z)$. Note that if $D(z) = z$, then z is equivalent to money. The agent's private cost of effort is $C(e)$.

Let $R_S(x, t)$ be the contractual compensation the principal offers the supervisor and $t(e, z)$ the payment the supervisor will make the agent (on behalf of the principal). Note that the latter contract is non-stochastic given perfect observability of its two arguments. The principal and the agent do not contract, since they do not observe any common contingencies.

Again, the optimal contract for the supervisor can be assumed linear. We write it in the form: $R_S(x, t) = \omega + \alpha x - \tau t + t$. The last term represents a reimbursement for wages paid to the agent. Given (α, τ) , the supervising agent will choose (e, z) to:

$$(21a) \quad \text{Maximize } \alpha e + z - \tau t,$$

subject to

$$(21b) \quad t \geq C(e) + D(z).$$

The first order-conditions for this program are:

$$(22a) \quad C'(e) = \alpha/\tau,$$

$$(22b) \quad D'(z) = 1/\tau.$$

The principal's program then is to choose (α, τ) so that it:

$$(23) \quad \text{Maximizes } e + z - C(e) - D(z) - (r_S/2)\alpha^2\sigma^2,$$

subject to (22).

As usual, optimal incentives are determined by maximizing joint surplus subject to the relevant incentive constraints.

Notice that rather than having the principal use the instruments α and τ , we could have him choose α and \bar{t} , where \bar{t} is a maximum allowable wage. The equivalence follows because there is no uncertainty about equilibrium wage payments. In this alternative version, τ would be the shadow price of the wage restriction.

The first thing to observe is that by setting $\alpha = \tau$, the principal can implement the first-best level of effort e . In this case the principal pays the supervisor as a function of profit $(x - t)$ rather than as a function of wage and revenue separately. This is equivalent to letting the supervisor contract with the agent independently (i.e. unregulated side-contracting as studied in the previous section). Setting $\alpha = \tau$ will induce excess side-trade, however, since the supervisor

receives the full benefits from z , but he only pays αz . To strike a better balance, we can expect τ to be set above α .

It is straightforward to solve program (23). One way of characterizing the solution is through the following equations in the three unknowns α , e , z :

$$(24a) \quad \alpha = (1 - r_S \alpha^2 \sigma^2 \eta_C) / (1 + r_S \alpha^2 \sigma^2 \eta_D),$$

$$(24b) \quad C'(e) = 1 - r_S \alpha^2 \sigma^2 \eta_C,$$

$$(24c) \quad D'(z) = 1 + r_S \alpha^2 \sigma^2 \eta_D,$$

where $\eta_C = C''/C'$ and $\eta_D = D''/D'$ are measures of the curvature of the agent's cost functions. Note that (24a) is just the ratio of the two last equations, and follows from $C'/D' = \alpha$ by (22).

Suppose $\eta_D = 0$ so that z is equivalent to money. Then $D'(z) = 1$ and therefore $\tau = 1$. As expected, the supervisor must be made fully responsible for wage payments in order to prevent pure arbitrage. In this case, (24a-b) simply reduces to the optimal single-agent solution discussed at the beginning of the paper.

In the general case $\eta_D > 0$, (24) implies that $C' > 1$ and $D' < 1$; thus effort will be below its efficient level and side-trade will be above its efficient level. Also, $\alpha < \tau < 1$, so the principal will place a surcharge on wage payments; he will not merely make the supervisor responsible for profits. When we view the principal's instruments as α and the wage ceiling \bar{w} , this result says that the principal will want to constrain the supervisor's freedom to pay wages.

Proposition 6: Suppose the supervisor is risk averse ($r_S > 0$), profits are uncertain ($\sigma^2 > 0$), and the cost of private trade is non-linear ($\eta_D \gg 0$). Then the principal is strictly better off by not allowing the agent and the supervisor to use money as a medium of payment in their private trade. Furthermore, it will be optimal to constrain the amount of wages that the supervisor is allowed to pay the agent or equivalently, to place a surcharge on the payment of wages ($\tau > \alpha$). The optimal solution will feature excessive side-trade ($D'(z) > 1$) and insufficient effort ($C'(e) < 1$).

Proof: Setting $\alpha = \tau$ is equivalent to letting the supervisor use money to pay for the agent's private services. This is suboptimal by (24). Q.E.D.

Evidently, the principal can gain considerably by restricting the supervisor's and the agent's freedom. For instance, if the cost function D is L-shaped, the principal can achieve the first-best by setting $\alpha = 0$. As this extreme case shows, some forms of trading between the supervisor and the agent should typically be allowed. Note that the principal will get his share of a socially beneficial trade between the agent and the supervisor by reducing the supervisor's wage. In effect, the agent's services pay part of the supervisor's compensation. Indeed,

a more cooperative and pleasant work environment is a substitute for higher wages.

The second part of the proposition, that wages will be constrained, accords with observed practice: wage restrictions are a rule in virtually all firms. Even top executives are limited in what they can pay their employees, lest shareholders bring suit against them (which happens on occasion).

Proposition 7: As variability of measured profits increases ($\sigma^2 \uparrow$) or the supervisor becomes more risk averse ($r_S \uparrow$), it will be optimal to set a lower commission ($\alpha \downarrow$). In the new solution, the agent works less ($e \downarrow$) and trades more with the supervisor ($z \uparrow$).

Proof: From (24). Q.E.D.

The proposition suggests that one can expect more collusion in organizations in which performance can be measured less accurately. One interpretation is that since increased uncertainty makes it more expensive to pay the supervisor via a share in profits, the other alternative, to pay him by way of agent services, has become relatively cheaper.

It is clear that if the supervisor also happens to be the residual claimant (say because he is risk neutral), concerns about bribing or other forms of collusion will not arise. Collusion in this case will simply represent efficient trade. Conversely, one might guess that the less the supervisor shares in profit, say because of increased uncertainty, the less his payroll budget should be. However, this is not necessarily true for the following reason.

In setting a wage restriction, the principal provides the supervising agent with a budget that he can spend either on buying private services or on buying (expected) output. With a larger budget, more will be bought of both goods. Thus, one way the principal can get the agent to spend more effort is to give the supervisor a more generous payroll budget. Suppose now that α is smaller, say because of increased uncertainty (Proposition 7). Keeping the payroll budget (\bar{w}) constant, the principal will buy more private services and less output, because the price of output (α) has gone down. Given this initial response, should the payroll budget be reduced or increased? The answer is ambiguous. It depends on the shape of the Engel curves of the supervisor's purchases as well as on the iso-wealth curves of the objective function in (23). We have examples of both situations, but not a convenient set of assumptions that delineates the case of payroll restriction from the case of payroll expansion.

We should stress that our previous work (HOLMSTRÖM and MILGROM [1989]) shows that if the principal can directly restrict private activities, he will do so in response to weaker performance measurement. Thus, if the principal could directly restrict trade in z , he would want to do so in response to a lower α . However, in the present model, the principal cannot restrict z without also restricting e and this leads to an ambiguity.

6. Concluding Remarks

The problem of regulating agent trade within a firm is closely related to the problem of regulating market trade through subsidies and taxes. Indeed, agency costs give rise to externalities both within firms and across firms. Our analysis is analytically similar to the literature on market externalities. In particular, GREENWALD and STIGLITZ [1986] discuss the importance of affecting incentives by subsidizing or taxing all activities of a firm rather than just the one in which performance is desired.

What the literature on market regulation often overlooks is that there always is a potential alternative to government intervention: private regulation of trade. This is underscored by our perspective. We have not said anything about how the government and the firms should divide the task of controlling incentives, though eventually we hope our line of analysis will have bearing on this fundamental issue.

Summary

Using a linear incentive model, the paper assesses the benefits and costs of agent side-contracting. Side-contracts enable agents to cooperate more effectively, provided they share information the principal does not have. Cooperation is useful when there is a need to coordinate decisions. Also, it enables the principal to rely on group incentives in which agents monitor each other. However, cooperation makes activities more substitutable and introduces arbitrage opportunities that are costly. Ideally, the principal would like to encourage cooperation in some dimensions and competition in others. It is shown that restricting monetary side-payments can be effective in achieving a balance.

Zusammenfassung

Im Rahmen eines linearen Anreizmodells werden in diesem Artikel Nutzen und Kosten untersucht, die einem Prinzipal entstehen, wenn die Agenten untereinander bindende Verträge schließen können. Solche Abmachungen erlauben den Agenten eine effektivere Zusammenarbeit, wenn sie über Informationen verfügen, die der Prinzipal nicht hat. Kooperation ist aus der Sicht des Prinzipals nützlich, falls Entscheidungen koordiniert werden müssen. Darüber hinaus erlaubt sie es dem Prinzipal, sich auf kollektive Anreizmechanismen zu beschränken, bei denen sich die Agenten gegenseitig kontrollieren. Gleichzeitig erhöht Kooperation jedoch die Substituierbarkeit der Aktivitäten der Agenten und ermöglicht Arbitrage auf Kosten des Prinzipals. Im Idealfall würde sich der Prinzipal in einigen Dimensionen des Aufgabenbereiches Kooperation und in anderen Wettbewerb der Agenten wünschen. Es wird gezeigt, daß eine Beschränkung monetärer Seitenzahlungen ein effektives Mittel zur Erzielung eines Ausgleichs sein kann.

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