

Team Production, Sequential Investments and Stochastic Payoffs

by

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Summary

We investigate a team production problem in which two parties invest sequentially to generate a joint surplus. In this framework, it is possible to attain the first best even if the investment return is highly uncertain. The optimal contract entails a basic dichotomy: it is a simple option contract if investments of both parties are substitutive, and a linear incentive contract if they are complementary. These schemes can be interpreted in terms of asset ownership: for the case of substitutive investments, a conditional ownership structure is optimal while for complementary investments shared equity in combination with a bonus component renders efficiency feasible. In either case, the parties renegotiate the initial arrangement after the first party invested.

Keywords: Team Production, Sequential Investments.

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1 Introduction

This paper studies a team production problem where two parties sequentially invest into an asset whose value is realized subsequently. We allow for a stochastic environment where uncertainty is resolved at any arbitrary date in the game, and show that efficient investments can generically be implemented. The optimal type of contract - and, more basically, the informational requirements - crucially depend on whether investments are substitutive or complementary on the margin. If they are substitutive, a simple option-to-buy contract leads both parties to invest efficiently. Under this contract, the second agent is assigned the right to buy the asset at a prespecified option price after the first agent invested, and a first best is attained even if the final payoff (the asset value) is not verifiable.

Conversely, if the investments of both parties have a complementary effect on the return, a verifiable asset value is required to facilitate an efficient outcome of the relationship.¹ Assuming verifiability, we demonstrate that a simple linear incentive contract in form of a bonus scheme that is based on the asset value uniquely implements the first best. In equilibrium, the initial incentive structure is modified after the first party invested. Since the second agent refrains from any investment when the initial bonus contract remains in force, the parties successfully rescind their initial agreement in order to make the latter party residual claimant for the return on its own investments. In line with results by Hermalin and Katz [1991] and Edlin and Hermalin [1999], [2001], our findings stress the important role that equilibrium renegotiation can play in moral hazard situations with verifiable outcome.²

The model draws on distinct strands of the literature. First, it is related to the literature on moral hazard in teams which starts with Holmström [1982], and shows

¹Edlin and Hermalin [2000] prove that even a general mechanism cannot attain the first best when parties are risk neutral, investments are complementary, and the asset value is non-contractible.

²While the reason for renegotiation in these papers is to free the risk-averse agent from an uncertain payoff, renegotiation in the present framework ensures (conditionally) efficient investments of the party which invests subsequently.

that team production in general yields inefficient results when team members simultaneously expend effort and a budget-balancedness requirement is imposed. Strausz [1999] has shown that efficient investments can be attained when the parties invest sequentially, and when output is deterministic. He develops a mechanism where a deviating party faces a punishment that serves to deter shirking, and under which the initially contracted sharing rule is not renegotiated in equilibrium. In line with the present approach, the functioning of the mechanism (at least out-of-equilibrium) requires the agents to make monetary side payments which, however, do never exceed a finite level.³ The present paper is less general in the sense that the team size is confined to two individuals (see, however, the extension at the end of Section 4). On the other hand, however, the mechanism we develop guarantees efficiency even if output (the asset value) is subject to any degree of uncertainty.

We also bear on asset ownership models with sequential investments where the asset value is assumed to be nonverifiable. Demski and Sappington [1991], Nöldeke and Schmidt [1998] and Edlin and Hermalin [2000] have shown that the first best is attainable if the investments of both parties are either substitutive (Edlin and Hermalin [2000]), or if renegotiation is either infeasible or can be prevented (Demski and Sappington [1991], Nöldeke and Schmidt [1998]).⁴ In all these papers, the optimal mechanism is an option contract which is never renegotiated and grants the second party the right to sell the asset to (or to acquire the asset from) the first agent at a predetermined fixed price. While Edlin and Hermalin allow for the resolution of uncertainty at a date after both parties invested, the efficiency results of Demski and Sappington and Nöldeke and Schmidt require the absence of any

³In our model, it is sufficient that the second agent has some initial wealth, while the first agent may have no monetary endowment.

⁴In contrast to Edlin and Hermalin [2000] whose approach is taken up in the present model, Demski and Sappington and Nöldeke and Schmidt admit option contracts with an exercise date after both parties invested. Under the optimal contract, the second party is then (after having observed efficient investments of the first party) just indifferent between investing efficiently and exercising his option, and not to invest and let his option expire. Edlin and Hermalin [2000] notice that the effectiveness of a date-2 option contract is sensitive with respect to the timing of investments. For a detailed discussion, see their paper.

significant uncertainty.⁵

Finally, the paper is related to the literature on renegotiation in complete contracting principal-agent problems, notably Hermalin and Katz [1991] and Edlin and Hermalin [1999], [2001]. There, it is shown under mild conditions that renegotiation facilitates an efficient outcome of the standard principal-agent relationship in a setup where the agent (the first party in our framework) is risk averse. While the principal (the second agent in our setting) does not expend own effort in these models, Edlin and Hermalin [1999, fn.4] note that their results carry over to bilateral sequential investments as long as the principal's effort does not affect the verifiable signal (the asset value in our model). The present paper shows that, at least if both parties are risk-neutral, optimal investments can be implemented even if the principal's subsequent investment affects the verifiable asset return on which the agent's compensation is based.

Basically, the present paper extends the findings from the previous literature on agency models with sequential investments in two respects: first, suppose the final asset value is unverifiable so that output-contingent contracts cannot be enforced. For this case, Edlin and Hermalin [2000] have shown that efficiency can be attained if investments are (weak) substitutes, and if the resolution of uncertainty is confined to a date after both parties invested.⁶ We extend their positive implementation result to a framework where uncertainty is resolved at any arbitrary point in the game,⁷ and show that the optimal contract in our setting has quite different economic implications. Namely, in contrast to Edlin and Hermalin, the second agent is not 'just indifferent' between exercising his option-to-buy under the optimal contract,

⁵Nöldeke and Schmidt [1998] show that the first best can be attained if uncertainty is not "too large", but not otherwise. For details, see their paper. Schmidt [2000] analyzes a similar model in which the investment of the second agent is a binary (rather than a continuous) variable. He shows that - under certain parameter constellations - a first best can be attained even if uncertainty is resolved at any arbitrary point in the game.

⁶If one subscribes to the contractual possibilities admitted in Nöldeke and Schmidt [1998], a first-best outcome also prevails when investments are complementary, as long as the economic environment exhibits no (significant) uncertainty.

⁷Edlin and Hermalin [2000] consider a more general setting with a risk-averse agent, but do not allow for the resolution of uncertainty after the first party (and before the second party) invested.

but rather has a strict preference to do so in a generic set of states of the world which are realized prior to his exercising decision. Also, the precontracted option is not always exercised in equilibrium and the parties renegotiate their initial arrangement with positive (but less than full) probability after the first agent invested.

Second, we show that efficiency is generically attained if the final asset value is verifiable. The optimal contract in case of complementary investments⁸ is an arbitrary mixed ownership structure in combination with a simple linear incentive plan which is assigned to the first agent. This contractual arrangement renders the first best feasible in a general framework where uncertainty is resolved at any arbitrary point in the game. In this respect, we also extend the efficiency result in the team production problem in Strausz [1999] (who, however, allows for any arbitrary number of agents), and in the asset-ownership model by Nöldeke and Schmidt [1998] (who, however, do not require verifiability of the asset value). Under the optimal contractual provisions, the initial bilateral arrangement is always modified after the first agent invested, which further distinguishes our paper from the results in this literature.

The remainder is organized as follows. Section 2 introduces the model, which is solved in Section 3 for the case of substitutive investments, and in Section 4 for complementary investments. Section 5 concludes.

2 The Model

Consider two risk-neutral parties, A and B who can invest in an asset, e.g., a joint venture. At *date 0*, both agents sign an initial contract. Thereafter, A expends at *date 1/2* value-enhancing effort $a \in \mathbf{R}_0^+$ into the asset. At *date 1*, the parties observe a stochastic signal $s \in [\underline{s}, \bar{s}]$ which provides some information on the asset return and is drawn from a continuous cumulative distribution $F(s)$. After observing s , A

⁸Clearly, the above efficiency result for substitutive investments *a fortiori* applies when the final asset value is verifiable.

and B can renegotiate their initial contract. Subsequently, B invests at *date* $3/2$ an amount $b \in \mathbf{R}_0^+$, and an additional signal $\theta \in [\underline{\theta}, \bar{\theta}]$ is drawn from a continuous distribution function $F(\theta)$ at *date* 2. At that date, the final asset value $v(a, b, s, \theta)$ materializes and the game ends at *date* $5/2$ where final payoffs are realized.

We suppose that both parties have complete information throughout the game. Moreover, the asset value $v(a, b, s, \theta)$ as realized at date 2 is verifiable and therefore contractible, while investments (a, b) and the stochastic signals (s, θ) are so complex that they are not.

Notice that renegotiations will (although technologically feasible) never occur after date $3/2$. Since the expected asset value is already fixed at those points in time and both parties are risk neutral, the continuation after date $3/2$ is a constant-sum game and further bargaining cannot facilitate a Pareto improvement. The sequence of events is illustrated in the following figure.

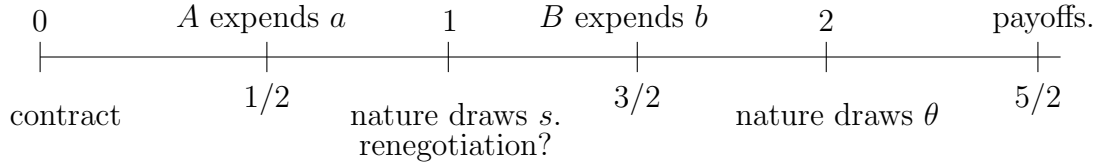


FIGURE 1

We denote the cost functions for the parties' idiosyncratic investments (i.e., their efforts) as $\psi(a)$ and $\phi(b)$, respectively. Also, we define $V(a, b, s) \equiv E_\theta v(a, b, s, \theta)$ as the date-1 expected asset value conditional on B 's subsequent investment b .

Assumption 1. The functions $v(\cdot)$, $\psi(\cdot)$ and $\phi(\cdot)$ are non-negative, twice continuously differentiable, strictly increasing in their arguments, and satisfy for all a , b and s (subscripts denote derivatives)

- (a) $V(a, b, s) \geq 0$ for all (a, b, s) .

- b) $v(\cdot)$ is strictly concave in (a, b) . In addition, $\lim_{i \rightarrow 0} v_i(\cdot) = \infty$ and $\lim_{i \rightarrow \infty} v_i(\cdot) = 0$ for $i = \{a, b\}$,
- c) $\psi_{aa}(\cdot) \geq 0$, $\psi(0) = \lim_{a \rightarrow 0} \psi_a(a) = 0$ and $\lim_{a \rightarrow \infty} \psi_a(a) = \infty$,
- d) $\phi_{bb}(\cdot) \geq 0$, $\phi(0) = \lim_{b \rightarrow 0} \phi_b(b) = 0$ and $\lim_{b \rightarrow \infty} \phi_b(b) = \infty$,

These assumptions ensure that the asset has a non-negative expected value in every state of the world s and for any investment tuple, and that a finite pair of positive investment levels maximizes joint surplus.

We suppose that the outcome of renegotiations is described by the generalized Nash-bargaining solution. Hence, when renegotiations occur at date 1, the parties share the efficiency gain above their respective threat point payoffs in fixed proportions determined by bargaining parameters γ for A and $(1 - \gamma)$ for B , respectively.⁹

Benchmark Cases

I. First Best

For later comparison, we compute the first-best effort levels $(a^{FB}, b^{FB}(s))$. Define $S(a, b) = E_s V(a, b, s) - \psi(a) - \phi(b)$ as the ex ante expected joint surplus for any investment tuple (a, b) . Also, let $b^*(a, s)$ be the conditionally efficient investment level of agent B in state s for given a . Then, the first-best investment of agent A is

$$a^{FB} = \arg \max_a S(a, b^*(a, s), s) = E_s V(a, b^*(a, s), s) - \psi(a) - \phi(b^*(a, s)), \quad (1)$$

while the efficient investment level of B in state s maximizes the date-1 joint continuation surplus indicated as $\tilde{S}(a, b, s) \equiv V(a, b, s) - \phi(b)$, i.e.,

$$b^{FB}(s) = \arg \max_b \tilde{S}(a^{FB}, b, s) = V(a^{FB}, b, s) - \phi(b). \quad (2)$$

Under Assumption 1 and using the envelope theorem, these first-best investment levels are uniquely determined by the first-order conditions

$$E_s V_a(a^{FB}, b^{FB}, s) = \psi_a(a^{FB}) \quad \text{and} \quad V_b(a^{FB}, b^{FB}, s) = \phi_b(b^{FB}), \quad (3)$$

⁹The efficiency gain is the difference between the maximal joint continuation surplus after A invested and s has been realized, and the sum of the parties' threat point payoffs at that date.

respectively. The efficient investments of both parties equate the marginal return and the marginal costs from effort.

II. No Initial Contract

Let us now assume that the parties do not sign an initial contract, and that party A is asset owner at date 0.¹⁰ If A remains owner after she invested, B will expend no own effort at date 3/2 because he appropriates none of the returns. Hence, joint surplus can be raised when the parties renegotiate the ownership structure at date 1.¹¹ Let $\hat{U}^A(a, 0, s) = V(a, 0, s)$ be the corresponding default payoff of A at date 1, and notice that the renegotiation surplus at that date is given by $\Delta \equiv \tilde{S}(a, b^*(a, s), s) - \tilde{S}(a, 0, s)$ which is strictly positive. Taking equilibrium renegotiation into account, A thus chooses at date 1/2 an investment level $\hat{a}$ which maximizes her utility

$$\begin{aligned} U^S(a) &= E_s[\hat{U}^S(a, 0, s) + \gamma\Delta] - \psi(a) \\ &= E_s\{(1 - \gamma)V(a, 0, s) + \gamma[V(a, b^*(a, s), s) - \phi(b^*(a, s))]\} - \psi(a). \end{aligned} \quad (4)$$

Under Assumption 1, the equilibrium investment $\hat{a}$ is uniquely determined by the corresponding first-order condition

$$E_s\{(1 - \gamma)V_a(\hat{a}, 0, s) + \gamma V_a(\hat{a}, b^*(\hat{a}, s), s)\} - \psi_a(\hat{a}) = 0. \quad (5)$$

To interpret this condition, notice that $\hat{a} = a^{FB}$ if and only $\gamma = 1$ or if investments are independent on the margin, $V_{ab}(\cdot) = 0$. If they are substitutive, i.e., $V_{ab}(\cdot) < 0$, we have $\hat{a} > a^{FB}$ and A overinvests. Conversely, A chooses $\hat{a} < a^{FB}$ and underinvests if investments are complementary, $V_{ab}(\cdot) > 0$. The next sections show that there exist simple date-0 contracts which can restore an efficient outcome for the cases of substitutive as well as complementary investments.

¹⁰One can easily verify that A will expend no investments if B is owner from the beginning.

¹¹Of course, A could also retain ownership but agree on an incentive contract with B . Since B will expend the conditionally efficient investment $b^*(a, s)$ in either case, we can concentrate w.l.o.g. on the - informationally less demanding - transfer of ownership.

3 Substitutive Investments

In a model where no uncertainty s is resolved at date 1, Edlin and Hermalin [2000] have shown that a simple option-to-own contract uniquely implements efficient investments if those investments are substitutive. Under the optimal contract, B is in equilibrium just indifferent between exercising his option or not at date 1 provided A invested a^{FB} , while he will not exercise (and insist on renegotiation) after observing any $a < a^{FB}$. In the former case, he pays the option price and accrues ownership, and therefore exerts b^{FB} at date 3/2.

To obtain an intuition for this result, consider the strike price $\hat{p} = \gamma[V(a^{FB}, b^{FB}) - \phi(b^{FB})] + (1 - \gamma)V(a^{FB}, 0)$ and suppose that A undertakes an investment $a \geq a^{FB}$ at date 1/2. Then, B will exercise his option at date 1 because his corresponding payoff $V(a, b^*(a)) - \phi(b^*(a)) - \hat{p}$ exceeds (weakly so for $a = a^{FB}$) the payoff he can accrue in renegotiations, $(1 - \gamma)[V(a, b^*(a)) - \phi(b^*(a)) - V(a, 0)]$. It is now clear that A will never invest more than a^{FB} , while B will not exercise after observing any $a < a^{FB}$ because the difference in the above payoffs increases in a . As a last step, one must show that - for substitutive investments - A will not deviate to some $a < a^{FB}$ at date 1/2 and trigger renegotiation. To see this, notice that her payoff when choosing a^{FB} is $\hat{p} - \psi(a^{FB})$. Conversely, she appropriates $(1 - \gamma)V(a, 0) + \gamma[V(a, b^*(a)) - \phi(b^*(a))] - \psi(a)$ for any $a < a^{FB}$ which is smaller if and only if investments are substitutive.¹² As a consequence, the option-to-buy contract p^* is not renegotiated and prompts both parties to invest efficiently.

In our model where some uncertainty is already resolved at date 1, this logic does not immediately apply for the following reasons: first, if the option price is chosen sufficiently small so that B exercises in *every* state s after A invested efficiently,

¹²Notice that the maximizer of $(1 - \gamma)V(a, 0) + \gamma[V(a, b^*(a)) - \phi(b^*(a))] - \psi(a)$ is $\hat{a}$ as defined in (5). Since $\hat{a} < a^{FB}$ if investments are complementary, a payoff comparison for this case yields

$$\begin{aligned} \hat{p} - \psi(a^{FB}) &= (1 - \gamma)[V(a^{FB}, b^{FB}) - \phi(b^{FB}) - V(a^{FB}, 0)] - \psi(a^{FB}) \\ &< (1 - \gamma)[V(\hat{a}, b^*(\hat{a})) - \phi(b^*(\hat{a})) - V(\hat{a}, 0)] - \psi(\hat{a}), \end{aligned}$$

so that A will find it optimal to underinvest.

A may prefer to choose an effort smaller than a^{FB} because the option price is so unattractive that she fares better with renegotiations (at least) in some states. Second, for a larger strike price, B does *not* exercise in every state s and subsequent renegotiation deteriorates A 's investment incentives. Still, the following proposition shows that the efficiency properties of option contracts can be generalized to the case where the asset value is subject to uncertainty s .

Proposition 1. *Suppose the asset value is stochastic, and consider substitutive investments. Then, there exists an option contract with positive strike price p^* which implements efficient investments $(a^{FB}, b^{FB}(s))$. Moreover, B exercises his option-to-buy with positive but less than full probability. Even in states s where B lets the option expire, renegotiation ensures that ownership is transferred at date 1.*

Proof: Consider an option contract with strike price p . At date 1, B finds it optimal to exercise his option iff

$$V(a, b^*(a, s), s) - \phi(b^*(a, s)) - p \geq (1 - \gamma)[V(a, b^*(a, s), s) - \phi(b^*(a, s)) - V(a, 0, s)], \quad (6)$$

i.e., iff

$$p \leq \gamma[V(a, b^*(a, s), s) - \phi(b^*(a, s))] + (1 - \gamma)V(a, 0, s). \quad (7)$$

If (7) is not satisfied, B lets his option expire and renegotiations ensure that he becomes owner at date 1. Define $\hat{s}(a, p)$ as the (unique) boundary state where B is just indifferent between his two actions for given (a, p) provided that indifference indeed prevails for some $s \in [\underline{s}, \bar{s}]$. Otherwise, let $\hat{s}(\cdot)$ be the boundary state $\underline{s}$ if (7) is satisfied, and $\bar{s}$ if (7) is not satisfied. Notice that any interior $\hat{s}(a, p)$ is decreasing in a and increasing in p . Anticipating B 's decision to exercise and the outcome of renegotiation, A therefore maximizes at date 1/2

$$U^A(a, p) = \int_{s < \hat{s}(a, p)} \{(1 - \gamma)V(a, 0, s) + \gamma[V(a, b^*(\cdot), s) - \phi(b^*(\cdot))]\} dF(s) + \int_{s \geq \hat{s}(a, p)} p dF(s) - \psi(a). \quad (8)$$

Verifying that this payoff function is strictly concave in a for any p (because $d\hat{s}(a, p)/da \leq 0$), the equilibrium investment a^* is uniquely determined by the first-order condition

$$\int_{s < \hat{s}(a, p)} \{(1 - \gamma)V_a(a^*, 0, s) + \gamma V_a(a^*, b^*(a^*, s), s)\} dF(s) = \psi_a(a^*). \quad (9)$$

Suppose first $p = 0$. By Assumption 1, B then exercises his option for any (a, s) so that $\hat{s}(a, p) = \underline{s}$ and A finds it optimal not to invest. Conversely, consider an option price $p = \bar{p}$ so large that B never exercises for any s and any $a \leq \hat{a}$ as defined in (5). Then, program (8) coincides with (4) and A overinvests because investments are substitutive, $V_a(a, 0, s) > V_a(a, b^*(a, s), s)$. Accordingly, and recalling that $a^*(p)$ is unique for any p , the theorem of the maximum and an intermediate value argument imply the existence of some $p^* \in (0, \bar{p})$ which implements $a^*(p^*) = a^{FB}$. $\square$

The result of Proposition 1 has a simple intuition.¹³ When investments are substitutive on the margin, the optimal contract must prevent an overshooting of A 's investments. Granting an option to B serves this purpose: in a given state s and for a given strike price p , B exercises his option whenever A 's effort exceeds some threshold level. If p is very large, B will never exercise and the parties rely on bargaining to realize their maximal joint continuation surplus. Accordingly, A will overinvest and choose $\hat{a} > a^{FB}$. On the other end of the price spectrum, for p very small, B always exercises his option, which means that A 's return on investments is zero and she expends no effort. By continuity, there thus exists an intermediary strike price p^* under which A expends first best investments and B exercises his option in a subset of (favorable) states of the world. Also, A 's optimization program is well behaved for any precontracted p so that the investment solution is unique.¹⁴

¹³While an option contract implements efficient investments, it is not the only solution to the parties' contracting problem: another way to achieve the same outcome is stochastic ownership where a date-1 random draw determines whether B accrues ownership of the firm. However, stochastic ownership schemes are rarely seen in practice which may be due to legal obstacles to the use of lotteries.

¹⁴Intuitively, A 's payoff function is concave because a marginal increase in a augments the set of states where the option is exercised and A obtains no return on effort.

Thus, and as has been already emphasized by Edlin and Hermalin [2000] for the deterministic case, option contracts are an efficient tool to *reduce* A 's investments below the level $\hat{a}$ that prevails when A holds unconditional ownership. For this reason, a date-1 option contract implements an efficient outcome when the parties' investments are substitutive, while it cannot improve upon unconditional A -ownership otherwise. In fact, Edlin and Hermalin show that, when the asset value is unverifiable, even a general mechanism is unable to raise A 's investments above the level $\hat{a}$. As a consequence, the first best is infeasible when investments are complementary.¹⁵ The next section demonstrates that efficiency is restored when the asset value is verifiable and the parties agree on a contract that directly conditions on $v(\cdot)$.

4 Complementary Investments

Suppose now that investments are complementary, and consider the following simple arrangement. At date 0, the parties sign a contract $(T(v(\cdot)), \delta)$ which grants B an equity fraction δ of the asset (possibly in return for some lump sum payment). In addition, A becomes eligible for an incentive payment $T(v(\cdot))$ as a function of the verifiable asset value which is realized at date 2. When designing an incentive scheme that leads A to expend proper investments, the parties face the following problem: since the asset value is verifiably observed only after *both* parties invested, B 's subsequent effort affects the signal $v(a, b, s, \theta)$ on which A 's incentive payment is based, and he may have an incentive to disturb this signal for strategic reasons.

Nevertheless, the following Proposition shows that a simple linear bonus plan overcomes the hold-up problem.

Proposition 2. *Suppose the asset value $v(a, b, s, \theta)$ is verifiable, and that investments are complementary on the margin. Then, an initial contract that (a) assigns*

¹⁵As noted in the Introduction, Nöldeke and Schmidt [1998] find that an efficient outcome can even then be implemented provided the parties operate in an environment without significant uncertainty. This result applies because they allow for mechanisms which are played at date 2 after both agents invested.

B an arbitrary fraction $\delta \in [0, 1]$ of the firm's equity, and (b) makes A eligible for a linear bonus payment $t^*v(\cdot)$ with a constant and strictly positive incentive factor

$$t^*(\delta) = (1 - \gamma) \frac{\psi_a(a^{FB})}{E_s V_a(a^{FB}, 0, s)} - [1 - \gamma - \delta]$$

implements the first best. In equilibrium, renegotiation ensures that the initial incentive scheme is rescinded at date 1 after A invested, and B accrues full asset ownership at that date.

Proof: Consider an initial contract $(\delta, t^*(\delta))$. Imagine first that date-1 bargaining is unsuccessful. Then B chooses his investment b at date 3/2 so as to maximize his (default) payoff

$$\hat{U}^B(a, \delta, s) = V(a, b, s)(\delta - t^*) - \phi(b) = (1 - \gamma) \left[1 - \frac{\psi_a(a^{FB})}{E_s V_a(a^{FB}, 0, s)} \right] V(a, b, s) - \phi(b). \quad (10)$$

Notice that, for any s , this function is strictly decreasing in b since $\psi_a(a^{FB}) > E_s V_a(a^{FB}, 0, s)$ when investments are complementary. Hence, B will not invest at date 3/2 when the initial contract $(t^*(\delta), \delta)$ is still in force and, as a consequence, A 's threat point payoff in date-1 bargaining becomes $\hat{U}^A(\cdot) = (1 - \delta + t^*)V(a, 0, s)$. In equilibrium, the parties renegotiate their initial contract after A invested. At date 1, A sells her ownership stakes and the parties invalidate the bonus scheme. Anticipating this outcome, A chooses at date 1/2 her equilibrium investment a^* in order to maximize the (strictly concave) function

$$\begin{aligned} U^A(a, \delta, t^*) &= E_s \{ (1 - \delta - \gamma + t^*)V(a, 0, s) + \gamma[V(a, b^*(a, s), s) - \phi(b^*(a, s))] \} - \psi(a) \quad (11) \\ &= E_s \left\{ (1 - \gamma) \frac{\psi_a(a^{FB})}{E_s V_a(a^{FB}, 0, s)} V(a, 0, s) + \gamma[V(a, b^*(a, s), s) - \phi(b^*(a, s))] \right\} - \psi(a). \end{aligned}$$

Using the envelope theorem, the corresponding first-order condition reads

$$(1 - \gamma)\psi_a(a^{FB}) + \gamma E_s V_a(a^*, b^*(a, s), s) = \psi_a(a^*), \quad (12)$$

which yields the unique solution $a^*(t^*(\delta), \delta) = a^{FB}$. $\square$

The optimal ex-ante contract combines an arbitrary equity structure with a linear bonus plan.¹⁶ This bonus scheme (whose specification depends on the initially chosen ownership structure δ) serves to increase A 's investment incentives above those prevailing under unconditional A -ownership. Under the optimal plan, t^* is chosen in a way that B does not invest when renegotiations at date 1 fail. This is easily accomplished: for example, since t^* is positive even if $\delta = 0$, any own effort would increase A 's bonus payment and thus reduce B 's own payoff. Since B does not invest unless he becomes residual claimant, both parties have at date 1 a joint interest to assign (conditionally) efficient investment incentives to B . At that date, A is bought out and the bonus plan is rescinded in equilibrium. The only remaining question is whether the initial combination of property rights and bonus contract can give A efficient investment incentives. We find an affirmative answer: for any $\delta \in [0, 1]$, A will underinvest when investments are complementary. With an appropriately chosen additional bonus that is conditional on the final asset value, however, her investment incentives are raised and the first best can be implemented.¹⁷

In a related model, Strausz [1999] uses a punishment scheme to deter agents from expending suboptimal investments. Under the optimal scheme, the agent "next in line" refuses to expend any further investment and insists on a penalty payment after observing a deviation by his immediate predecessor. This scheme prevents all agents from shirking if the verifiable outcome is deterministic. However, in general it cannot implement the efficient solution if output is a stochastic function of investments.¹⁸ Our results are thus complementary to those of his work: while our findings apply

¹⁶Note that, for δ set equal to unity, the implementation result of Proposition 2 carries over to a 'trade' model where the asset has positive value at date 5/2 only if it is owned by B .

¹⁷There exist alternative non-linear incentive schemes which implement the same outcome. For example, the parties could agree upon a goal-dependent bonus that is realized when $v(a, b, \theta)$ exceeds some boundary.

¹⁸While the bonus scheme we explore uses no punishments, it requires that agent B (though not agent A) is not severely wealth constrained: he must be able to pay agent A an amount of maximal size $t^*v(a^{FB}, 0, \bar{s})$ if the bonus contract remains in force. While this payment is never provided in the equilibrium of the game where bargaining is successful, a lack of a monetary endowment on B 's side would alter the parties' threatpoint payoffs and hamper the efficient outcome of the mechanism.

only to team production with two agents, our mechanism can also cope with the possibly more realistic scenario where the outcome of team production is subject to significant uncertainty.

Before concluding this section, we should note that a bonus contract can in principle facilitate an efficient outcome even in team production problems with more than two agents. However, since the mechanism we explore relies on equilibrium renegotiation, the bargaining solution with more than two agents is sensitive to the underlying bargaining process. To see this, consider a setting with three agents A , B and C . Indicate the effort of this last party as c , and let z be a stochastic signal that is resolved in between the investment stages of party B and C , respectively. Suppose first that C is selected as a team member only after A invested and after A and B renegotiated their initial contract. Then, agent B will ‘buy out’ agent A before he signs a contract with agent C and undertakes effort b . Moreover, since we face after date 1 a truncated game played by B and C , their optimal arrangement for any given a is again a linear bonus contract, now with incentive parameter

$$t^{**}(\delta) = (1 - \gamma_C) \frac{\phi_b(b^*(a, s))}{E_z V_b(b^*(a, s), 0, z|a, s)} - [1 - \gamma_C - \delta] \quad (13)$$

where γ_C represents the bargaining strength of agent C vis-a-vis agent B , and $V(b, c, z|a, s)$ is the expected asset value for given a and given first-period state s . According to our previous arguments, B will find it optimal to choose the conditionally efficient investment $b^*(a, s)$, while subsequent renegotiation with C leads this agent to invest $c^*(a, b^*(a, s), z)$. Now, consider the first stage of the game where A and B sign a contract. Using our previous notation, a bonus contract t^* [with $E_s V_a(a^{FB}, 0, s)$ replaced by $E_s E_z V_a(a^{FB}, 0, 0, s, z)$] again renders it optimal to invest a^{FB} . In particular, this outcome prevails because A anticipates that neither B nor C will undertake any investment unless renegotiation with B is successful, so that his utility is well defined and concave in a . Taken together, provided that bargaining is a bilateral process at any point in the game, our previous results extend to the case of more than two agents. Alternatively, one might find it reasonable that the team composition is known from the beginning. Then, however, party C may

already enter the renegotiations between A and B after A invested, which would further complicate the analysis and render the Nash-bargaining concept inapplicable. While we conjecture that efficiency in this case can still be attained for specific assumptions on the bargaining process, we have to leave a thorough analysis for future research.

5 Conclusion

This paper explores a team production problem where two parties sequentially invest to enhance the value of a joint project (an asset). We show that an efficient outcome is generically feasible even if the output, i.e., the final asset value, is subject to any degree of uncertainty. Hence, we complement a recent efficiency result by Strausz [1999] who considers deterministic environments but allows for more than two agents. In our framework, efficient contracting is characterized by a basic dichotomy. If the parties' inputs are complementary on the margin, it is optimal to combine some arbitrary equity structure with a properly chosen bonus scheme that is linear in the ex-post verifiable asset value. In equilibrium, this initial incentive scheme is always renegotiated after the first agent invested, and the second party becomes residual claimant for the returns from his own investments. Conversely, if investments are substitutive, efficient investments are feasible even if the asset value is non-verifiable. In this case, the optimal contract is an option-to-buy arrangement under which the second party has the right (but not the obligation) to acquire the asset at a fixed price after the first agent expended his effort. We thus extend a recent result by Edlin and Hermalin [2000] to a setting where the asset value is stochastic rather than deterministic. In contrast to their findings, however, the option is not always exercised in equilibrium, and renegotiation arises with positive probability.

All in all, the results of our paper reinforce previous insights that the moral hazard in teams problem can often be resolved if the parties invest sequentially rather than simultaneously. This scenario also bears empirical relevance, for example with regard

to research joint ventures where a small high-tech firm exerts the basic research for a large enterprise that is responsible for subsequent later-stage development and marketing. While our paper confines attention to the important case of team production with only two agents, an analysis of optimal contracting with sequential investments and stochastic payoffs is a fruitful direction for future research.

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