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Contracting still matters! Or: how to design a letter of intent

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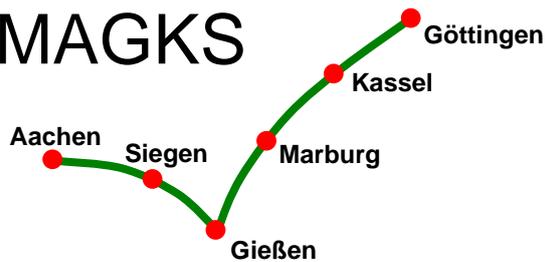
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Contracting still matters!

Or: How to design a letter of intent

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Abstract

Any cooperation that profits from relation-specific investments suffers from the well-known hold-up problem. If investments are not enforceable by an outside authority, the gains fall prey to individual opportunism caused by a free-rider problem. If, in addition, individual investments exhibit positive cross effects, Che and Hausch (1999) provide a negative result and show that contracts cannot overcome the hold up due to a lack of verifiable commitment. This paper develops a mechanism that provides such a commitment device: (1) It introduces an acknowledgement game that procures reliable. (2) It embeds the original contracting problem into two institutional designs – a market based one and a private design – that support enforcement. These two devices reestablish efficient investments as enforceable results of a contract.

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1 Introduction

The need for relation-specific investments is known as a source of inefficiency for all kinds of collaborations. It causes collaborators to choose lower-than-optimal investment levels which may prevent potentially beneficial collaborations. Accordingly, the question of how to overcome these impediments has been addressed in a huge literature.

It has started out from Goldberg (1976), Klein et al. (1978) and Williamson (1975, chapter 2)) who have addressed this main source of inefficiency as the hold-up problem. A solution to this problem is especially hard to find if parties are unable to write contracts that can be enforced by a court, because, for instance, investment levels are unverifiable for third parties. This missing enforcement makes any contract ‘incomplete’.¹

The literature on incomplete contracts has provided different solutions to the underinvestment problem. If physical assets are essential to production, a specific assignment of property rights helps to correct investment incentives (Grossman and Hart (1986); Hart and Moore (1990)). If individual investments can be done sequentially, use of the timing structure can produce the desired result (De Fraja (1999); Che (2000)).

An alternative approach that can be applied to problems where the investment does not produce physical assets has used redefined contracts. Seminal work in this branch has been Hart and Moore’s (1988) paper that shows that sophisticated contracts can overcome the hold up and induce first-best investments *if* the parties to the contract can commit not to start renegotiations in case of an adverse outcome.² This latter condition has been challenged in a number of papers that aim at developing self-enforcing contracts to cir-

¹Incompleteness has a number of other sources than those addressed here. Hart and Moore (1988, 1999), Tirole (1999), Segal (1999), Maskin and Tirole (1999), and Maskin (2002) have discussed incomplete contracts from different perspectives. We will, however, restrict our attention to non-verifiability of investments.

²Yet, Jolls (1997) and Shavell (2007) argue that prevailing legal practice destroys such a commitment.

cumvent or preclude renegotiations. This issue has been addressed in, for instance, Aghion et al. (1994), Nöldeke and Schmidt (1995), Hermalin and Katz (1993), and Edlin and Reichelstein (1996). In addition, recent work has shown that the question if renegotiations are harmful or beneficial depends on a number of details of the contracting problem at hand like completeness vs. incompleteness (see Schmitz (2005)) and the magnitude of complexity of the contract (see Schwartz and Watson (2004)).

An – at least from a theoretical perspective – “final” word came from Maskin and Moore (1999) and Che and Hausch (1999). The former have shown that any social choice rule can be implemented (which includes efficiency) if the original contract can be augmented by an additional mechanism. The latter have established a negative result that proves that no contract can implement first-best investments as long as it is impossible to exclude renegotiations and partners’ relation-specific investments exhibit externalities (which they label as “cross effects”). Thus, they conclude that contracting – a usually time-consuming and expensive activity – is not useful at all.

This paper starts out from Che and Hausch’s and Maskin and Moore’s analyses of contracts and aims at establishing a link between the extremely positive and the extremely negative view that can be taken from these two papers. Empirical evidence shows that firms establish collaborations and use contracts (for reference Narula and Hagedoorn (1999), Hagedoorn (2002) and Reuer, Arino and Mellewigt (2006)) and – as we might add – probably not all of these activities are inefficient and vain. Thus, we ask if there can be conditions named that are favourable for getting contracts “work”.

We model a situation where two parties want to start a joint project that needs relation-specific investments. In that we might think of a project to develop a new software, where both partners have to contribute to the programme code, or of a research joint venture between two firms that cannot be integrated – for instance, because they are physically distant, maybe even across different countries. Both scenarios have in common that a property-rights approach cannot be used. Investments are relation specific as they

have aspects that are more valuable for the joint product than anywhere else and they are not enforceable by a third party. For the software example this non-enforceability results from the fact that it is hard to assess the value of a software unless it is accomplished. For the joint research project enforceability can either be curtailed because partners are located in different jurisdictions – leading to uncertainty as to which rules apply – or simply because of features that are unobservable for outsiders. In addition, we assume that individual investments exhibit mutual positive externalities. Here, one might think of modules of a software that work better if fitted to each other or, for the research joint venture, of investments in infrastructure or corporate culture that support knowledge spillovers.

Thus, our basic scenario has the structure of Che and Hausch's (1999) model which implies that first-best investments cannot be supported by contracts between both partners as long as renegotiations cannot be excluded. We augment the original contract by an additional mechanism in the style of Maskin and Moore (1999) that aims at a self-enforcing defense against disturbing renegotiations. In that, we introduce a so-called message game that aims at turning unverifiable information (the actual level of investments) into verifiable one (reports on the level of investment). This message game is part of the contracting process. It consists of reports concerning own investment activities and mutual acknowledgement of these activities. Such a process of an ex-interim information exchange is a way to model the system of so-called letters of intent which are widely used as part of the initiation of cooperation in real-life contracting.³ By means of these letters parties to a contract can cross-check each other's progress. Our model abstracts from the timing aspect found within real-world contracting but describes the incentive effects of this ex-interim communication.

We show that such an additional mechanism does not help to avoid inefficiencies if there are no institutions that support parties in contract enforcement.

³For a short introduction into costs and benefits of letters of intent from a more practical point of view see, for instance, Homburger and Schueller (2002).

We analyse the effects of such institutions. In that we concentrate on two types:

In a first setting, we allow parties to introduce a third party that helps to enforce the contract. Third-party payments have been shown to help enforce contracts, so this is in principle no news.⁴ What distinguishes our setting from other work is that the payment scheme is endogenous to the contract and depends on the course of the collaboration. In a second setting, we allow for costs that are due to a loss of reputation if it becomes known that the partners had difficulties in implementing the agreed terms. Thus, in this scenario the market offers the only corrective mechanism.

A comparative statics analyses which parameters allow for an implementation of first-best investments. We show that the market is a good support only if both partners are necessary for the project's success after investments have been made and partners have to accept substantial reputation losses in case of a break down of cooperations. In consequence, the market solution only applies to a limited range of problems.

The solution including a third party leads to stable results independent of outside conditions. Yet, the details of the contract with the outside party have to be well chosen which renders the design of the optimal contract complex.

Both settings share this latter property of contract complexity which makes contracting expensive. As we will show, this feature is on the one hand onerous but on the other hand useful as a commitment device.

2 Basic Model

We consider two players A and B that are symmetric, risk-neutral, rational, and enter a joint activity (a software project or a research joint venture as indicated above). The value of the joint product is $R(\alpha, \beta)$ where α denotes

⁴For instance, Hart and Moore (1988) (footnote 20), Che and Hausch (1999) (footnote 10), and Maskin and Moore (1999) hint at this possibility.

A 's nonnegative investment and β that of B . We assume $R(\alpha, \beta)$ to be twice differentiable, increasing, and concave in investments.

In addition, investments are relation specific and exhibit mutual positive externalities on partner's productivity. That is, $R(\alpha, 0) = R(0, \beta) = 0$, $\frac{\partial R}{\partial \alpha}|_{(0, \beta)} \gg 0$, $\frac{\partial R}{\partial \beta}|_{(\alpha, 0)} \gg 0$, and $\frac{\partial^2 R}{\partial \alpha \partial \beta} = \frac{\partial^2 R}{\partial \beta \partial \alpha} > 0$. Investment costs are private and linear $c_A = \alpha$, $c_B = \beta$. We assume that partners know each other sufficiently well such that properties of the production function are common knowledge to both parties when starting the collaboration and designing a contract.

Throughout the paper we assume that it is beneficial to cooperate, that is, $R(\alpha, \beta) \gg \alpha + \beta$ for α and β below a certain threshold. The total profit from cooperation is $\pi = R - \alpha - \beta$. Thus, efficient investments are characterized by $\frac{\partial R}{\partial \alpha} = \frac{\partial R}{\partial \beta} = 1$. Throughout the paper we will denote these efficient investment levels by α^* and β^* .

Revenue from the final product will be split between both partners according to an initially negotiated splitting rule $(\lambda, 1 - \lambda)$ where λ denotes A 's share of the revenue. For sake of simplicity we set $\lambda = 1/2$. Thus, as each party has to bear its own investment costs to a full extent but receives only half of its benefits, a free-riding problem arises. Individually rational levels of investment are characterized by $\frac{\partial R}{\partial \alpha} = \frac{\partial R}{\partial \beta} = 2$. These investment levels are denoted by α^{sb} and β^{sb} . Due to concavity of the production function these investment levels are lower than first-best levels.

Now, both firms would like to design a contract that helps to overcome the hold-up as well as the free-riding problem and implements first-best investments. Yet, we assume that investments are observable between partners but cannot be verified by an outside party (we will discuss this assumption in section 5). From Che and Hausch (1999) we know that in this situation both parties will stick to second-best investments no matter how sophisticated the contract has been as long as there is no means to curb renegotiations after unfavorable outcomes.

In what follows we describe a mechanism that helps to overcome the prob-

lems characterized by Che and Hausch (1999). In detail, we will construct a mechanism that consists of two parts: First, parties implement an initial contract that sports mutual subsidies to balance the underinvestment incentives. Second, they enrich the contracting process by an additional stage where parties exchange reports concerning their investments. These reports transform the observable but unverifiable information on investments into verifiable information. Yet, this transformation alone does not suffice to implement the first-best solution. In addition, we need to establish an *endogenous* means to curb renegotiations. In that we compare two institutional designs: The introduction of a third party and a market-based scheme of information transmission. Both scenarios have in common that contract breach will be punished. In the third-party scheme the parties to the original contract stipulate a damage payment for this event and ask a third party to enforce this payment. In the market-based scheme no active third party is involved; instead, the original contract is designed in a way that the consequences of a contract breach will get public and both parties take into account that they have to accept a loss of reputation from that.

We analyze equilibria of the contracting game within these two settings in the flavor of Maskin and Moore's (1999) idea of an additional mechanism. As the scenario under consideration is endogenous (parties can decide if they want to hire an active third party), we add a comparative statics that discusses costs and benefits of both institutional frames.

3 Model Extension - a Message Game

In their original contract parties agree upon investment levels – which are α^* and β^* – and on mutual subsidies that are supposed to balance the underinvestment incentives. These subsidies amount to one half of each partner's investment cost. Thus, for party A the overall profit turns into $\pi_A(\alpha, \beta) = 1/2R(\alpha, \beta) - \alpha + 1/2\alpha - 1/2\beta$ (correspondingly for B). The cost of an additional investment is now borne by both parties and first-best levels

would be implemented under such a payoff scheme. Yet, as investments are not verifiable to an outside party, this payoff scheme is not enforceable: Each party has an incentive to claim higher subsidies than would be appropriate which cannot be proven as a false claim.

In order to transform this unverifiable information into verifiable one, we introduce a so-called message game. It takes place when investments have already been made and are common knowledge to both parties (but not to outsiders). The message game itself has two stages. At stage one each party reports on its investments. These reports are named $\tilde{\alpha}$ and $\tilde{\beta}$. At stage two parties have to authenticate each other's report. This additional mechanism is shown in the left part of Figure 1 on page 11. The message game is played in a "public" environment, either in front of a solicitor or by use of other publishing devices that help to prevent cheating.

If both parties validate the other's report (labeled as strategy v), it is agreed upon in the original contract that mutual subsidies are paid according to these reports (instead of to the unverifiable real investment levels). That is, if parties have reported $\tilde{\alpha}, \tilde{\beta}$, true investments have been α, β (which need not necessarily to be the same values), and both parties have validated each other's report, there will be a payment of $1/2\tilde{\alpha}$ from B to A and $1/2\tilde{\beta}$ from A to B . Thus, the initial contract leads to payoffs

$$\pi_A(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, v, v) = 1/2R(\alpha, \beta) - \alpha + 1/2\tilde{\alpha} - 1/2\tilde{\beta},$$

$$\pi_B(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, v, v) = 1/2R(\alpha, \beta) - \beta - 1/2\tilde{\alpha} + 1/2\tilde{\beta}.$$

Within the original investment decision overinvestment is not to be expected. Yet, there might be incentives for exaggerating own investment at the reporting stage. To avoid possibly misleading incentives only reports $\tilde{\alpha} \leq \alpha^*$ and $\tilde{\beta} \leq \beta^*$ are accepted. If one of both parties sends a higher report, it is read as α^* or β^* . In the same way we restrict the set of reports from below by α^{sb} and β^{sb} where α^{sb} and β^{sb} follow from the considerations on second-best investment levels on page 6. Reports lower than these values are read as α^{sb} and β^{sb} .

However, if one party rejects the other one's report – or even both parties do so – cooperation is interfered and might even break down. For these cases, the original contract has to allot mutual payments and a plan for further proceedings. The details of these payments and proceedings depend on the institutional frame of the contracting problem and are therefore given in the subsections to follow.

Yet, the structure of the stipulated payments is the same for both cases and is based on the following reasoning: If one of both players, say A , rejects (labeled as strategy r) whereas the other one (B) validates, the situation could be read as “ A has reported truthfully and B has tried to cheat”. Therefore, further cooperation would be restrained. For this case both parties agree on a damage payment that should reimburse A for the loss of potential profit caused by B 's misbehaviour.

This payment is constructed in the style of an expectation damage used in contract law.⁵ The damage is based on reports $\tilde{\alpha}$ and $\tilde{\beta}$ which is the only available information concerning the size of the loss occurred. If $\tilde{\alpha}$ and $\tilde{\beta}$ were the true investment levels, A 's revenue under validation would have been $1/2R(\tilde{\alpha}, \tilde{\beta}) + 1/2\tilde{\alpha} - 1/2\tilde{\beta}$. B has to pay this amount to indemnify A .⁶ So far, the contract says that after unilateral rejection of a report cooperation breaks down and the rejecting party receives a damage payment. Yet, without any further precautions the contracting process will not stop here. By abandoning the cooperation both parties have waived $R(\alpha, \beta)$. They could regain this value if they would enter renegotiations and split the revenue according to their bargaining power – which we assume to be equal as parties are symmetric. If parties account for this possibility, the damage payment

⁵An expectation damage is a default remedy for contract breach in contract law. The expectation damage is supposed to put the truster in the position he would have enjoyed had the contract been carried out. For a discussion see Shavell (2004).

⁶To put A in the position he would have been in if the contract had been fulfilled, the payment should actually include the surplus following from real investments $R(\alpha, \beta)$. Yet, as this information is not contractible, the use of $R(\tilde{\alpha}, \tilde{\beta})$ is as close as we can get to the original contract.

and the renegotiation payoff following the break down induces them to over-report and reject the other party's offer to extract an excessive payment from the partner.

To avoid this problem, an additional part of the original contract covers that the rejecting party has to waive its part of the joint surplus of the project. This precaution in its own right diminishes incentives to renegotiate.⁷ But parties have to use an additional means to keep each other honoring the original agreement. As a start the partner who paid the damage – in our example B – continues the project on his own.⁸ Depending on the problem at hand this can or cannot be possible without any restrictions: As investments have already taken place, it only remains to produce the output based on the joint production function. If both parties' inputs have been sufficiently close (in a spatial or factual sense), the remaining party might have the capacity to go on alone. However, if (as in the cross-country example) production cannot be handled by one partner, there is a cost d to continue the project alone. We assume that d can take values in $[0, \infty)$ – depending on the project under consideration – where large values imply a prohibitive cost. Now that the rejecting party (in our example A) has waived its part of the surplus and the other one controls the production process, different scenarios could apply that are outlined in Figure 1:

The first one – which we mentioned before as the “market-based scheme” – assumes that the contracting mechanism stops here. That is, B keeps the whole revenue and receives $R(\alpha, \beta)$ minus the continuation cost d and possibly an additional reputation loss. This loss might arise because the fact that B continues the project on his own gets public and possible future partners see that B “snatched” A 's part of the surplus. For the technical part of the paper the value of this loss is assumed to be part of d . In sum, payoffs after investments α, β , messages $\tilde{\alpha}, \tilde{\beta}$ and onesided rejection by player

⁷A similar procedure – albeit in a different context – has been used by Brennan and Watson (2002) and Ramey and Watson (2002).

⁸Lerner and Malmendier (2008) have analyzed the effect of reassigning property rights within a contracting problem that includes cooperative as well as competitive aspects.

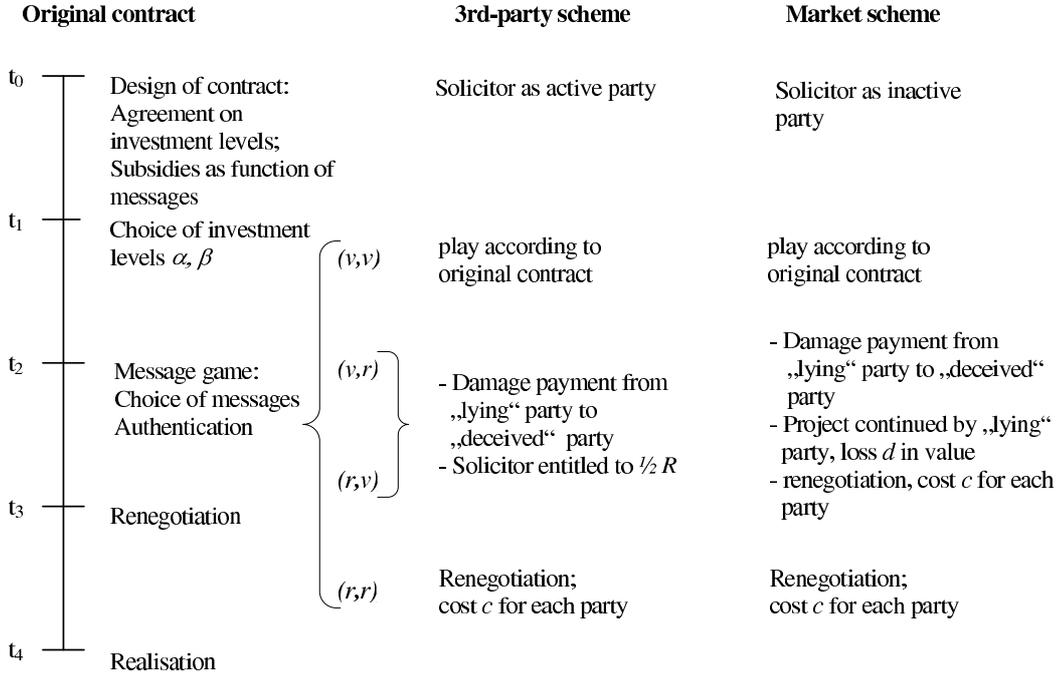


Figure 1: The Contracting process

A take on the form

$$\begin{aligned} \pi_A(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, r, v) &= -\alpha + 1/2R(\tilde{\alpha}, \tilde{\beta}) + 1/2\tilde{\alpha} - 1/2\tilde{\beta}, \\ \pi_B(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, r, v) &= R(\alpha, \beta) - d - \beta - 1/2R(\tilde{\alpha}, \tilde{\beta}) - 1/2\tilde{\alpha} + 1/2\tilde{\beta}. \end{aligned}$$

If A validates and B does not, payoffs are determined analogously.

The second scenario – which we have mentioned as the “third-party scheme” – assumes that due to the original contract B controls the production process but that A ’s part of the revenue $1/2R(\alpha, \beta)$ – which is verifiable after production has taken place – gets transferred to the solicitor (or another mediating agent). Thus, in that scenario the game is enlarged by a third active player. As we will see in the analysis section, the additional continuation cost d do not add to the incentive structure under the third-party scheme. Therefore, we will assume $d = 0$ throughout this scenario. Thus, payoffs

after investments α, β , messages $\tilde{\alpha}, \tilde{\beta}$ and onesided rejection by player A take on the form

$$\begin{aligned}\pi_A(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, r, v) &= -\alpha + 1/2R(\tilde{\alpha}, \tilde{\beta}) + 1/2\tilde{\alpha} - 1/2\tilde{\beta}, \\ \pi_B(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, r, v) &= 1/2R(\alpha, \beta) - \beta - 1/2R(\tilde{\alpha}, \tilde{\beta}) - 1/2\tilde{\alpha} + 1/2\tilde{\beta}.\end{aligned}$$

The remaining $1/2R(\alpha, \beta)$ is part of the solicitor's payoff. If A validates and B does not, payoffs are determined analogously.

In case both players choose non-validation, that is, they accuse each other of misreporting, independent of the scenario under consideration no payments are settled and cooperation breaks down, thus, $\pi_A(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, r, r) = -\alpha$, $\pi_B(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, r, r) = -\beta$.

Now we have stated the payoffs following from an initial contract that covers all possible modes of behaviour under the third-party and the market-based scheme. Yet, there might be incentives to renegotiate. Thus, before we can enter a backward-induction analysis of the game to describe possible equilibrium paths of the game, we have to analyze possible renegotiation scenarios.

4 Analysis

4.1 Third-party scheme

In this setting we assume that parties have developed a contract that includes a solicitor as an active party to the game. To start a backward-inductive analysis of the different stages of the game, we have to determine final payoffs. As follows from the description in section 3, the payoff matrix of the authentication stage (that is, when real investments α, β and messages $\tilde{\alpha}, \tilde{\beta}$ are fixed) in the third-party scheme takes the form shown in Table 1.

Here, “subsidy A ” denotes the net subsidy A receives which equals $1/2\tilde{\alpha} - 1/2\tilde{\beta}$ (correspondingly for B) and “damage to A ” is the above-named pay-

A/B	v	r
v	$\pi_A = 1/2R - \alpha + \text{subsidy A}$ $\pi_B = 1/2R - \beta + \text{subsidy B}$	$\pi_A = 1/2R - \alpha - \text{damage to B}$ $\pi_B = -\beta + \text{damage to B}$
r	$\pi_A = -\alpha + \text{damage to A}$ $\pi_B = 1/2R - \beta - \text{damage to A}$	$\pi_A = -\alpha$ $\pi_B = -\beta$

Table 1: Authentication game under the third-party scheme *before* renegotiations

ment $1/2R(\tilde{\alpha}, \tilde{\beta}) + 1/2\tilde{\alpha} - 1/2\tilde{\beta}$ (again correspondingly for B). The payment of $1/2R(\alpha, \beta)$ for the solicitor is not included in this payoff matrix.

To cover all strategic options, we have to check if parties want to enter renegotiations. We assume that renegotiations are possible but costly where c is the (lump sum) renegotiation cost to be borne by each party.⁹ An analysis of all entries of the payoff matrix yields:

If both parties have validated each other's report, there is no room for renegotiations as there is no additional rent to be shared. In contrast, if both parties have rejected each other's report, they lose $1/2R(\alpha, \beta)$ each according to the original contract. Thus, as long as c is small enough there might be scope for renegotiations.¹⁰

As the original contract is not valid anymore once renegotiations have started, the division of revenue will now be subject to bargaining. We assume that parties have symmetric bargaining power. Following Rubinstein's (1982) model of bargaining we assume that in equilibrium a split according to

⁹We have assumed that parties are risk neutral – thus, renegotiation costs are modelled as a fixed payment. Maskin and Moore (1999) allow for risk averse parties. In that case renegotiation costs can be covered by an uncertain outcome of the renegotiations – which leads to a fixed payment under a risk-premium calculation.

¹⁰We actually assume that $c < 1/2R(\alpha^{sb}, \beta^{sb})$ as a regularity condition that is explained in the proof of proposition 1. This assumption suffices to keep renegotiations possible in all relevant scenarios.

A/B	v	r
v	$\pi_A = 1/2R - \alpha + \text{subsidy A}$ $\pi_B = 1/2R - \beta + \text{subsidy B}$	$\pi_A = 1/2R - \alpha - \text{damage to } B$ $\pi_B = -\beta + \text{damage to } B$
r	$\pi_A = -\alpha + \text{damage to } A$ $\pi_B = 1/2R - \beta - \text{damage to } A$	$\pi_A = 1/2R - \alpha - c$ $\pi_B = 1/2R - \beta - c$

Table 2: Authentication game under third-party payments

the Nash-bargaining solution results: an equal division of the rent to be shared. Thus, each party receives $1/2R(\alpha, \beta)$. In consequence, parties receive $\pi_A^{RN}(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, r, r) = 1/2R(\alpha, \beta) - \alpha - c$ and $\pi_B^{RN}(\alpha, \beta, \tilde{\alpha}, \tilde{\beta}, r, r) = 1/2R(\alpha, \beta) - \beta - c$ after renegotiations.

If there has been unilateral rejection, partners want to regain the lost $1/2R(\alpha, \beta)$.

But, as this part of the surplus now belongs to the solicitor, he will prevent any further agreement – and the original payoff remains unchanged.

In sum, the payoff matrix at the authentication stage including possible renegotiations is shown in Table 2. A detailed pay-off structure is given in the appendix within the proof of proposition 1.

Based on Table 2 we can start backward induction by analysing Nash equilibria of the authentication stage including renegotiations.

For the analysis to follow it is important to recall that messages are capped at α^* and β^* . Thus, investments above the efficient level – may they be real or just reported – are not supported by subsidies and will not occur as long as players are rational. Accordingly, for sake of simplicity we will not address the possibility of overinvestment.

At the authentication stage, validation is a best response to validation as long as $R(\alpha, \beta) \geq R(\tilde{\alpha}, \tilde{\beta})$. In addition, in this case rejection is a best response to rejection if $c \leq 1/2R(\alpha^{sb}, \beta^{sb})$.¹¹ Thus, if $R(\alpha, \beta) \geq R(\tilde{\alpha}, \tilde{\beta})$

¹¹From A 's perspective validation is a best response to rejection if both parties have significantly underreported, B has chosen a low report and A himself has considerably

(which means that either no party has overreported or one has over- and the other sufficiently underreported), there are two Nash equilibria of the authentication game: (v, v) and (r, r) .

In case of bilateral overreporting or high unilateral overreporting ($R(\tilde{\alpha}, \tilde{\beta}) > R(\alpha, \beta)$), (v, v) is not a Nash equilibrium anymore. However, (r, r) remains as a Nash equilibrium.

Now we know that (v, v) or (r, r) are the results to be expected from the authentication stage and we turn to the reporting decision. At this stage investments have taken place such that α and β are given. We distinguish two cases: (1) Both parties have invested efficiently; (2) at least one party has chosen underinvestment.

(1) Both have invested efficiently ($\alpha = \alpha^*$ and $\beta = \beta^*$):

In that case, overreporting is not a meaningful alternative as reports get cut at α^* and β^* . Thus, for all reports $R(\alpha, \beta) = R(\alpha^*, \beta^*) \geq R(\tilde{\alpha}, \tilde{\beta})$ holds which implies that either mutual validation or mutual rejection result.

Under mutual validation A 's payoff is

$$\pi_A(\alpha^*, \beta^*, \tilde{\alpha}, \tilde{\beta}, v, v) = 1/2R(\alpha^*, \beta^*) - \alpha^* + 1/2\tilde{\alpha} - 1/2\tilde{\beta}$$

which is strictly increasing in $\tilde{\alpha}$ and therefore takes its maximum at $\tilde{\alpha} = \alpha = \alpha^*$.

Under mutual rejection A 's payoff is

$$\pi_A(\alpha^*, \beta^*, \tilde{\alpha}, \tilde{\beta}, r, r) = 1/2R(\alpha^*, \beta^*) - \alpha^* - c$$

which is independent of $\tilde{\alpha}$. The same considerations apply for player B .

Thus, if efficient investments have taken place, truthful reporting is a weakly dominant strategy for both players.

(2) At least one player has chosen underinvestment ($\alpha \leq \alpha^*$ and $\beta \leq \beta^*$ and at least one inequality is strict):

overreported such that $2c \geq R(\tilde{\alpha}, \tilde{\beta}) + \tilde{\beta} - \tilde{\alpha}$. For B these considerations hold analogously. Due to our assumptions on c and the production function, these cases can be excluded. Details are given in the proof of proposition 1.

In that case there is scope for overreporting for any party that has made a less-than-optimal investment. Mutual rejection can result after any combination of reports. Therefore, the argument to follow concentrates on the question of which combinations can be followed by mutual validation.

Yet, the first result is a negative one. If both parties overreport, mutual rejection will follow for sure. So, the remaining combinations are truthful reporting and pairs of under- and overreporting. As will be shown in more detail in the proof of proposition 1, mutual truthful reporting constitutes a Nash equilibrium that can be followed by mutual validation for any pair of investments. These equilibria are stabilized from two directions: If one party chooses a truthful report, the other one would not raise its revenue by overreporting as this behaviour would lead for sure to mutual rejection – which is for $2c \geq |\beta - \alpha|$ dominated by truthful reporting and mutual validation. Underreporting is as well not a best response as for the case of mutual validation a low report would reduce own subsidies and in the case of mutual rejection payments are not influenced by reports.

In addition, there are combinations where one party overreports and the other one chooses a balancing underreport. Here, “balancing” means that the combination of reports still allows for mutual validation to follow. To do so, the condition $R(\alpha, \beta) \geq R(\tilde{\alpha}, \tilde{\beta})$ needs to hold. Yet, if both parties choose mutual best responses, the underreporting party will receive exactly the same payoff under subsequent mutual validation as under mutual rejection.

In sum, at the reporting stage a number of paths could be part of a subgame-perfect Nash equilibrium: (1) Truthtelling and mutual validation or mutual rejection; (2) if investments have been inefficiently low, combinations of under- and overreporting and mutual validation or mutual rejection. Thus, independent of the play at the reporting stage, mutual validation or mutual rejection might follow. So, parties might end up with a payoff without subsidies no matter which reports have been chosen.

If we now turn to the investment stage, this result implies that a course of the game where both parties choose second-best investments, report truthfully,

and reject each other's message cannot be excluded. Accordingly, the second-best solution is on the path of a subgame-perfect equilibrium of the game and cannot be excluded by a contracting mechanism.

However, as long as truthful reporting is a best response to truthful reporting independent of investment levels, efficient investments can be part of a subgame-perfect equilibrium. This latter property depends on the magnitude of renegotiation costs. Thus, we can show that a subgame-perfect equilibrium exists where both parties choose first-best investments if renegotiation costs are sufficiently high.

Proposition 1. *1. If renegotiation cost are sufficiently high, that is $2c \geq \alpha^* - \alpha^{sb}$, the game based on the above third-party contract scenario has a subgame-perfect equilibrium in which both players choose first-best investments, report truthfully, and mutually validate reports.*

If the initial contract is costly, this equilibrium is the only forward-induction-proof equilibrium of the game.

2. If $2c < \alpha^ - \alpha^{sb}$, Che and Hausch's (1999) negative result applies and first-best investments cannot be implemented by a contract in the third-party scenario.*

3. Independent of the contract parameters there is a subgame-perfect equilibrium that leads to second-best investments.

The proof is given in the appendix of the paper.

The result on uniqueness under forward induction is based on the following considerations: No contract can rule out shirking behaviour for sure. If one of both parties wants to choose second-best investments, it can turn this behaviour into a part of a Nash-equilibrium strategy by choosing rejection in the final stage of the message game. Yet, if a party has no interest in cooperative behaviour there is no need to bear the cost of writing a sophisticated contract whose unique aim is to overcome the underinvestment problem. Put it differently: A party that is willing to incur the cost of contracting sends a

A/B	v	r
v	$\pi_A = 1/2R - \alpha + \text{subsidy A}$ $\pi_B = 1/2R - \beta + \text{subsidy B}$	$\pi_A = R - \alpha - \text{damage to } B - d$ $\pi_B = -\beta + \text{damage to } B$
r	$\pi_A = -\alpha + \text{damage to } A$ $\pi_B = R - \beta - \text{damage to } A - d$	$\pi_A = -\alpha$ $\pi_B = -\beta$

Table 3: Authentication game under the market scheme *before* renegotiations

signal that it wants to get a higher payoff from cooperation than it could have by the second-best result always at hand. Thus, by burning the money for writing the initial contract, players select the equilibrium that implements the first-best outcome.

4.2 Market scheme

The analysis of the market-based contract is analogous to that of the contract under third-party payments. However, as the payoff matrix at the authentication stage differs from that under the third-party scheme, backward induction may take a different path.

The original payoff matrix at the authentication stage ($\alpha, \beta, \tilde{\alpha}, \tilde{\beta}$ are already chosen) in the market-based scenario is shown in Table 3. Yet, to start a backward-inductive analysis we have as before to determine final payoffs by checking incentives for renegotiations.

Again, mutual validation is renegotiation proof whereas mutual rejection leads to renegotiation if $c < 1/2R(\alpha^{sb}, \beta^{sb})$ (see footnote 10 on page 13).

Unilateral rejection deserves a closer look under the market scheme than under the third-party scheme. Here, the proceedings stipulated by the original contract would have one party leaving the business which induces an overall loss of d as described on page 10. If partners enter renegotiations, their respective outside options would be the payment under the original contract. If

A/B	v	r
v	$\pi_A = 1/2R - \alpha + \text{subsidy A}$ $\pi_B = 1/2R - \beta + \text{subsidy B}$	$\pi_A = R - \alpha - \text{damage to B} - 1/2d - c$ $\pi_B = -\beta + \text{damage to B} + 1/2d - c$
r	$\pi_A = -\alpha + \text{damage to A} + 1/2d - c$ $\pi_B = R - \beta - \text{damage to A} - 1/2d - c$	$\pi_A = 1/2R - \alpha - c$ $\pi_B = 1/2R - \beta - c$

Table 4: Authentication game under the market scheme

we again assume symmetric bargaining power, renegotiations would lead to an equal split of d in addition to parties' initial payoffs. Accordingly, parties will enter renegotiations as long as $c \leq 1/2d$.

Thus, the payoff matrix including renegotiations is shown in Table 4. A detailed pay-off structure is given in the appendix within the proof of proposition 2.

Again, we start backward induction by analysing Nash equilibria of these final payoffs. In the determination of mutual best responses the parameter values for c (renegotiation cost) and d (continuation cost) are crucial. To find best responses to rejection and validation we therefore need to enter a case distinction on c and d .

First, we assume that $c = 1/2d$ as in this case both values cancel out for one partner after (v, r) and (r, v) .

In that case, mutual validation can result as an equilibrium – analogous to the third-party case – if $R(\alpha, \beta) \geq R(\tilde{\alpha}, \tilde{\beta})$. Yet, to check if mutual rejection is an equilibrium, we have to consider the possibility of unilateral rejection as well.

We know that r is a best response to v if $R(\alpha, \beta) \leq R(\tilde{\alpha}, \tilde{\beta})$. In that case unilateral rejection of player A (and correspondingly for player B) constitutes a Nash equilibrium of the authentication game if in addition for B v is a best response to r . This latter condition holds if

$$d \leq R(\alpha, \beta) - R(\tilde{\alpha}, \tilde{\beta}) - (\tilde{\alpha} - \tilde{\beta}).$$

Analogous considerations apply to the case where B unilaterally rejects A 's report. In sum, we can state the converse result: (r, r) constitutes a Nash equilibrium at the authentication stage if $R(\alpha, \beta) \geq R(\tilde{\alpha}, \tilde{\beta})$ and $d \geq R(\alpha, \beta) - R(\tilde{\alpha}, \tilde{\beta}) - |\tilde{\alpha} - \tilde{\beta}|$.

In a backward-induction analysis we have, thus, to consider four possible Nash-equilibrium outcomes of the authentication stage: (r, r) – which leads to payoffs that are independent of players' messages – and (v, v) , (v, r) , (r, v) whose payoffs all depend on investments as well as messages.

The analysis of those game paths leading to (v, v) and (r, r) is analogous to that of the third-party scheme as the payoffs from these paths are identical in both scenarios. Therefore, we will concentrate on the (v, r) and (r, v) cases. If unilateral rejection constitutes an equilibrium at the authentication stage, it can happen that truthtelling is not a best response to truthtelling – which it had been in all subgames of the third-party scheme. In that case a situation may result where underinvestment and overreporting is a best response to efficient investment and truthtelling. Whether such a situation may occur, depends on details of the revenue function (for details see the proof of proposition 2). Yet, we can show that

$$d \geq \alpha^* - \alpha^{sb} = \beta^* - \beta^{sb} \tag{1}$$

is a sufficient condition to exclude these cases.

As d is a measure for the loss the partner remaining in business has to accept if the other party leaves, condition (1) implies that this loss has to be substantial. From an economic perspective the loss of a business partner is substantial if his contribution to the collaboration is substantial. Therefore, condition (1) implies that our contract supports first-best investments only if there are big gains to cooperation.

In sum, if condition (1) holds, (v, r) and (r, v) can be excluded as Nash equilibria of the authentication game. In that case the further analysis is the same as under the third-party scheme. If condition (1) does not hold, cooperation may break down for a number of production functions. As we

are interested in stating conditions for successful contracting, we will not address this case furthermore.

It remains to address the cases $c > 1/2d$ and $c < 1/2d$. The latter case is analogous to the case of low renegotiation cost in the third-party scheme, that is, cheating is cheap and cooperation will break down for sure. The former case, $c > 1/2d$, leads to perturbances of a different kind. In this case, unilateral rejection would not be followed by renegotiations as explained at the beginning of the section. If renegotiations after unilateral rejection are too costly, parties would be willing to validate each other's report even if it includes a slight overreport. Therefore, each party would choose a small mark-up on its actual investments when reporting. In consequence, the subsidies paid according to the contract are higher than they would be under truth-telling. Parties account for that when choosing their investment decision. In equilibrium investments will be smaller than first-best investments but higher than second-best investments – the difference depending on renegotiation costs. In such a scenario contracting would still improve the value of cooperation but could not implement the first-best solution.

In sum, we can state

Proposition 2. *1. If the loss from one partner leaving business is sufficiently high, that is $d \geq \alpha^* - \alpha^{sb} = \beta^* - \beta^{sb}$ and the cost of renegotiation equals $1/2d$, a contract based on the market scenario has a subgame-perfect equilibrium in which both players choose first-best investments, report truthfully, and mutually validate reports.*

If the initial contract is costly, this equilibrium is the only forward-induction-proof equilibrium of the game.

2. If either the loss from one partner leaving business or the renegotiation cost are too small, Che and Hausch's (1999) negative result applies and first-best investments cannot be implemented by a contract in the market scenario.

The market-based scenario looks at first sight more appealing (at least from

a theoretical perspective) than the third-party scenario as it does not refer to an *active* third party. Yet, as the results of proposition 2 show, cooperation can only be established in a rather narrow range of parameters. So, the question arises if contracting is really valuable in such an environment. That is, we have to discuss the admissible ranges of c and d . We will address this issue in the next section within a comparative analysis of the third-party and the market-based scheme.

5 Discussion of the assumptions

The analyses described above are based on a number of assumptions: First of all, they make heavy use of two parameters treated as exogenously given, namely renegotiation cost and continuation cost. Second, the model assumes that the collaborating parties can observe each other's input although it is not observable (or verifiable) to outside parties. Third, we have assumed that parties might enter renegotiations at the end of the game but not before. All three assumptions will be discussed in what follows.

Renegotiation and continuation cost

The positive result obtained in both scenarios depends on renegotiation cost; in the market-based scenario continuation cost are important as well. Hence, two issues have to be addressed.

(1) In the third-party scenario we have stated an upper and a lower bound for renegotiation cost – both of which were essential in the proof of proposition 1. We need to show that the set of admissible parameter values is not empty. We have stated that renegotiation cost should be smaller or equal than $1/2R(\alpha^{sb}, \beta^{sb})$ and greater or equal than $1/2(\alpha^* - \alpha^{sb})$. Both conditions can hold at the same time if $1/2R(\alpha^{sb}, \beta^{sb}) \geq 1/2(\alpha^* - \alpha^{sb})$ which implies that the expected revenue is big compared to investments. Now, the contract described above is a rather complex construct and, therefore, presumably expensive. So, parties will only be apt to invest into the contracting process if the profit at stake is substantial – which fits the economic essence

of the condition. Yet, this precondition is out off the sphere of influence of the contracting parties which implies a slight restriction of the proposition's statement.

(2) In both scenarios we have stated lower bounds for the cost parameters: In the third-party scenario on renegotiation cost (as mentioned above) and in the market-based scenario on continuation cost. So, the question arises if parties can make sure that these costs are sufficiently high. To answer that question, we have to look at possible sources of each cost parameter.

In the third-party scenario renegotiation cost can be stipulated in the original contract. For instance, they could be designed as a fee to the already involved solicitor that has to be paid if (r, r) had been the outcome at the authentication stage and collaboration is resumed afterwards – which is verifiable and can, therefore, not be part of a tacit agreement to circumvent the fee. As α^* as well as α^{sb} are known in advance, parties can make sure that this fee is sufficiently high. Thus, this aspect of a successful contract lies in the sphere of the cooperating parties.

In the market-based scenario continuation cost covers on the one hand aspects of the production process and on the other hand the cost of a loss of reputation as a reliable partner for other potential collaborations. Both of these aspects are out off the sphere of both partners. Thus, in the market-based scenario there is no endogenous way to make sure that continuation costs are sufficiently high. Accordingly, the possibility to install a successful collaboration is exogenously determined.

As we have argued before, only those collaborations justify a complex contracting process where both partners are important – which implies that continuation costs are high. Yet, one problem here could be that neither the continuation cost nor the loss in reputation can exactly be evaluated in advance. So, there is uncertainty at the initial stage whether the contract will be self-enforcing or not.

In addition, proposition 2 stated that renegotiation costs have to be exactly one half of the continuation costs to support first-best investments. Thus,

even if we assume that these costs can be endogenously determined as in the third-party scheme, the implementation of this condition is much less robust than that of the third-party case.

In sum, for both scenarios success of the contracting process depends on exogenous as well as on endogenous parameters. Yet, we argue that the optimal contract is easier to find in the third-party scenario than in the pure market-based scenario. If we account for costs of the inclusion of a third party (which we have not done explicitly at the message-game stage), we can combine both scenarios: As long as potential partners are convinced that a market solution suffices to establish cooperation – which still includes set-up costs for the initial contract – they will rely on a pure market- and reputation-oriented mechanism. If, however, potential partners are uncertain as to the effectiveness of the market or assess the market mechanism differently, they can still resort to the more costly third-party scheme.

In that scenario an external solicitor is involved at two stages (at the set-up and at the message-game stage). If we transfer elements of the theoretical model to reality, we can identify correspondents for these two positions where agents with a legal education might be involved in the process of designing letters of intent. First, in the design of the initial contract it is helpful to involve an external agent to document – and maybe raise – the cost of the contract. As we have seen, making the contract costly is a device to stabilize cooperation by a forward-induction argument. Second, an outside reliably neutral party is needed at the authentication stage of the theoretical model. This fact might explain why real-world firms consult law firms during the contracting process in addition to their own legal departments.

In sum, both aspects of our model together might add some insight to the question why a big law industry is involved in designing letters of intent and why these lawyers are not employees of the firms signing the contract.

Observability

The question might arise how firms get so detailed insight into their partner's activities. In particular, if we comprise that in reality cooperative projects

are tainted with considerable uncertainty, it is not at all obvious why firms should be able to observe each other's actual commitment and investment into the joint project. We think that this question can be addressed from two angles.

First, one could ask who would be apt to start a joint project. If partners know each other well and have already established long-term relations, it can well be presumed that they have a sound knowledge of each other's activities. An empirical analysis by Bönnte (2008) suggests such a connection. The author shows that firms who are spatially close or have long-term relations are more prone to start cooperations and are, in addition, more willing to trust each other. Yet, as we have argued in the paragraph above, a recent development sees firms that are located far apart, in particular across different jurisdictions, starting cooperative projects. Here, we cannot assume that there is an a-priori intimate knowledge of each other's corporate structure. Thus, it is not clear in how far these partners could have mutual knowledge that is superior to that courts could gain. In that case the second explanation applies.

Second, if there is no natural way to ensure observability, firms can design institutions that help to establish observability. Within simpler settings, the information from the business plan and those facts that are exchanged within the letter-of-intent system can provide observability. Although the business plan and the messages exchanged at ex-interim meetings can be checked by third parties – and are, thus, verifiable in our definition – these meetings allow for an exchange of informal messages that satisfy the informational needs of the project partners but cannot be assessed by outsiders. Another possibility that establishes a long-term communication is to exchange team members. So, if one employee of firm A works at firm B and vice versa, both firms gain a basic knowledge of the other one's activities. Such an exchange on the one hand allows for unbiased information and on the other hand prevents fraud.

Timing of Renegotiations

As Watson (2007) has shown, timing of renegotiations has a serious impact

on the structure and results of a contracting process. The author analyzes the different impacts of ex-interim and ex-post renegotiations on the implementation of first-best solutions. If we transfer this analysis to our setting, we find that there is one additional point in time where renegotiations could occur: After investments have taken place and before messages have been exchanged.

These ex-interim renegotiations could have an effect on the implementation of first-best results in the third-party scenario only. In that scenario the parties to the original contract could gain by excluding the solicitor from payments in the case of unfavorable investment decisions. However, in our setting this option does not change the implementation result. Renegotiations could only occur to avoid the outcomes (v, r) or (r, v) of the message game which would induce a payment to the solicitor and, thus, a loss of a rent to the parties to the original contract. In all other cases the message game results in division of a rent that has been fully determined by investment decisions. Renegotiations could cover side payments to prevent play along those two unfavorable paths. Yet, these outcomes would not result under rational play of the original game.

In the market-based scenario there is no difference between ex-interim and ex-post renegotiations as the enforcing effect of the loss in reputation lies far ahead from parties' interaction. So, there is no scope for ex-interim renegotiations.

6 Conclusion

We propose a contractual solution to the hold-up problem if investments are relation specific, non verifiable, and have positive cross effects on the partner's benefit. Based on Maskin and Moore's (1999) implementation result we have augmented the initial contract by a message game which turns the originally incomplete contract into a complete one. This additional mechanism provides verifiable information (acknowledged reports) that allows for

subsidy payments which help to induce efficient investments.

Our analysis provides several results that connect Maskin and Moore's approach with a negative result by Che and Hausch (1999) who show that without a means to prevent renegotiations any contract in the above setting is worthless. We have shown that the additional mechanism alone cannot prevent the incentives for underinvestment. However, if parties make use of the institutions that surround them, they can implement first-best investments by enhancing their contract by the above message game.

We have considered two such institutional settings: (1) a scenario that allows for payments to a third party and (2) a scenario where parties use the information transmission provided by the market surrounding their cooperation, in particular reputation effects. Both systems have been known before as helpful means to overcome problems of shirking in partnerships. Yet, in former work the payments used have been exogenous to the contracting problem at hand. Our analysis enriches the literature by a mechanism that provides an endogenous set of sanctions to enforce the contract. In addition, we discuss the robustness of the contractual success in supporting first-best decisions in both scenarios. We could show that the third-party scheme supports first-best decisions more often as it leaves more discretion to the contracting parties. Put it differently, the third-party mechanism could be used as a contractual means for all those cases where partners do not want to rely on the market (see the discussion in section 5).

The mechanism we have designed can be seen as a translation of the (real-world) system of writing letters of intent into theory. In legal practice such contractual devices are frequently applied. They define a series of messages or meetings where partners report on their investment into a joint project. By use of letters of intent parties are able to exchange verifiable information and signal their willingness to continue their relationship. Such stable internal mechanisms become particularly important in contracting environments where contractual terms are non-verifiable or non-enforceable – which is the case, for instance, in international cooperations where partners lack a joint

reliable legal system. Our analysis shows which elements of a letter-of-intent system are important to close this gap by private means.

We have shown that letters of intent themselves contribute to the solution of the underinvestment problem by turning unverifiable information into verifiable one. In addition, the payments to solicitors that have to be made to write these letters of intent are valuable from a contracting perspective. For, they are a means to establish cooperation. A party who is willing to pay for an accomplished contract “burns money” and therefore sends a signal that it is willing to cooperate in the contractual relationship. Such a signal is more important the less parties know about each other, the worse their reputation as a collaborator, or the more severe the underinvestment problem gets. In all these cases an expensive signal (the commissioning of a reliable external solicitor) helps to show own commitment to cooperate. Thus, as a byproduct of our analysis the law industry might appear in a better light: The fact that more and more lawyers who are more and more expensive are needed for writing contracts cannot be explained exclusively by market power and rent extraction of the law industry (which would be an obvious explanation). We would rather stress an aspect that is due to new possibilities in worldwide cooperation resulting from advancements in information technology. As worldwide communication has become cheap, firms can start cooperations that cannot rely on a proven and tested institutional framework (like long-term relation, a joint legal system, etc.). Thus, the inclusion of solicitors can be seen as a substitute for these institutions. In consequence, payments to them are costs of the realization of beneficial projects that would have been infeasible without this device. In sum, they contribute to an enlargement of the worldwide production set.

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A/B	v	r
v	$\pi_A = 1/2R - \alpha + 1/2\tilde{\alpha} - 1/2\tilde{\beta}$ $\pi_B = 1/2R - \beta + 1/2\tilde{\beta} - 1/2\tilde{\alpha}$	$\pi_A = 1/2R - \alpha - 1/2\tilde{R} + 1/2\tilde{\alpha} - 1/2\tilde{\beta}$ $\pi_B = -\beta + 1/2\tilde{R} + 1/2\tilde{\beta} - 1/2\tilde{\alpha}$
r	$\pi_A = -\alpha + 1/2\tilde{R} + 1/2\tilde{\alpha} - 1/2\tilde{\beta}$ $\pi_B = 1/2R - \beta - 1/2\tilde{R} + 1/2\tilde{\beta} - 1/2\tilde{\alpha}$	$\pi_A = 1/2R - \alpha - c$ $\pi_B = 1/2R - \beta - c$

Table 5: Extended payoffs under third-party scheme *after* renegotiation

Appendix: Proofs

Proof of Proposition 1

We prove all three claims of the proposition within a single process and start a backward analysis that takes at first the payoffs of the authentication stage into account. The results of this analysis will be used to prune the game tree. The same procedure will be applied to the message stage which allows for an analysis of the payoffs at the investment level. From this analysis the two subgame-perfect equilibria of the game will follow. The proof concludes with the application of the forward induction argument to exclude the second-best investment path.

Authentication stage:

We start our analysis with the payoff matrix of the game when renegotiations are taken into account, that is, we have a detailed look at the payoff matrix from table 2.

Here, R denotes $R(\alpha, \beta)$, that is, the true revenue, and \tilde{R} denotes $R(\tilde{\alpha}, \tilde{\beta})$, that is, the revenue that would result from reported investments. This payoff matrix is based on the third-party scenario explained in section 4.1. Thus, in case of unilateral rejection, the rejecting party receives a damage payment but has to waive its part of the revenue which goes to a third party (the solicitor). The party that remained within business is capable of continuing the project without a loss.

This subgame from table 5 has at most two Nash equilibria as will be shown

by a best-response analysis.

1) Player A 's best response to B playing r is r if

$$\begin{aligned} 1/2R - \alpha - c &\geq 1/2R - \alpha - 1/2\tilde{R} + 1/2\tilde{\alpha} - 1/2\tilde{\beta} \\ \Leftrightarrow 1/2\tilde{R} + 1/2(\tilde{\beta} - \tilde{\alpha}) &\geq c. \end{aligned}$$

B 's best response to A playing r is analogously r if $1/2\tilde{R} + 1/2(\tilde{\alpha} - \tilde{\beta}) \geq c$.

Thus, for (r, r) being a Nash equilibrium we need

$$1/2\tilde{R} + 1/2|\tilde{\beta} - \tilde{\alpha}| \geq c. \quad (2)$$

As we have assumed (see page 13) that $c \leq 1/2R(\alpha^{sb}, \beta^{sb})$ where α^{sb}, β^{sb} are rational investments without a contract following from $\frac{\partial R}{\partial \alpha} = \frac{\partial R}{\partial \beta} = 2$, condition (2) will hold for all investments and reports above $(\alpha^{sb}, \beta^{sb})$ for the following reasoning:

Condition (2) can only be hurt if \tilde{R} is low and the difference between $\tilde{\beta}$ and $\tilde{\alpha}$ is very high. Yet, the most extreme difference between reports that can actually happen is given by $\tilde{\beta} = \beta^*$ and $\tilde{\alpha} = \alpha^{sb}$. Due to the assumptions on α^{sb}, β^{sb} and α^*, β^* we know that $R(\alpha^{sb}, \beta^*) \geq R(\alpha^{sb}, \beta^{sb}) + \beta^* - \beta^{sb} = R(\alpha^{sb}, \beta^{sb}) + \beta^* - \alpha^{sb}$. Substituting this inequality into (2) we get

$$1/2\tilde{R} + 1/2|\tilde{\beta} - \tilde{\alpha}| \geq 1/2(R(\alpha^{sb}, \beta^{sb}) + \beta^* - \alpha^{sb}) - 1/2|\beta^* - \alpha^{sb}| = 1/2R(\alpha^{sb}, \beta^{sb}) \geq c$$

which holds if $c \leq 1/2R(\alpha^{sb}, \beta^{sb})$. Thus, (r, r) is always a Nash equilibrium of the considered game.

2) Player A 's best response to B playing v is v if

$$\begin{aligned} 1/2R - \alpha + 1/2\tilde{\alpha} - 1/2\tilde{\beta} &\geq -\alpha - 1/2\tilde{R} + 1/2\tilde{\alpha} - 1/2\tilde{\beta} \\ \Leftrightarrow R &\geq \tilde{R}. \end{aligned}$$

The same condition holds for B . Thus, (v, v) is a Nash equilibrium of the authentication game if $R \geq \tilde{R}$, that is, none of the players has overreported or one has overreported and the other one has chosen a balancing underreport. If $R < \tilde{R}$, r is a best response to v . In that case (r, r) remains as the only Nash equilibrium of the authentication game.

In sum, if $R < \tilde{R}$, (r, r) is the only equilibrium of the authentication game resulting in payoffs $\pi_A = 1/2R - \alpha - c$ and $\pi_B = 1/2R - \beta - c$. If $R \geq \tilde{R}$, there is an additional equilibrium (v, v) resulting in payoffs $\pi_A = 1/2R - \alpha + 1/2\tilde{\alpha} - 1/2\tilde{\beta}$ and $\pi_B = 1/2R - \beta + 1/2\tilde{\beta} - 1/2\tilde{\alpha}$.

Message stage:

We now look for Nash equilibria of the message game, that is, when investments have already been chosen. As payoffs are independent of the messages when (r, r) will be played in the continuation of the game, all messages are mutual best responses within this part of the game tree. Therefore, we concentrate at first on those combinations of messages where (v, v) can follow in the continuation of the game. To make (v, v) a possible equilibrium of the authentication game, $R \geq \tilde{R}$ needs to hold. For that we distinguish two cases: Mutual truthful reporting and onesided overreporting.

1) Assume that B has chosen a truthful message, that is, $\tilde{\beta} = \beta$.

In that case A 's payoff is strictly increasing in $\tilde{\alpha}$ if (v, v) is the outcome of the authentication game. This outcome can only occur if $\tilde{\alpha} \leq \alpha$ as this would imply $R(\tilde{\alpha}, \tilde{\beta}) \leq R(\alpha, \beta)$. Thus, A 's best response to a truthful report of B is a truthful report if A prefers the outcome after (v, v) to the outcome after (r, r) , that is, if

$$\begin{aligned} 1/2R - \alpha + 1/2\tilde{\alpha} - 1/2\tilde{\beta} &\geq 1/2R - \alpha - c \\ \Leftrightarrow 2c &\geq \tilde{\beta} - \tilde{\alpha}. \end{aligned}$$

Analogous considerations apply for B such that mutual truthful reporting is an equilibrium of the message game if $2c \geq |\tilde{\beta} - \tilde{\alpha}|$. Again, the biggest possible difference between reports – and under the assumption of truthtelling between actual investments – is given by a combination $\tilde{\beta} = \beta^*$ and $\tilde{\alpha} = \alpha^{sb}$ or vice versa. As both partners are symmetric, we know that $\beta^* = \alpha^*$ and $\beta^{sb} = \alpha^{sb}$.

Thus, we can state that truthtelling is a best response to truthtelling if

$$2c \geq \alpha^* - \alpha^{sb} = \beta^* - \beta^{sb}. \quad (3)$$

If condition (3) does not hold, two cases apply: (i) If A has chosen an inefficiently small investment, he prefers to overreport his investment to secure that (r, r) will result in the continuation of the game. Thus, overreporting is a best response to truthful reporting. In that case B has to use the considerations that will be presented in case 2) to follow. With condition (3) being invalid we will see that B will prefer truthful or overreporting in that case. (ii) If A has chosen an efficient investment, there is no scope for overreporting as reports are bounded from above by α^* . So, truthtelling is the best response to truthtelling in this case. If B has chosen an efficient investment as well, mutual truthtelling will result. Yet, if B has invested inefficiently low, his best response with condition (3) being invalid will be overreporting which again leads to case 2) below.

2) Assume that B has chosen an overreport, that is, $\tilde{\beta} > \beta$.

As reports are bounded from above by β^* this case can only occur after B has chosen an inefficiently low investment. In his decision on a best response A has to consider two possibilities: He can choose a message $\tilde{\alpha}_1$ that is close to or even bigger than α . In that case $R(\tilde{\alpha}_1, \tilde{\beta}) > R(\alpha, \beta)$ and (r, r) results for sure in the continuation of the game. Or he can choose an underreport $\tilde{\alpha}_2$ such that $R(\tilde{\alpha}_2, \tilde{\beta}) \leq R(\alpha, \beta)$ in which case (v, v) can follow in the continuation of the game. As payoffs after (v, v) are increasing for A in $\tilde{\alpha}_2$ as long as $R(\tilde{\alpha}_2, \tilde{\beta}) \leq R(\alpha, \beta)$ holds, A will choose a report $\tilde{\alpha}_2$ such that $R(\tilde{\alpha}_2, \tilde{\beta}) = R(\alpha, \beta)$.

A prefers a message $\tilde{\alpha}_2$ to a message $\tilde{\alpha}_1$ if

$$1/2R - \alpha + 1/2\tilde{\alpha}_2 - 1/2\tilde{\beta} \geq 1/2R - \alpha - c$$

which – due to condition (3) – holds for any possible combination of $\tilde{\alpha}_2, \tilde{\beta}$. Thus, if B chooses an overreport, A 's best response will be to choose a balancing underreport.

If B anticipates A 's best response to his overreport, he will choose his message either such that $\tilde{\alpha}_2 = \alpha^{sb}$ is the balancing underreport or if that is infeasible such that $\tilde{\beta} = \beta^*$. For, B 's payoff if (v, v) will be played in the continuation of the game is increasing in his message and therefore he will choose an

overreport that maximizes his payoff which is a message that is not above the threshold $\tilde{\beta} = \beta^*$ and can just be balanced by A . Thus, there is a second equilibrium where B overreports and A chooses a significant underreport.

Analogous considerations apply to the case that A has invested inefficiently low and has chosen an overreport.

In sum, we can state that after mutual efficient investments – which implies that case 2) cannot occur – mutual truthtelling is the only message choice that can be part of a subgame-perfect Nash equilibrium. Yet, if at least one party has invested inefficiently low and condition (3) holds, there are additional equilibria where one party overreports and thus exploits the other party. If both parties have chosen underinvestment, there are two asymmetric Nash equilibria as both parties could be the overreporting player. But – and this aspect is important for the claim of proposition 1 – mutual truthtelling remains part of a subgame perfect Nash equilibrium, no matter how different reports have been.

If condition (3) does not hold, mutual truthtelling will only occur after mutual efficient investments (due to a lack of alternatives). After one- or double-sided underinvestment overreporting will happen such that (r, r) is the only possible outcome of the authentication game.

Investment stage:

Now we have determined the path through the game tree that would follow each possible combination of investment decisions such that we can turn to the investment stage. We show that both efficient and second-best investments can be part of a subgame-perfect Nash equilibrium of the game.

If player A expects that player B will report truthfully after the investment stage, his best response is truthful reporting as well. Mutual truthfull reporting can be followed by mutual validation (if $2c \geq \alpha^* - \alpha^{sb}$) as well as mutual rejection. Therefore, we have to distinguish two pathes through the remainder of the game tree.

1) If truthful reporting and mutual rejection will follow, player A 's payoff

function at the investment stage from the pruned game tree is

$$\pi_A = 1/2R(\alpha, \beta) - \alpha - c.$$

This function is maximised at $\frac{\partial R}{\partial \alpha}|_{(\alpha, \beta)} = 2$ which defines player A 's best response to an investment level β of B . As an analogous argument holds for B which leads to $\frac{\partial R}{\partial \beta}|_{(\alpha, \beta)} = 2$, we know that second-best investments are a part of a subgame-perfect Nash equilibrium if players expect (r, r) at the authentication stage. This argument proves claim 3 of the proposition.

2) If $2c \geq \alpha^* - \alpha^{sb}$, mutual validation is also a Nash equilibrium of the authentication stage. In that case truthful reporting implies that A 's payoff function at the investment stage of the pruned game tree is

$$\pi_A = 1/2R(\alpha, \beta) - \alpha + 1/2\alpha - 1/2\beta.$$

This function is maximised at $\frac{\partial R}{\partial \alpha}|_{(\alpha, \beta)} = 1$ which defines player A 's best response to an investment level β of B . As again an analogous argument holds for B which leads to $\frac{\partial R}{\partial \beta}|_{(\alpha, \beta)} = 1$, we know that first-best investments are a part of a subgame-perfect Nash equilibrium if players expect (v, v) at the authentication stage. This argument proves claim 1 of the proposition.

If $2c < \alpha^* - \alpha^{sb}$, there is no mutual-validation equilibrium at the authentication stage. Thus, (r, r) is the only play to be expected which leaves second-best investments as the only subgame-perfect-equilibrium investments. This is exactly Che and Hausch's result as stated in claim 2 of the proposition.

□

Proof of Proposition 2:

The proof is analogous to that of proposition 1 as long as we can exclude (r, v) and (v, r) as equilibrium outcomes of the authentication stage. These cases provide the only differences between both scenarios. Thus, we have to check, when v and r are mutual best responses. To analyse these cases, we take a look at a detailed payoff matrix that covers the possibility of renegotiations as given in Table 6:

A/B	v	r
v	$\pi_A = 1/2R - \alpha + 1/2\tilde{\alpha} - 1/2\tilde{\beta}$ $\pi_B = 1/2R - \beta + 1/2\tilde{\beta} - 1/2\tilde{\alpha}$	$\pi_A = R - \alpha - 1/2\tilde{R} - 1/2\tilde{\beta} + 1/2\tilde{\alpha} - 1/2d - c$ $\pi_B = -\beta + 1/2\tilde{R} + 1/2\tilde{\beta} - 1/2\tilde{\alpha} + 1/2d - c$
r	$\pi_A = -\alpha + 1/2\tilde{R} + 1/2\tilde{\alpha} - 1/2\tilde{\beta} + 1/2d - c$ $\pi_B = R - \beta - 1/2\tilde{R} - 1/2\tilde{\alpha} + 1/2\tilde{\beta} - 1/2d - c$	$\pi_A = 1/2R - \alpha - c$ $\pi_B = 1/2R - \beta - c$

Table 6: Extended payoffs under market scheme *after* renegotiation

Here, as before, \tilde{R} means $R(\tilde{\alpha}, \tilde{\beta})$.

Now, from A 's perspective r is a best response to v if

$$\begin{aligned}
1/2R - \alpha + 1/2\tilde{\alpha} - 1/2\tilde{\beta} &\leq -\alpha + 1/2\tilde{R} + 1/2\tilde{\alpha} - 1/2\tilde{\beta} + 1/2d - c \quad (4) \\
\Leftrightarrow \quad 1/2R &\leq 1/2\tilde{R} + 1/2d - c.
\end{aligned}$$

As we have assumed that $c = 1/2d$, condition (4) can only hold if there had been overreporting.

If (r, v) is to be a Nash equilibrium, we need, in addition, that from B 's perspective v is a best response to r which holds true if

$$\begin{aligned}
R - \beta - 1/2\tilde{R} - 1/2\tilde{\alpha} + 1/2\tilde{\beta} - 1/2d - c &\geq 1/2R - \beta - c \quad (5) \\
\Leftrightarrow \quad \tilde{\beta} - \tilde{\alpha} - d &\geq \tilde{R} - R.
\end{aligned}$$

Thus, if condition (5) holds, depends on the size of d as well as on true and reported investments. The existence, of (r, v) as an equilibrium corrupts the implementation of first-best investments if it supports an equilibrium where one party chooses underinvestment and overreporting *and* this combination leads to a payoff for the underinvesting party that is higher than that from first-best investments, truthtelling and mutual validation. To analyse that case, assume that B has invested efficiently and reported truthfully, while A has chosen α^{sb} as investment and reported $\tilde{\alpha} = \alpha^{sb} + \varepsilon$.

In that case, A would prefer (r, v) and underinvestment to (v, v) and efficient investment if

$$\begin{aligned}
& 1/2R(\alpha^*, \beta^*) - \alpha^* + 1/2\alpha^* - 1/2\beta^* \\
\leq & -\alpha^{sb} + 1/2R(\alpha^{sb} + \varepsilon, \beta^*) + 1/2(\alpha^{sb} + \varepsilon) - 1/2\beta^* + 1/2d - c \\
\Leftrightarrow & 2\varepsilon \geq \frac{R(\alpha^*, \beta^*) - R(\alpha^{sb} + \varepsilon, \beta^*)}{\alpha^* - (\alpha^{sb} + \varepsilon)}.
\end{aligned}$$

Whether this latter condition holds for at least one value of ε depends on the revenue function and cannot be excluded by general considerations. Yet, if it holds, efficient investments, truthtelling, and mutual validation do not constitute a subgame-perfect equilibrium anymore. Therefore, to exclude this possibility, we have to make sure, that condition (5) does not hold for all possible combinations of investment.

As has been argued before, the biggest distance that might arise between investment levels is $\alpha^* - \alpha^{sb} = \beta^* - \beta^{sb}$. If investment levels have been α^{sb} and β^* and reports have been $\tilde{\alpha} = \alpha^{sb} + \varepsilon$ and $\tilde{\beta} = \beta^*$, condition (5) reads

$$\frac{\beta^* - \alpha^{sb}}{\alpha^{sb} + \varepsilon - \alpha^{sb}} + \frac{\alpha^{sb} - (\alpha^{sb} + \varepsilon)}{\alpha^{sb} + \varepsilon - \alpha^{sb}} - \frac{d}{\alpha^{sb} + \varepsilon - \alpha^{sb}} \geq \frac{R(\alpha^{sb} + \varepsilon, \beta^*) - R(\alpha^{sb}, \beta^*)}{\alpha^{sb} + \varepsilon - \alpha^{sb}}$$

which can never hold true independent of ε if $d \geq \beta^* - \alpha^{sb} = \alpha^* - \alpha^{sb}$.

Analogous considerations apply for the exclusion of (v, r) . Thus, we have found a sufficient condition to stabilize efficient investments in the market-based scenario independent of the functional form of the revenue.

□