Incomplete Contracts, Non-Verifiable Quality, and Renegotiation

Christoph Lülfesmann *
Department of Economics
University of Bonn
Adenauerallee 24-42
D-53113 Bonn

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Abstract

This paper reconsiders the hold-up problem in long term, bilateral trade relationships with specific investments. In contrast to the canonical framework of Hart and Moore (1988), we assume that the parties face several trading opportunities (goods) whose characteristics are observable but non-verifiable. Specifically, the parties can trade either an 'innovative' good of high quality or a 'standard'good of low quality. The latter is unaffected by specific investments and quality is non-contractible ex ante. In this framework, we show that a first-best result may be supported by the appropriate choice of an at-will contract even in the general case of both-sided investments. The solution to the hold-up problem requires that the alternative trade opportunity must be valuable with positive probability. Furthermore, we demonstrate that in the context of non-verifiable quality, at-will contracts strictly outperform option (specific-performance) contracts. Finally, the paper extends the renegotiation game originally developed by Hart and Moore to incorporate bargaining over multiple objects.

1 Introduction

When parties enter a long-term trade relationship, the value of their transaction can often be increased by provision of relationship-specific investments. In many situations, however, the intangible nature of these assets prevents their specification in an initial contract, and it is also infeasible to condition on benefits and production costs which would be an indirect way to assign efficient investment incentives. Accordingly, each party must fear an exploitation of its own investments by the other party in subsequent bargaining, and underinvestment may occur. Various contributions in the literature have explored this hold-up problem, but have (at least implicitly) confined attention to the case where disagreements on the object of trade are no matter of concern. This is surprising, since the incomplete-contracting paradigm often starts from the idea that the innovative nature of the object of trade prevents a sufficient description of its physical characteristics in advance. Hence, if alternative goods are available when the parties finally have to decide on trade, the initial contract has to remain silent on the differences among these goods and their respective prices. In other words, the question arises how to *identify* the object of trade ex post when it cannot be sufficiently described ex ante, which generates an additional source of conflict between the trading partners beyond their diverging interests on transfer payments. Most long-term relationships observed in reality, as, for instance, the procurement processes for military equipment or satellites, bear this additional verification problem.[1] It renders efficient trade particularly difficult when the supplier of innovations is an established producer of the class of commodities (fighter aircrafts, particle accelerators) ordered by the buyer, and can therefore easily deliver a lower-quality good rather than a more expensive, and more valuable, real innovation.[2]

The present paper raises this issue of unverifiable quality in a multi-goods variant of Hart-More (1988). Their pioneering article identified a situation where underinvestment in long-term bilateral trade cannot be avoided if both parties have to provide noncontractible specific investments to the relationship. We extend their one-good setting by supposing that the seller has an alternative good of lower quality at her disposal, and postulate that the initial contract cannot distinguish between this commodity (which will be labelled the

[1]For example, most high-tech goods consist of various components which are available in different qualities.

[2]In a different interpretation, there may be a buyer and a seller who have signed a contract for trading a good tomorrow at a specified price. In many cases, they will be aware of the possibility that a technological innovation may make an improved design available (and/or the old design redundant), but they cannot foresee the exact nature of this design change and hence cannot make a contract contingent on that event. The early survey of Holmström-Tirole (1989) already mentions this scenario.

'standard good') and a good of higher quality (labelled the 'innovation').[3]

Hart-Moore (1988) found that even the optimal long-term contract (allowing for complex revelation mechanisms) cannot overcome the hold-up problem. Moreover, the second-best contractual arrangement is a simple at-will contract which specifies only a trade and a no-trade price, and leaves the realization of trade as a voluntary decision of both parties. The subsequent literature on the hold-up problem showed that their underinvestment result crucially depends on one important assumption. In Hart-Moore, the court can only observe the realization of final trade, rather than determine individual responsibility in case of an eventual no-trade outcome. Chung (1991), Edlin-Reichelstein (1996) and, in particular, Aghion-Dewatripont-Rey (1994) analyze variable-quantity versions of the Hart-Moore model which replace this 'black box' characterization of the trade stage and allow the court to observe individual responsibilities for a no-trade outcome. Under this modification, specific-performance contracts attain a first-best result. Nöldeke-Schmidt (1995) extend this finding to the original indivisible-good setting of Hart-Moore (and use their extensive-form renegotiation game) by showing that option contracts guarantee efficient investments.[4]

The decisive difference between at-will contracting on the one hand and option/specific performance contracts on the other hand is the disagreement point in renegotiations. While the realization of trade in Hart-Moore (i.e., under at-will contracting) requires a common agreement of both parties, this consensus is not needed under a contract-specific environment where the court observes individual delivery and acceptance decisions. In many empirically relevant situation, one must assess the latter assumption on verifiability as reasonable. Therefore, the positive implementation results mentioned above suggest that the holdup problem can easily be resolved by means of even simple contractual arrangements.[5]

All these articles, however, neglect the fact that contractual incompleteness may give rise to disputes on the identity of the object of trade ex post.[6] As has been argued above,

[3]Even if a standard good is describable in advance, it is reasonable to assume that a seller can modify the standard design to make it look like a newly invented commodity. Examples of such behavior are frequently observed, and are notorious in government procurement of military equipment.

[4]Under this contract type, the decision on final trade essentially rests with the seller who holds the option to deliver. A similar result has been obtained by Hermalin-Katz (1993).

[5]Efficient investments are not feasible if the parties' investments are not of a self form: Che-Hausch (1996) and Edlin-Hermalin (1997) show that not even complete contracting involving revelation mechanism can guarantee efficiency if the seller's investments increase the buyer's valuation.

[6]The literature surveyed above considers either a one-good world or, alternatively, assumes that the court can unambiguously distinguish between all project designs. An exception is Nöldeke-Schmidt (1995), who investigate the case of multiple innovations, and demonstrate that under some technical conditions a first-best result still applies if a nonempty subset of innovations is desctribable in advance; see subsection

this assumption is somewhat delicate, since a main motivation for incomplete contracting is that the object of trade is undescribable ex ante. We will refer to this issue as a quality-choice problem. To isolate the argument, imagine an - admittedly unrealistic - situation where *no* physical attribute of the object of trade can be fixed in the initial contract. In this extreme case, the seller might deliver *anything* claiming that this was the good which was ordered. Even in more realistic situations where the initial contract can specify a certain subset of characteristics, she still has an inherent incentive to deliver a cheaper (and presumably lower-quality) version to the buyer. We model this problem by assuming that the seller disposes of two goods, whereby the initial contract cannot distinguish between the (high-quality) innovation which is developed only in course of the relationship, and the low-quality 'standard good' whose technological characteristics have already been established. It is thus natural to assume that the investments of both parties affect only the expected value and the expected production costs of the innovative design. Only after the state of the world has been revealed, the parties can make both versions of the good distinguishable for the court if this in in their mutual interest.

Our main results are as follows:

1. The presence of multiple unverifiable qualities reverses the efficiency properties of contracts relying on voluntary trade (at-will contracts) and contracts enforcing a disagreement point with positive level of trade (option or specific performance contracts).

2. The hold-up problem may be resolved by at-will contracting even if both parties invest in relationship-specific assets.

The latter outcome stands in sharp contrast to the main result of Hart-Moore. It demonstrates that the existence of a quality-choice problem can restore an efficient outcome. We establish a necessary condition for the validity of this surprising result: Trade of the low-quality good (which requires no specific investments) must sometimes be ex-post efficient. This requirement will frequently be met in situations where the buyer prefers the development of advanced projects to the purchase of a standard good from an ex ante point of view, but cannot dispense with a substitute if the development of the innovation is not successful, or the innovations turns out to be prohibitively costly. The intuition for our finding rests on two effects: First, the existence of a standard good makes trade more likely, and hence insures the parties against states of the world where the innovation fails to generate a positive surplus. Obviously, this insurance decreases the efficient investment level. Second, surplus-sharing in the canonical one-good model reduces the parties' investment incentives. While this feature still applies to our model in states where the innovation is

4.2 below.

traded ex post, surplus-sharing *increases* the parties' investment incentives relative to the first-best in states of the world where trade of the standard good is efficient. These effects possibly offset each other in equilibrium and, hence, a first-best outcome may be feasible.

The first result suggests that the virtues of option or specific-performance contracts vanish when a quality-choice problem arises. The intuition here is straightforward. In contrast to at-will contracts, option or specific-performance contracts do not restrain the seller's incentive to deliver inferior quality: While the buyer can reject bad quality if trade is voluntary, he has no means to do so when the seller can insist on trade. While ex-post efficient trade can still be assured in renegotiations, we show that the seller has no investment incentives at all under option contracting.

The present paper considers the renegotiation game originally developed in Hart-Moore (1988). We extend this game in that quality choice and the correponding issue of trade over multiple objects are incorporated into the renegotiation process. In particular, the projects' characteristics may now be specified in the course of renegotiation. This is a natural assumption given that the state of the world has been realized and the physical attributes of the inovation have become clear. We show that the success of this 'ex-post verification' depends on the strategic interests of both parties, and is a frequent element of renegotiation on the equilibrium path.[7] The outcome of renegotiations largely corresponds to the original one-good setup. In particular, while renegotiations occur if one party does not agree to efficient trade under the initial terms of contract, the other party holds all renegotiation power. This property is very plausible in renegotiations: It makes bargaining strength dependent on the alternative events that the initial trade was 'too high' or 'too low'.[8] However, one main difference emerges: In situations where the seller can credibly threat to deliver a low-quality good under the initial terms of contract, his disagreement payoff increases relative to the one-good setup. This outcome bears resemblance with the 'outside option principle' [Shaked-Sutton (1984)] of the bargaining literature although, in the present context, the outside option is exercised within the relationship.

Some variations test the robustness of our results. First, while only one low-quality standard project exists in the basic framework, we later allow for any number of standard

[7]We confine our attention to the case of unverifiable messages [case (A) in Hart-Moore (1988)]. Their paper demonstrates that the outcome remains largely unchanged if messages are verifiable and standard revelation games become feasible. We ignore the case of verifiable messages in order to avoid additional complexity and because a first-best result may already be obtained even if revelation games are ruled out. We conjecture, however, that - as in Hart-Moore - revelation games do not improve upon the outcome of simple contracts as long as the court cannot observe the responsibility for a no-trade outcome.

[8]In contrast, the outcome of Nash-bargaining (and the strategic Rubinstein-game) would be unaffected by the identity of the party which credibly refuses to trade under the initial terms of contract.

goods, and show that our main results still apply. Second, we suppose that the court may lack the technical knowledge to verify a project's exact physical attributes, which renders ex-post verification infeasible. Even then, a first-best result under at-will contracting is still possible. In general, however, not even ex-post efficient trade of the innovation can now be guaranteed. Finally, we impose the standard assumption that different designs can unambiguously be described in the initial contract. In this case, it is not surprising that option contracts (if they are feasible) always induce efficient investments. Although this does not generally hold for at-will contracting, we show that ex-ante verifiability of designs makes it easier to attain efficiency compared to the basic setup.

The paper is related to some other articles which have investigated quality-choice problems in long-term trade models.[9] Aghion-Tirole (1994) and Segal (1995) explore setups where it is ex ante uncertain which of many possible designs should finally be traded (i.e., which good turns out to be the innovation). While Aghion-Tirole follow a property-rights approach by assuming that an initial contract can specify only the property rights on forthcoming innovations, Segal derives the optimal complete contract in a situation where renegotiation cannot be precluded. Both articles find that a first best is not feasible even if only one party invests in relationship-specific assets. This difference to our results is mainly due to the different modelling of renegotiations. Roughly speaking, Aghion-Tirole and Segal assume that an initial contract cannot be enforced if quality is unverifiable. In contrast, our approach follows a different philosophy in that the initial terms of contract commit the parties even in presence of a quality-choice problem.

The remainder of this paper is organized as follows. Section 2 exposes the basic model (Subsection 2.1) and calculates the first-best benchmark (Subsection 2.2). Subsection 2.3 introduces our extended version of the Hart-Moore renegotiation game. Section 3 provides the equilibrium analysis. Section 4 discusses the variations mentioned above, and Section 5 concludes.

2 The Model

2.1 Setup and Stages

Two risk-neutral agents (a buyer B and a seller S) enter a long-term relationship to trade one unit of an indivisible good, frequently called the 'project'. The project can take

[9]Farrell and Shapiro (1989) examine quality choice in an incomplete-contract framework with deterministic benefits and costs; their paper focuses on a comparison between spot markets and long-term contracts.

two different forms ('designs'): First, the seller disposes of a standard good (good 1) which cannot be improved by specific investments.[10] Second, both parties can invest in an innovative version of the good (good 2). Throughout the paper, we consider a game with complete and perfect information between the parties: In particular, at each stage both parties have common knowledge on the history of the game.

Figure 1 illustrates the time structure.

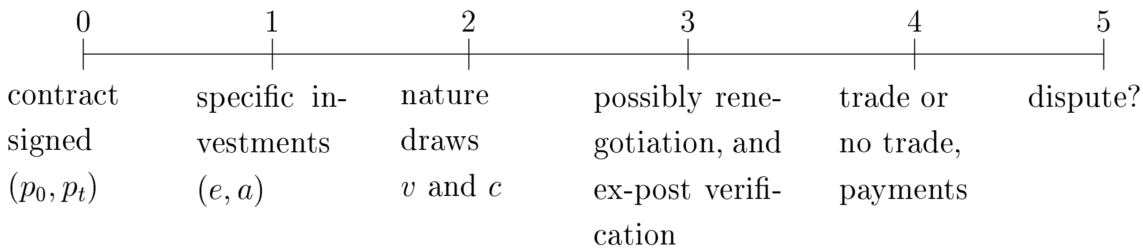

Figure 1

The relationships starts at *date 0* when buyer and seller write an initial contract. Focusing on incomplete contracting, and in line with the literature, this contract can neither be contingent on the specific investments nor on benefits and production costs of both projects. More specifically, we will suppose that the court observes only:
(1) if there is (any) trade or not, and
(2) whether the corresponding payments have been provided.

These verifiability assumptions correspond to those in Hart-Moore (1988). They differ from the verifiability assumptions made in the subsequent literature [in particular Chung (1991), Aghion-Dewatripont-Rey (1994), Nöldeke-Schmidt (1995) and Edlin-Reichelstein (1996)] in that the court cannot assign individual responsibilities for an eventual no-trade outcome. Hence, individual breach penalties, or more generally contracts which are contingent on delivery/acceptance decisions, are ruled out. This assumption will be relaxed in subsection 4.2 which investigates option contracts. As shown by Hart-Moore, the optimal contract under the verifiability assumptions (1) and (2) is an at-will contract even if complex revelation mechanisms can be played after the parties learned benefits and costs of trade. Under at-will contracting, the initial arrangement specifies only two prices, a trade price and a no-trade price, and the realization of final trade is a voluntary decision of both agents.

In the present two-goods setting, (1) and (2) additionally imply that the initial contract cannot discriminate between both versions of the project, because the court can not observe

[10] As will become clear in subsection 4.1 below, we could more generally allow for any number of standard goods.

which design is traded between the parties. The rationale behind this assumption is that the innovative design is not yet invented and, therefore, its characteristics are unknown at the start of the relationship. Moreover, even the characteristics of the standard good may not be describable ex ante if these attributes can be easily modified by the seller.[11]

Denoting quantities by $x_i \in \{0,1\}, i \in \{0,1,2\}$ (for convenience, we denote 'no trade' as trade of good 0), the court's information partition is

$$\mathcal{I} = \{(x_0),(x_1,x_2)\}, \tag{1}$$

and any enforceable contract specifies a tuple (p_0, p_t), where p_t has to be paid from the buyer to the seller if a good is traded at date 3, and p_0 if no trade occurs.

After having signed the contract, at *date 1* both parties can simultaneously provide relationship-specific investments. The buyer's (seller's) investments a (respectively e) stochastically increase (decrease) the expected gross benefit v_2 (production costs c_2) of the innovation. We indicate the corresponding convex investment cost functions as $\gamma(a)$ and $\psi(e)$, and impose the Inada-conditions in order to ensure interior solutions.

At *date 2*, nature determines the state of the world $s = (v_1, c_1, v_2, c_2) \in \mathcal{S}$, where v_i, c_i denote project i's gross value and production costs, respectively. All elements in s are drawn from independent distributions. A design with positive net surplus, $v_i - c_i > 0$, will be called a *valuable* project. Since the development of innovative design utilizes relationship-specific assets, it fits closer to the buyer's demands. Hence, we will assume that its gross benefit, v_2, always exceeds v_1. On the other hand, it is natural to argue that the innovative project has higher production costs than the standard project (we consider a product rather than a process innovation). Finally, despite its higher production costs, we suppose that trade of the innovation is efficient whenever it is valuable. Formally, these assumptions can be summarized as follows:

ASSUMPTION 1: (1) $v_2 > v_1 > 0$,
(2) $c_2 > c_1 > 0$,
(3) $v_2 - c_2 > 0 \quad \Longrightarrow \quad v_2 - c_2 > v_1 - c_1$.

The crucial parts (1) and (2) of assumption 1 imply a conflict between the parties which project should be traded: At any given trade price, the seller prefers to deliver the standard good, while the buyer favours trade of the innovation. Since we also allow for the possibility that either project may be non-valuable in some states of the world, after date 2 the agents

[11] Alternatively, any specification of the standard project is useless if its vector of attributes is a subset of the innovation's characteristics. Otherwise, the setup is equivalent to a situation where both goods can be described ex ante; see subsection 4.4.

face one of the following four situations A to D:
A: Both standard and innovative good are valuable, and the innovation should be traded;
B: Only the innovative good is valuable and should be traded;
C: Only the standard good is valuable and should be traded;
D: No good is valuable; no trade is the efficient solution.

To simplify the exposition, we will confine ourselves to an example which is sufficiently rich to provide the main insights. A general analysis based on Assumption 1 would significantly increase mathematical complexity without adding to the economic message.[12] The example which we will refer to in what follows is described in table 1.

Standard Project (x_1)	Innovative Project (x_2)
• benefits $v_1 \in \{\underline{v}_1, \overline{v}_1\}$, with $q = \text{prob}\{v_1 = \overline{v}_1\}$.	• benefits $v_2 \in \{\underline{v}_2, \overline{v}_2\}$, with $\mu = \text{prob}\{v_2 = \overline{v}_2\}$.
• costs $c_1 \equiv c$.	• costs $c_2 \in \{\underline{c}_2, \overline{c}_2\}$, $\underline{c}_2 = c + \underline{F}$, $\overline{c}_2 = c + \overline{F}$, with $\rho(e) = \text{prob}\{F = \underline{F}\}$, $\rho'(e) > 0$, $\rho''(e) = 0$.

$$\min\{\overline{v}_2 - \overline{c}_2, \underline{v}_2 - \underline{c}_2\} > \overline{v}_1 - c_1 > 0 > \max\{\underline{v}_2 - \overline{c}_2, \underline{v}_1 - c_1\}.$$

Table 1

The specifications in Table 1 ensure that any of the relevant four cases A to D occur in some states of the world. In particular, the relations in the last line of the table guarantee that the realization of the innovative project is valuable and efficient in every state of the world unless low benefits of this project and high production costs occur simultaneously. In this latter case, the innovation is non-valuable and the standard good should be produced if it is valuable, which is the case if high gross benefits $\bar{v}_1$ have been drawn by nature.

Facing a state of the world, the initial terms of contract can be revised (and extended)

[12]All subsequent results of this paper require only Assumption 1; the specification of the example is utilized only in the proof of Theorem 1 below. Moreover, while parts (1) and (2) of Assumption 1 are indispensable, part (3) is not essential as long as the presence of a standard good reduces first-best investments.

at *date 3*. These renegotiations take place in a game form originally developed by Hart-Moore (1988), which will be described in detail below (subsection 2.3). Apart from agreeing upon new transfer payments, it will now be possible to extend the initial contract with a description of the physical attributes of either project, which makes it possible for the court to verify which project is actually traded.[13] If this 'ex-post verification' takes place, the court's information partition is shifted from $\mathcal{I}$ to

$$\mathcal{I}^* = \{(x_0), (x_1), (x_2)\}. \tag{2}$$

At *date 4*, at most one of the goods is traded if both buyer and seller voluntarily agree. The corresponding transfers - initially contracted or renegotiated - are made and the game ends unless there is a dispute on payments. If such a dispute occurs at *date 5*, the court applies a decision rule (specified in subsection 2.3 below as part of the renegotiation game) to enforce either the old or a revised contract.

2.2 Objectives and First Best Benchmark

The benefit of trade accrues to the buyer. Accordingly, his utility is

$$U^B = \Sigma_{i=0}^2\, x_i[v_i - p_i] - \gamma(a) \tag{3}$$

where p_i is the equilibrium price after good $i \in \{0, 1, 2\}$ has been traded. Recall our assumption that the projects are indivisible and mutually exclusive. Thus, at most one of the goods is ex-post traded, i.e. $x_1 + x_2 \in \{0, 1\}$.

The seller bears the production costs if trade takes place and is compensated by a payment from the buyer. Therefore, her utility is

$$U^S = \Sigma_{i=0}^2\, x_i[p_i - c_i] - \psi(e). \tag{4}$$

It should be noted that any desired ex-ante distribution of the joint surplus can be achieved by an appropriate choice of the no-trade price p_0.

For future reference, let us derive the first-best benchmark.

Ex-post efficiency requires (a) that trade takes place if and only if a valuable project exists and (b) that the project with the higher net value is realized:

$$x_1^* = 1 \iff \quad \max\{v_1 - c, v_2 - c_2, 0\} = v_1 - c \tag{5}$$

$$x_2^* = 1 \iff \quad \max\{v_1 - c, v_2 - c_2, 0\} = v_2 - c_2 \tag{6}$$

$$x_0^* = 1 \iff \quad \max\{v_1 - c, v_2 - c_2, 0\} = 0. \tag{7}$$

[13]This scenario is quite natural: After the state of the world has been realized, there exist blue prints of both versions of the project which can be handed over to the court in case that the parties decide to do so.

Ex-ante efficiency implies welfare-optimal specific investments e^* and a^*, respectively. Under the assumptions of table 1, the efficient investment levels maximize

$$\begin{aligned} \mathcal{W} &\equiv U^S + U^B = \mu(a)\rho(e)(\bar{v}_2 - \underline{c}_2) + \rho(e)(1-\mu(a))(\underline{v}_2 - \underline{c}_2) \\ &+ (1-\rho(e))\mu(a)(\bar{v}_2 - \bar{c}_2) + (1-\rho(e))(1-\mu(a))q(\bar{v}_1 - c) - \gamma(a) - \psi(e). \end{aligned} \tag{8}$$

The corresponding (necessary and sufficient) first-order conditions for a unique interior maximum are

$$\mathcal{W}_e(a^*, e^*) = 0 \quad \Leftrightarrow \quad \rho_e(e^*)\{(1-\mu(a^*))[\underline{v}_2 - q(\bar{v}_1 - c)] + \mu(a^*)\bar{c}_2 - \underline{c}_2\} - \psi_e(e^*) = 0 \tag{9}$$

and

$$\mathcal{W}_a(a^*, e^*) = 0 \quad \Leftrightarrow \quad \mu_a(a^*)\{\bar{v}_2 - \rho(e^*)\underline{v}_2 - (1-\rho(e^*))[\bar{c}_2 + q(\bar{v}_1 - c)]\} - \mu_a(a^*) = 0. \tag{10}$$

The efficient investments implicitly defined by (9) and (10) will be used as a benchmark for comparison with the actual choice of investments in the equilibrium of the game. A *first-best result* is established if both ex-ante and ex-post efficiency are attained in subgame-perfect equilibrium.

2.3 Renegotiation Game and the Sequencing of Trade

After the state of the world has been revealed, the parties can revise the initial terms of contract. We assume that these renegotiations follow a game form introduced by Hart and Moore (1988), but extend the parties' strategy spaces to allow for an ex-post verification of the alternative goods.[14] This renegotiation game essentially consists of two different subgames, a *revision game* at date 3 and a *dispute game* at date 5. In between, physical trade can be carried out at date 4.

Revision Game

At date 3, the parties can renegotiate the initially contracted prices as follows: Both parties can simultaneously exchange messages whose delivery is unverifiable for the court. After a submission, the receiver holds (prior to date 4) a message of his trade partner in hands,

[14] We start from a simplified version of the Hart and Moore renegotiation game which was developed by Nöldeke and Schmidt (1995). The main differences to the original formulation are that (a) messages can only be sent at one certain point in time, so that the revision game is reduced to a one-shot game with simultaneous moves, and (b) the strategy spaces are restricted to new price offers (i.e. contingent clauses, for example, are not allowed). The Nöldeke-Schmidt approach avoids technical problems inherent in the Hart-Moore formulation without violating the spirit of the idea; for details, see their paper.

which is interpreted as a new contract offer. Legally, the offer becomes relevant only if the receiver accepts the new proposal by revealing it to the court in the dispute game which is possibly played at date 5.

As in the original Hart-Moore version of the revision game, messages can include new price offers. In addition, however, they may contain a description of the physical attributes of either project, which are now describable after the veil of uncertainty has been resolved. We assume that the court will be able to check the conformity of the good which was traded and the listed vector of attributes in a message if it comes to know this message at date 5.[15]

The exact specification of the parties' strategy spaces at date 3 is as follows:

(R1) 'Ex-post Verification'

The message can include a detailed description of the physical attributes of one (or two) goods. The vector of attributes of good i is labelled V_i, $i \in \{1,2\}$.[16]

(R2) Price Revision

The message can consist of (or include) a new price offer, which can be any $p_0^k, p_t^k, k \in \{B,S\}$ if the offer does not contain a verification element, or p_0^k, p_i^k if the offer includes V_i (multiple offers (p_i^k, V_i, p_j^k, V_j) for $j \neq i$ are feasible).[17]

Denote a message submitted by party k as O^k. Then, an *unconditional* offer of party k is (at most) the tuple $O^k = (p_0^k, p_t^k)$. A *conditional* offer which is tendered to the trade partner includes a verification-element, and is (at most) $O^k = (p_0^k, p_1^k, V_1, p_2^k, V_2)$. In the following, we will frequently refer to such messages as V-offers.[18]

Note that ex-post verification makes sense only in combination with a new price offer. Moreover, it is not a necessary element of the parties' messages - they are free to tender an unconditional offer, or no offer at all. We should also emphasize that date 3 is the only date in the game where a physical description of the projects is both possible and useful: At earlier dates, the parties themselves do not know the characteristics of both

[15]In certain economic situations, the opposite assumption seems also reasonable: Although the parties are able to define a good exactly, the court may not have the (for example, technical) ability to check whether the specified good corresponds to the object of trade. In this case, ex-post verification is not possible. We will analyze this modified setup in subsection 4.2. below.

[16]In principle, even a non-existing good could be described in a message. Given the court's decision rule as specified below, however, such a specification is strategically irrelevant [for a formal proof, see Lülfesmann 1996)].

[17]'Blanks' are also allowed; for example, partial offers (p_0^k, p_i^k, V_i) or (p_i^k, V_i) are feasible.

[18]A V_{ij}-offer is a message $O^k = (p_0^k, p_i^k, V_i, p_j^k, V_j)$, $i,j \in \{1,2\}$, while a V_i-offer is a message $O^k = (p_0^k, p_i^k, V_i)$. Of course, p_0^k does not have to be part of the message in either case.

projects (or, at least, they are not able to unambiguously state the differences between the standard good and an innovation); after trade, verification cannot succeed since the allocative decisions have already been taken, and the parties face a constant-sum game with respect to payments.

Trade Decision

At date 4, both parties have to decide on the realization of physical trade. We assume the following sequential structure: First, the seller decides whether to produce one of the goods and to deliver it to the buyer. Second, the buyer can accept the delivery, in which case final trade is realized, or reject. After a rejection, the good immediately depreciates which renders later trade impossible. In addition, transfer payments are made.

Dispute Game

Dispute occurs if one of the parties does not agree with the realized payments and files a lawsuit against his trade partner.[19] In this dispute game, each party $l \in \{B, S\}$ can reveal a message O^k to the court which was submitted by $k, k \neq l$ at the revision stage. This revelation of messages occurs simultaneously. It can be interpreted as a public signing of a new contract offer submitted by the other party. As an outcome of the dispute game, the court enforces the following set of decision rules: The initial contract remains valid unless

1. exactly one of the parties l presents a revised contract O^k referring to a date-4 allocation as observed by the court; or

2. both parties present new contracts, which refer to the physical outcome at date 4 as observed by the court, and do not contradict each other with respect to payments.

According to these decision rules, the court enforces new contracts if it observes new relevant evidence, and is not irritated by contradictory revised contracts.[20] Relevant evidence means that the allocative outcome of the trade stage is in line with the specifications in the new contract, while irrelevant offers are considered as nonexisting by the court. Conflicting evidence hence arises if both parties present new relevant contracts which contradict each other with respect to payments.

[19]Since the parties can anticipate the court's decision, a dispute will never occur in any equilibrium of the game.

[20]Note that an identical price for the observed outcome does not require that both parties submit identical conditional (or unconditional) messages; a set of offers $O^k = p_t^k$, $O^l = (p_i^l = p_t^k, V_i)$ is treated as 'identical' in this sense if good i has been traded (if j has been traded, O^l is ignored by the court and 1. applies), while O^k is relevant since it refers to trade of any good.

3 Equilibrium Analysis

3.1 Ex-post Decisions - Renegotiation and Trade

After the state of nature has been realized, the parties may revise the initial contract at date 3, engage in trade and exchange transfer payments at date 4, and take legal steps against each other at date 5.

The following proposition summarizes the subgame-perfect equilibrium outcome of the renegotiation/trade stages of the game:

Proposition 1: *For any state of the world and any initial price arrangement, there exists an ex-post efficient subgame-perfect equilibrium (SPE) under at-will contracting. In this equilibrium, the renegotiation power is endogenously assigned to the party which prefers efficient trade to all other allocations under the initial terms of contract. Specifically,*

(1) if no project is valuable (case D), no trade is the (unique) equilibrium allocation, and p_0 is paid from the buyer to the seller.

(2) If only one design - project $i, i \in \{1, 2\}$ - is valuable (cases B and C), trade at p_t is the (unique) equilibrium outcome if both parties prefer trade of i to no-trade, i.e. if $v_i \geq p_t - p_0 \geq c_i$. If only party $k, k \in \{B, S\}$ agrees to trade i at p_t, renegotiation induces an equilibrium trade price which makes the other party l just indifferent between trade and no trade at p_0.

(3) If both goods are valuable (case A), but trade of innovation is efficient (Assumption 1), the equilibrium outcome in (2) still applies (replace good i by good 2) unless $v_1 \geq p_t - p_0 \geq c_1$. In this latter case, where the buyer even accepts the standard project, renegotiation induces efficient trade of the innovation at an equilibrium price $p_t + F$, which makes the seller indifferent between trade of good 1 and good 2.

Neglecting pareto-dominated equilibria, the above equilibrium outcomes are unique unless $v_1 < p_t - p_0 < c_2$ in case A. For price differences in this interval, there exists an additional undominated and inefficient SPE, in which the standard good is traded at a price $p_0 + v_1$ which makes the buyer indifferent between trade of x_1 and no-trade. Finally, unless $p_t - p_0 \geq max\{v_1, c_2\}$, ex-post verification is a necessary element of the parties' equilibrium strategies in case A.

Proof: See appendix; Corollary 1 summarizes equilibrium trade prices.

The proposition asserts that the spirit of the Hart-Moore renegotiation game carries over to the present framework of multiple trading opportunities. In particular, the party which agrees to efficient trade under the initial terms of contract endogenously holds the whole renegotiation power (at least in the efficient equilibria). This realistic characteristic distinguishes the Hart-Moore renegotiation game from the outcome of a more familiar noncooperative bargaining procedure - the Rubinstein-game - where the outcome of renegotiations would be unaffected by the identity of the party which refuses trade under initial prices.

If at most one of the goods is valuable (cases B, C and D), Proposition 1 restates the outcome in Hart-Moore (1988); in the corresponding states of the world, only efficient equilibria exist (as long as pareto-dominated no-trade equilibria are neglected; see appendix), and equilibrium prices correspond to those in a one-good world.

If both goods are valuable (case A), however, an additional feature emerges: Since the seller has an interest to deliver the cheaper standard project, her disagreement utility is now determined by the maximum of (a) her no-trade payoff, and (b) the payoff she can attain if successful delivery of the standard project is possible at the initial prices.[21] This possible upward-shift of the seller's default point resembles the 'outside option principle' [Shaked-Sutton (1984)] which holds in a modified Rubinstein bargaining game where one of the parties has the option to terminate negotiations and engage in outside trade. As in this framework, the distribution of bargaining power is not influenced by the existence of an outside option, while the disagreement payoff of the option holder increases. In contrast to the Rubinstein-game, however, the exercise of a trade option in our model takes place *within* the relationship, so that it may be thought of as an 'internal outside option'.

It should be emphasized that an additional (undominated) inefficient equilibrium exists in case that both goods are valuable. This equilibrium is feasible under an initial contract and a state of the world where each party prefers trade of exactly one good to no trade (i.e., $v_1 > p_t - p_0 > c_2$). Obviously, any trade requires renegotiation in this situation, but the identity of the traded good now depends on the party submitting a renegotiation offer.[22] If it is the seller who tenders a message, the best she can do is to propose a new contract where the standard good is traded at a price which makes the buyer indifferent between trade and no trade, inducing an inefficient trade equilibrium. Therefore, while the presence of a quality choice problem does not render the existence of efficient equilibria impossible in the present setup, the Hart-Moore renegotiation game now gives rise to trade equilibria in which pareto-dominated trade of the standard good is realized. When analyzing the equilibrium of the global game, however, we will see that ex-post inefficient equilibria are no matter of concern under the optimal ex-ante contract.

[21] Note that (b) becomes relevant if and only if both goods are valuable, and both parties prefer trade of x_1 to no trade under initial prices (i.e., $v_1 \geq p_t - p_0 \geq c_1$).

[22] The appendix shows that, in equilibrium, just one offer will be submitted.

Finally, we should highlight the role of ex-post verification: Since a nonvaluable good can never successfully be delivered under at will contracting, its existence can never influence the parties' strategic options (cases B, C abd D). In contrast, ex-post verification is needed in equilibrium when both goods are valuable, and the seller's 'internal outside option' to deliver the standard project binds.[23]

Remark 1 If a conditional offer can refer to just one of the goods (i.e., V_{ij}-offers are ruled out), there exists a unique undominated and efficient SPE over the entire range of possible ex-ante prices. Reconsider case A and the 'problematic' interval $c_2 > p_t - p_0 > v_1$ (the analysis of all other price intervals is identical to the one summarized in Proposition 1). Under restricted V-offers, the unique undominated equilibrium outcome is now trade of x_2 at a price $p_2^e = p_0 + v_1 + F$, implying that the seller's production rent is identical to the standard good's net value. To verify this claim, assume a seller's offer $O^S = (p_1^S = p_0 + v_1, V_1)$. Given this offer, the buyer's best response is a counteroffer $O^B = (p_2^B = p_0 + v_1 + F, V_2)$. It is easy to check that these strategies form an equilibrium, and the corresponding outcome is the one stated above. Therefore, uniqueness of an ex-post efficient result can be restored by a restriction of the parties' strategy spaces, which is due to the fact that no party can now 'block' a renegotiation offer submitted by his trading partner.

Remark 2 Imagine that ex-post verification is not possible, for example, because the court is not equipped with the technical abilities to verify the physical descriptions of either project. In this case, one can show that no ex-post efficient equilibrium exists in case A for initial prices $p_t - p_0 < v_1$. The intuition for this result is as follows: At these initial prices, the buyer prefers trade of the standard good to no trade. Hence, the seller will - without renegotiation - always deliver the cheaper standard project (if any), so that trade of the innovation requires a buyer's renegotiation offer $p_t^B \geq p_0 + \max\{v_1, c_2\}$. Suppose that such an offer is submitted. Then, the seller can always tender a counteroffer inducing an (unconditional) trade price $p_t^e = p_0 + v_1$, and successfully deliver the standard good (Lemma 3; see appendix).[24] As a result, the innovation cannot be traded in equilibrium. The equilibrium outcome is inefficient, and the trade price of the standard good is identical to the one-good case. For initial contracts from the complementary interval $p_t - p_0 > v_1$,

[23] This is the case if $p_t - p_0 > \max\{v_1, c_2\}$ in case A; see the Appendix and Remark 2 below.

[24] To complete the proof, imagine a buyer's offer which makes the seller indifferent between trade of x_1 at $p_t^e = p_0 + v_1$ and efficient trade of the innovation, i.e. $p_t^B = p_0 + v_1 + F$. Given this offer, the seller will either submit an identical counteroffer or no offer at all. But, in either case, the buyer's best response is to tender an offer which induces efficient trade at a price $p_t^e = p_0 + c_2$. Anticipating this unprofitable outcome, the seller will respond by a counteroffer where x_1 is traded and the seller gets a positive production rent.

on the other hand, one can check that Proposition 1 fully carries over to settings in which ex-post verification is not feasible.[25]

3.2 Ex-ante Decisions - Investment Choices

We can now analyze the investment decisions at date 1. Recall from the description of the game that eight possible states can occur at date 2, which are grouped into one of the four possible cases illustrated in table 2 below. $s_k, k = i, ...viii$ denote the possible states of the world which can occur under the assumptions of table 1.

x_2 \ x_1	valuable	not valuable
valuable	A $x_2^* = 1$ $s_i = (\overline{v}_2, \underline{c}_2, \overline{v}_1)$ $s_{iii} = (\underline{v}_2, \underline{c}_2, \overline{v}_1)$ $s_v = (\overline{v}_2, \overline{c}_2, \overline{v}_1)$	B $x_2^* = 1$ $s_{ii} = (\overline{v}_2, \underline{c}_2, \underline{v}_1)$ $s_{iv} = (\underline{v}_2, \underline{c}_2, \underline{v}_1)$ $s_{vi} = (\overline{v}_2, \overline{c}_2, \underline{v}_1)$
not valuable	C $x_1^* = 1$ $s_{vii} = (\underline{v}_2, \overline{c}_2, \overline{v}_1)$	D $x_0^* = 1$ $s_{viii} = (\underline{v}_2, \overline{c}_2, \underline{v}_1)$

Table 2

For any ex-ante contracted prices, let $p_i^{(s)}$ be the equilibrium trade price of good i in state s. We search for initial prices which induce buyer and seller to invest efficiently anticipating the (efficient) subgame-perfect continuation of the game.

Under the assumptions of table 1, the seller's program at date 1 is

$$\max_e \quad U^S \quad = \quad \rho(e)\mu(a)\left[q(p_2^{(i)} - \underline{c}_2) + (1-q)(p_2^{(ii)} - \underline{c}_2)\right]$$

[25]This is straightforward for initial prices $p_t - p_0 > \max\{v_1, c_2\}$. Even if $v_1 < c_2$ and for prices $c_2 > p_t - p_0 > v_1$, however, an efficient equilibrium exists: For a buyer's offer $p_t^B \geq p_0 + c_2$, the seller cannot submit a counteroffer inducing an equilibrium trade price smaller than p_t (Lemma 2), so that the buyer's offer prevents trade of the standard project.

$$
\begin{aligned}
&+ \quad \rho(e)(1-\mu(a))[q(p_2^{(iii)} - \underline{c}_2) + (1-q)(p_2^{(iv)} - \underline{c}_2)] \qquad (11)\\
&+ \quad (1-\rho(e))\mu(a)[q(p_2^{(v)} - \bar{c}_2) + (1-q)(p_2^{(vi)} - \bar{c}_2)]\\
&+ \quad (1-\rho(e)(1-\mu(a))[q(p_1^{(vii)} - c) + (1-q)p_0\,]\\
&- \quad \psi(e).
\end{aligned}
$$

The (necessary and sufficient) first-order condition of this program yields the unique maximum e^N for any given a^N, which is implicitly defined by

$$
\begin{aligned}
\rho_e(e^N) \quad \{ \quad & \mu(a^N)[q(p_2^{(i)} - p_2^{(v)}) + (1-q)(p_2^{(ii)} - p_2^{(vi)})]\\
+ \quad & (1-\mu(a^N))[q(p_2^{(iii)} - p_1^{(vii)}) + (1-q)(p_2^{(iv)} - p_0)] \qquad (12)\\
+ \quad & \mu(a^N)\bar{c}_2 - \underline{c}_2 + q(1-\mu(a^N))c\} - \psi_e(e^N) = 0.
\end{aligned}
$$

The buyer's optimization problem can be written as

$$
\begin{aligned}
U^B \;=\; & \mu(a)\{\, \bar{v}_2 - \rho(e)\underline{v}_2 + \rho(e)[qp_2^{(iii)} + (1-q)p_2^{(iv)} - qp_2^{(i)} - (1-q)p_2^{(ii)}]\\
- \; & (1-\rho(e))[qp_2^{(v)} + (1-q)p_2^{(vi)} + q(\bar{v}_1 - p_1^{(vii)}) - (1-q)p_0]\} \qquad (13)\\
+ \; & (1-\rho(e))[q(\bar{v}_1 - p_1^{(vii)}) - (1-q)p_0] + \rho(e)[\underline{v}_2 - qp_2^{(iii)} - (1-q)p_2^{(iv)}] - \gamma(a)
\end{aligned}
$$

and the corresponding first-order condition yields

$$
\begin{aligned}
\mu_a(a^N)\{\bar{v}_2 \quad - \quad & \rho(e^N)\underline{v}_2 - (1-\rho(e^N))q\bar{v}_1\\
+ \quad & \rho(e^N)[q(p_2^{iii} - p_2^{i}) + (1-q)(p_2^{iv} - p_2^{ii})] \qquad (14)\\
- \quad & (1-\rho(e^N))[qp_2^{(v)} + (1-q)p_2^{(vi)} - q(p_1^{(vii)} - p_0) - p_0]\} - \gamma_a(a^N) = 0.
\end{aligned}
$$

Obviously, the equilibrium investments $e^N = f(a^N, p_i^{(\cdot)})$ and $a^N = f(e^N, p_t^{(\cdot)})$ as functions of the final prices depend on the initially contracted prices p_0 and p_t via Proposition 1. Comparing (12) and (14) with the corresponding conditions for efficient investments (9) and (10), one immediately finds that $e^N = e^*$, $a^N = a^*$ if and only if the following equations hold:

$$
\begin{aligned}
A \;\equiv\; & qp_2^{(iii)} + (1-q)p_2^{(iv)} - p_0 - q(p_1^{(vii)} - p_0) \qquad (15)\\
+ \; & \frac{\mu(a^*)}{1-\mu(a^*)}[q(p_2^{(i)} - p_2^{(v)}) + (1-q)(p_2^{(ii)} - p_2^{(vi)})] = \underline{v}_2 - qv_1 \equiv A^*
\end{aligned}
$$

for welfare-optimal investments of the seller, and

$$
\begin{aligned}
B \;\equiv\; & qp_2^{(v)} + (1-q)p_2^{(vi)} - p_0 - q(p_1^{(vii)} - p_0) \qquad (16)\\
- \; & \frac{\rho(e^*)}{1-\rho(e^*)}[q(p_2^{(iii)} - p_2^{(i)}) + (1-q)(p_2^{(iv)} - p_2^{(ii)})] = \bar{F} + (1-q)c \equiv B^*
\end{aligned}
$$

for efficient investments of the buyer. The following two subsections investigate the feasibility of efficient equilibrium investments under at-will contracting.

3.2.1 One-Sided Investments

Analyzing (15) and (16), we can state the following proposition:

Proposition 2: *Under at-will contracting the following results apply:*
(a) If only the seller's investments matter (i.e. $\mu(a) = \mu \; \forall a$), efficient investments can always be induced, at least by a contract $(p_t - p_0)^* \geq \bar{v}_2$;
(b) if only the buyer's investments matter (i.e. $\rho(e) = \rho \; \forall e$), efficient investments can always be induced, at least by a contract $(p_t - p_0)^* < c_1$.

Proof: See appendix.

The economic content of this proposition is identical to the corresponding results of Hart-Moore (1988).[26] By choosing an initial price difference above the highest possible benefits or below the lowest possible production costs, there is equilibrium renegotiation in every state of the world where trade is efficient. In these renegotiations, the investing party holds all the renegotiation power and receives the entire surplus from trade in every state. Hence, its marginal investment incentives are optimal. This feature of the original model generalizes to our two-good setting: Given $p_t - p_0 < c_1$, for example, the buyer endogenously holds the renegotiation power no matter whether trade of the standard or the innovative good is efficient (see Proposition 1), and vice versa for $p_t - p_0 \geq \bar{v}_2$.[27]

3.2.2 Both-Sided Investments

In a one-good world, Hart-Moore (1988) have showed that the hold-up problem cannot be overcome if both parties have to invest in relationship-specific assets. The intuition for this result is that the equilibrium trade price (or, to be more precise, the difference between trade and no-trade price) under at-will contracting must be in between the gross benefits v and the production costs c in every state of the world where trade is efficient. For this reason, it is impossible to design an ex-ante contract contract in a way that not at least one of the agents underinvests.[28]

[26]See Proposition 3 of their paper.

[27]Note that, since $\bar{v}_2 > \bar{c}_2$ under the assumptions of table 1, efficient investments of the seller are even induced for initial prices characterized by $p_t - p_0 \geq \bar{c}_2$: First, the seller is residual claimant for all realizations of gross values which are lower than $\bar{c}_2$; for higher values $v_2 > \bar{c}_2$, trade of the innovation is always efficient, and the equilibrium trade price is always p_t. Hence, we have a 'local' fixed-price contract which again induces efficient investment incentives. For a formal proof, see Bös-Lülfesmann (1996).

[28]More precisely, Hart-Moore prove this result (a) for at least two realizations of benefits and costs, respectively, and (b) under the assumption of linear distribution functions. The example in table 1 adopts both of these assumptions.

Let us now compare their seminal result, which proves the existence of the holdup problem, with the outcome in the present multiple-goods setting. To analyze this case, it is convenient to introduce the following definition:

Definition 2: *Let $\Sigma(q) = \{\mathcal{S} : \exists (p_t - p_0)^* : e^N = e^*, a^N = a^*\}$ be the set of all parameterizations of the state space $\mathcal{S}$ allowing for efficient investments under the Assumptions of table 1.*

In other words, the set $\Sigma(q)$ contains the possible numerical specifications of v_1, c, v_2 and c_2 compatible with Assumption 1, under which a first-best result in the case of two-sided investments can be attained for a certain q (the ex-ante probability that the standard good is valuable). At first glance, one should expect that the presence of a quality-choice problem makes it even harder to implement efficient investments. The following theorem, however, shows that the set $\Sigma(q)$is nonempty for all $q > 0$, and is strictly increasing in q.

Theorem 1: *In the case of two-sided investments, the set of state spaces $\Sigma(q)$ allowing for a first-best result under at-will contracting is non-empty if and only if $q > 0$. Moreover, for any $q' > q''$ we have $\Sigma(q'') \subset \Sigma(q')$.*

Proof: See appendix.

The theorem contrasts the main result of the Hart-Moore analysis (see Proposition 4 of their paper) as long as the standard good is valuable with some positive probability.

If $q = 0$ so that the standard good is never valuable, i.e. cases A and C do not exist, we are essentially back in the Hart-Moore world where efficiency is not feasible. This underinvestment result is driven by the fact that the final prices cannot simultaneously be equivalent to the production costs (which induces efficient investments of the buyer) and the benefits of the innovative good (guaranteeing efficient investments of the seller). More precisely, it is impossible to assign optimal marginal investment incentives to both parties at the same time.

Both-sided efficient investments may be feasible, though, if $q > 0$ so that trade of the standard project is sometimes efficient when the innovation is non-valuable. To see why, note first that the existence of an alternative (and potentially valuable) trade opportunity x_1 lowers the first-best investments compared to the Hart-Moore one-good analysis. This is intuitive: In expectation, trade of the innovation is less likely for higher realizations of production costs or lower gross benefits from the realization of this project. If the innovation is the only valuable trade opportunity, no gains from trade arise in these unfavorable states of the world. Hence, high investments are optimal in order to reduce the probability of no-trade. In contrast, if a standard project exists whose production may be efficient in states of the world where trade of the innovation is inefficient, the first-best investment levels must decrease, since a positive net gain from trade can be realized even if the innovation is not valuable.

Moreover, there is now an interplay of two opposing effects with regard to the parties' equilibrium investment choices: First, as in the standard setting, $(p_t - p_0)$ cannot be chosen in such a way that both parties have the 'locally' correct marginal investment incentives in the states of the world where the innovation should be produced; this is the standard effect inducing underinvestment in Hart-Moore (1988). The second - and opposing - effect in our two-good framework is that, for any choice of $(p_t - p_0)$, at least one of the parties 'locally' *overinvests* in the states of the world where the standard good's realization is efficient. The motive for this overinvestment mirrors the explanation for underinvestments: Both parties cannot capture the whole net surplus from trade of the standard good at the same time (since $p_1^e - c_1 = \bar{v}_1 - c_1$ and $\bar{v}_1 - p_1^e = \bar{v}_1 - c_1$ cannot hold simultaneously). Accordingly, at least one of the parties underestimates the real surplus in states of the world where the standard good is traded. Hence, an interplay of 'local' overinvestments and underinvestments arises.

For certain parameter values, these opposing effects cancel by an appropriate choice of the ex-ante prices (see appendix). To be precise, given the assumptions of table 1 and by choosing

$$(p_t - p_0)^* = \rho(e^*)\underline{v}_2 + (1 - \rho(e^*))[\bar{c}_2 + q(\bar{v}_1 - c)] \tag{17}$$

the first-best is attained if and only if this optimal price difference is compatible with the interval $\bar{v}_2 \geq (p_t - p_0)^* \geq \bar{c}_2$. Since $\bar{v}_2 > (p_t - p_0)^*$ always holds (see (10)), the optimal solution $(p_t - p_0)^*$ must be 'sufficiently high', i.e. it must exceed $\bar{c}_2$. Moreover, since a higher q shifts the optimal price difference upwards, it increases the set of parameters under which a first-best result can be obtained.

The following figure illustrates these results:[29]

[29] The numerical specifications underlying this figure are as follows: $\bar{v}_2 = 30, \bar{c}_2 = 20, \underline{v}_2 = 15, \underline{c}_2 = 10, \bar{v}_1 = 8, c = 5$ and $q = 1$. Moreover, $\rho(e) = e, \mu(a) = a, \psi(e) = (1/2)be^2$, $\gamma(a) = (1/2)ba^2$ and $b = 20$. The corresponding solutions are $e^* = 2/7, a^* = 39/84$ and $(p_t - p_0)^* = 145/7$. Notice that the respective investment functions are drawn under the assumption that the other party invests efficiently.

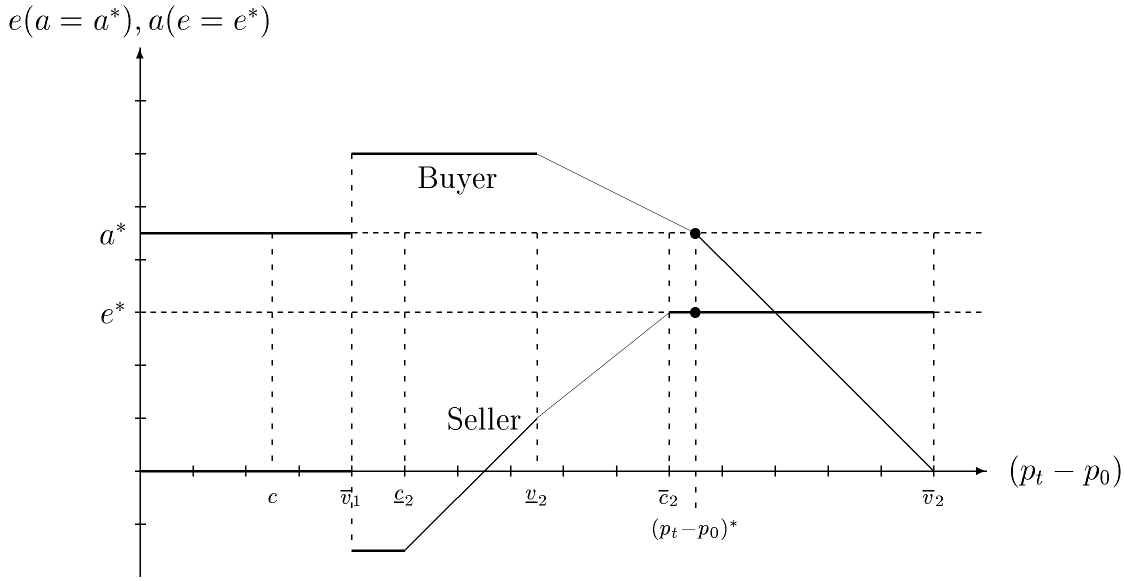

Figure 1

The figure displays equilibrium investments of both parties in dependence of the initial contract for $q > 0$. We see that the buyer's investments can be increased above the first-best level over a certain price range. Let us elaborate this point: As long as $(p_t - p_0) \leq \bar{v}_1$, the buyer's equilibrium investments are efficient, while the seller's marginal benefit from investing is zero. First, if $p_t - p_0 < c_1$, we have upwards renegotiation in every state of the world where trade is efficient. Since the buyer holds all the bargaining power, he is the global residual claimant. Second, for $c_1 \leq p_t - p_0 \leq \bar{v}_1$, the seller obtains a production rent $p_t - c_1$ in every state where the standard good is valuable. Since this event is independent of the parties' investments (it occurs with probability q), efficient investments of the buyer are guaranteed while the seller remains idle.

Consider now, however, the next interval $\bar{v}_1 < p_t - p_0 < \underline{c}_2$. On the one hand, the buyer remains the residual claimant if the innovation is traded, but he captures no surplus at all if trade of the standard project is efficient. This feature induces him to spend more effort than the efficient level.[30] The seller, on the other hand, would like to make even negative investments, because she enjoys a production rent only if the standard project is traded.

For higher price differences, the buyer's investments now continuously decrease (at least weakly), [31] and drop to zero for $p_t - p_0 \geq \bar{v}_2$. Hence, since efficient investments of the seller

[30] The buyer's overinvestment increases in q in this price range, since the first-best effort decreases in q; in contrast, if the standard good is never valuable ($q = 0$), the buyer's investment curve is horizontal (and identical to efficient investments) in the range $(p_t - p_0) \leq \underline{v}_2$, and decreases thereafter.

[31] From our previous arguments, the reader might wonder why the buyer's investment curve is not

require $p_t - p_0 \geq \bar{c}_2$, a first-best result is feasible if and only if the buyer still (weakly) overinvests under an initial contract $(p_t - p_0) = \bar{c}_2$.

The following corollaries supplement the previous analysis:

Corollary 2: *If (and only if) $q = 0$, or if there exists just one good in the world, both-sided efficient investments cannot be attained.*

Proof: Analoguous to Hart-Moore (1988), given Proposition 1.

Corollary 3: *Both-sided efficient investments are not generally feasible even if trade is efficient in every state of the world.*

Proof: Immediate from the previous results.

Corollary 2 states that the existence of non-valuable additional trade opportunities is irrelevant since these projects will never be realized under at-will contracting, and their existence does not influence the parties' renegotiation behavior. Hence, the analysis is equivalent to the one-good world investigated by Hart-Moore (1988).

Corollary 3 modifies Proposition (3)1 in Hart-Moore (1988) who prove that a first-best result is always feasible if there is no ex-ante uncertainty about the realization of the (unique) project. In our framework, underinvestments may be unavoidable even if $q = 1$ and, therefore, trade of *some* good is always ex-post efficient.[32]

4 Extensions

4.1 More Than One Standard Project

Imagine now the presence of any positive number of standard goods. We can prove the following results:

Proposition 3: *Suppose that n different versions of the standard project with v_1^i, c_1^i, $i = 1, .., n$ exist.*

(a) If only $i = 1$ is valuable with probability q, while all other standard projects $j \neq i$ are non-valuable, and $i = 1$ satisfies assumption 1, all previous results immediately apply.

downward sloped even in the range $\underline{c}_2 < (p_t - p_0) < \underline{v}_2$ since now he has to share the surplus of the innovation with the seller in some states of the world. While this argument would be valid in a more general framework, the effect cancels out under the assumptions of table 1.

[32] In contrast, the result of Hart-Moore carries over to our framework if $\bar{v}_2 > \bar{c}_2$ and trade of the innovation is efficient in every state of the world. In this case, the optimal contract $\underline{v}_2 \geq (p_t - p_0)^* \geq \bar{c}_2$ induces efficient investments and efficient trade without renegotiation.

(b) *If the innovation is valuable and efficient in every state of the world, i.e.,* $0 < v_2 - c_2 > v_1^i - c_1^i \; \forall\, v_2, c_2, v_i^i, c_1^i$, *a first-best result is feasible under at-will contracting with a contract specifying* $(p_t - p_0)^* = \underline{v}_2$.

Proof: Part (a) follows immediately, since the existence of non-valuable project versions does neither influence the allocative outcome nor the parties' bargaining power. To verify part (b), imagine an initial at-will contract prescribing a price difference $p_t - p_0 = \underline{v}_2$. Under this contract, both parties always prefer to trade the innovation to no-trade (since $v_2 \geq p_t - p_0 > c_2 \; \forall\, v_2, c_2$). Then, the existence of - even valuable - standard goods is irrelevant: Certainly, the seller can successfully deliver any standard good i if $v_1^i - p_t \geq -p_0$. But, since $v_1^i - c_1^i < \underline{v}_2 - \bar{c}_2$, she has no interest to do so since our assumptions guarantee $c_1^i > c_2$ which implies $p_t - c_1^i < p_t - c_2$. Consequently, if the initial price difference is chosen as specified above, the innovation will always be traded at the initial trade price, and a first-best result is attained.[33]$\square$

Aghion-Tirole (1994) and Segal (1995) have analyzed models with one innovation, and multiple non-valuable standard projects.[34] Both articles find that it is impossible to assign efficient investment incentives even if only one party has to provide relationship-specific investments.

In Aghion-Tirole, exactly one of many versions of a good turns out to be valuable in a given state of the world, and both parties can provide effort to increase the value of this innovation.[35] The initial contract specifies only the property rights on any forthcoming innovation, and a sharing rule of the (verifiable) benefits. Since the authors find that any ex-ante agreement on this sharing rule is irrelevant, the underinvestment outcome of Grossman-Hart (1986) qualitatively carries over to their setup.[36] In contrast to Aghion-

[33]It should be emphasized that the above first-best result under at-will contracting requires that the supports of different innovations do not differ. If (1) each project version can turn out to be the innovation, (2) the supports of values and costs of a good i are contingent on the fact if i is the innovation, and (3) these supports differ for different innovations, it may be impossible to find a price differential under which renegotiations do not occur in equilibrium.

[34]See also the comprehensive surveys of Tirole (1994) and Hart (1995).

[35]Production costs are normalized to zero; hence, the seller's investment generates a direct externality.

[36]Moreover, if commodities can be verifiably described ex ante, each party should hold a larger stake in innovation types whose value is stronger influenced by its own specific investments. In a related article, Aghion-Tirole (1995), it is assumed that both parties can invest to obtain private information on the value of different project versions; the informed party is then able to succeed with its preferred project. The focus of this theory is on a separation between formal and real authority in organizations. In line with our model, the approach allows for the analysis of situations where different project versions are valuable. In Aghion-Tirole's setup, however, it turns out that the second-best optimal contract specifies only the

Tirole's finding, Proposition 3(a) implies that a monetary ex ante contract is valuable since at least one-sided efficient investments can be attained (see Proposition 2). This difference in results arises since an initial sharing rule can be enforced in the present setting. Our result stresses the importance of the existence of a 'last day of trade', which guarantees the relevance of the initial contract in situations where both parties prefer efficient trade even under the initial terms of contract.[37]

As the present paper, Segal (1995) investigates a multi-project version of Hart-Moore (1988). The author analyzes the optimal ex-ante arrangement in a 'complete contract plus renegotiation' setting. Moreover, it is assumed that trade of the innovation (which is phrased the 'regular good' in his paper) is efficient with probability one. Segal demonstrates that any long-term complete contract is useless if there exists a continuum of non-valuable versions of the project.[38] Hence, the second-best optimal result can also be attained by pure bargaining only after the state of the world has been realized. Since, by assumption, the outcome of bargaining is described by the Nash-bargaining solution, not even one-sided efficient investments are feasible.

The intuition for Segal's result is, loosely speaking, as follows: When the number of possible projects increases, it becomes increasingly difficult to design a (renegotiation-proof) revelation mechanism in a way that both parties tell the truth. In the limit, the outcome of any mechanism replicates the outcome of pure bargaining. The result of Proposition 3(b) contrasts Segal's finding. In our framework, the presence of any number of (possibly even valuable) projects does not prevent a first-best result in case that trade of the innovation is always efficient. Again, this is due to the fact that a last day of trade exists in our model, while the revelation mechanism analyzed by Segal can only prescribe transfer payments and a pre-renegotiation allocation. In particular, the mechanism cannot further influence the post-renegotiation transfers and hence the parties' investment incentives.[39] This de-

property rights even if complete contracts are feasible. This result holds since, in their model, at least one of the parties is wealth-constrained and does not respond to monetary incentives.

[37]In contrast, Aghion-Tirole consider the irrelevance of any monetary ex-ante contract as an immediate consequence of non-verifiability of designs: *'The initial sharing rule cannot influence the ex post bargaining game ... since in contrast to some other incomplete contracts models with renegotiation [fn. Hart-Moore (1988), Aghion-Dewatripont-Rey (1994)], the good to be traded ex post is not ex ante contractible.'* (Aghion-Tirole(1994), p. 1193).

[38]The author assumes that some of these non-valuable goods are 'bad' (they have no production costs, but are worthless), and others are 'gold-plated' (they generate a high gross benefit, but are characterized by excessive costs of production). The existence of both categories of projects tightens the incentive-compatibility constraints in a revelation mechanism, since the buyer prefers trade of a goldplated project, while the seller would like to deliver a bad project given any transfer payment.

[39]Imagine, for example, that the revelation game induces a no-trade allocation although trade is efficient,

ficiency becomes severe if the number of potential goods increases, and (in the limit) the specification of incentive payments becomes an insufficient instrument to induce appropriate investment incentives in a revelation-proof mechanism. Taken together, Proposition 3 demonstrates that more favorable outcomes become feasible if a last day of trade strongly ties the parties to an initial contract.

4.2 Option Contracts

Imagine that the court can not only observe whether trade has been realized, but also whether the seller delivered a good to the buyer. This additional assumption on verifiability is the starting point of Nöldeke-Schmidt (1995), who show that the holdup-problem arising in Hart-Moore can now be resolved. To attain this result, the authors introduce option contracts under which the relevance of the precontracted price p_t hinges only upon the seller's delivery decision ($d_i \in \{0, 1\}$). In our context, if $d_i = 1$ for some project i at date 4, the buyer has to pay p_t unless renegotiation offers induce a different equilibrium price. Note that the buyer will never refuse the acceptance of a good after delivery, since payments and acceptance decision are separated, and $v_i > 0$ by assumption. Hence, option contracts can be interpreted as the assignment of the right to decide on trade to one party (the seller in their paper). Crucially, Nöldeke-Schmidt (1995) consider either a one-good world, or a world of multiple goods where (i) at least one of the goods can properly be specified in an initial contract and (ii) benefits and costs of this good are sufficiently sensitive to the parties' investments.[40]

In contrast to this positive result, for the present scenario of unverifiable project versions we obtain:

Proposition 4: *Under an option contract, the seller will never invest in relationship-specific assets.*

Proof: See appendix.

The proposition implies that option contracts are strictly welfare-dominated by at-will contracts when the different desgns are undescribable ex ante. The economic rationale for this performance reversal is relatively straightforward. In our framework with unverifiable

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and a corresponding transfer payment between the parties. Then, renegotiations will start from this payment (p_0 in our simple setup), while the outcome of renegotiations is not influenced by any trade price which is either precontracted, or imposed by the mechanism. Hence, there is no trade price p_t still influencing the outcome of renegotiations.

[40]In the present framework, the validity of these assumptions would imply that the innovation can be specified ex-ante.

designs, the seller can always deliver the cheaper standard project under option contracting, and she will have an interest to do so if $p_t - p_0 \geq c_1$. To prevent this outcome in states of the world where trade of the innovation (or no trade) is efficient, the buyer will submit a V_2-offer (or p_0^B offer, respectively), and the innovation will be traded in equilibrium. The logic of the Hart-Moore renegotiation game implies that the buyer endogenously holds all the renegotiation power (the renegotiation power rests with the party which must submit an offer to obtain ex-post efficiency). As a consequence, the seller will never invest since her (no-) production rent $\max\{p_t - c_1, p_0\}$ does not depend on her specific investments.[41] Interestingly, the no-investment result does not hinge on the standard good's value: Even if $q = 0$, the mere existence of a cheaper good deletes any investment incentives under option contracting.[42] In Nöldeke-Schmidt's framework, on the other hand, the parties can make the seller's option contingent on a prespecified project version whose net value can be influenced by specific investments. Hence, by optimally adjusting the option price difference, optimal investment incentives are assigned to the seller, while the renegotiation power rests with the buyer in the Hart-Moore renegotiation game. Since he obtains the whole surplus from trade up to a constant amount (the surplus accrued by the seller when exercising her option), efficient investments can be induced.

To conclude, rational parties will never sign option contracts in an economic situation where the court ex ante cannot distinguish between different projects,[43] since these arrangements support the seller's preference to deliver bad quality, and destroy her incentives to invest in relationship-specific assets. Hence, voluntary trade may perform best in protecting the parties' specific investments.

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[41] If only unconditional offers are feasible, the innovation will never be traded under option contracting. Since the court is not able to distinguish between both types of projects, the seller will always deliver the cheaper standard project at any price (ex-ante contracted or renegotiated).

[42] The reader can check that the inefficiency result of Proposition 4 also carries over to the variable-quantity setting examined by Chung (1991), Aghion-Dewatripont-Rey (1994) and Edlin-Reichelstein (1996) who attain a first-best under specific-performance contracting in the one-good case.

[43] The case of a buyer's option has not been investigated in the literature; in contrast to a seller's option, it requires the explicit specification of a fine which has to be paid from the seller to the buyer if the option was exercised but the seller refused the delivery. One could argue that a buyer's option solves the problem if the buyer not only can insist on trade (and then is forced to accept the good which is delivered by the seller) but also can refuse the good if he claims that it is not the good which was ordered. While I do not analyze this case, note that the buyer may now have an incentive to reject the acceptance of any good if this guarantees him a very high breach payment from the seller (which is a plausible assumption given that the buyer has the 'option' to insist on trade, and the seller violated her duties). Accordingly, the seller never agrees to such a type of contract. A careful analysis, however, would require to execute the tedious task of deriving the optimal fine endogenously.

4.3 Limiting Ex-Post Verification

It is interesting to see how our previous results change when ex-post verification is not feasible. As argued above, this will be the appropriate assumption when the court does not have the technical knowledge to understand the description of a good's characteristics. Hence, we briefly come back to the two alternative assumptions which were introduced at the end of subsection 3.1 above (see remarks 1 and 2): First, assume that V_i-offers, but no V_{ij}-offers, are allowed. In this case, verification is still possible although the parties' strategy spaces are restricted. Second, suppose that ex-post verification cannot be attained, and only unconditional renegotiation offers can be submitted at date 3. While the equilibria of the renegotiation and trade stage have been derived above, the following proposition appends the implications of these results for ex-ante efficiency.

Proposition 5: *If no conditional offers are allowed, or the conditional messages are restricted to V_i-offers, Theorem 1 can be applied. The set of parameterizations allowing for a first-best result in case of both-sided investments and the optimal price difference $(p_t - p_0)^* \geq \bar{c}_2$ do not change. For the case of one-sided investments, we have:*

(1) Proposition 2 still applies if V_i-offers are feasible.

(2) If no conditional offers are feasible, Proposition 2(a) applies so that efficient investments can be induced if only the seller's investments are relevant; in contrast, if only the buyer's investments matter, a first-best result can be attained if and only if both-sided efficient investments are feasible.

Proof: Under both assumptions on ex-post verification, Proposition 1 can be applied for initial prices $p_t - p_0 \geq \bar{c}_2$ (see remarks 1 and 2 in subsection 3.1). If both-sided efficient investments are feasible, the optimal ex-ante contracted trade price exceeds $\bar{c}_2$; accordingly, in case that the first best is feasible for V_{ij}-offers, an identical result applies for the two alternative assumptions on verifiability. Moreover, (1) follows immediately from Proposition 2 and the fact that the ex-post equilibrium outcome is identical to the case of unrestricted offers unless $\underline{c}_2 > p_t - p_0 > \bar{v}_1$. To establish (2), note that ex-post efficiency in every state of the world requires $p_t - p_0 \geq \bar{c}_2$ (see remark 2 in subsection 3.1). Since efficient investments of the seller apply when the initially contracted price difference exceeds this level, efficient investments of the seller can still be attained. In contrast, if only the buyer invests, efficient investments require overinvestment of the buyer at the interval border $p_t - p_0 = \bar{c}_2$. In this case, however, even both-sided efficient investments are feasible (see the proof of Theorem 1). □

The results show that the feasibility of both-sided efficient investments is robust with respect to plausible modifications of the renegotiation game. One-sided efficient investments of the buyer, however, cannot generally be attained if ex-post verification is not allowed, which is in contrast to Proposition 2 as to Hart-Moore (1988). This result is a consequence of the fact that the innovation cannot be traded for small initial price differences, so that it is impossible to induce efficient investments of the buyer by an initial contract which makes him the residual claimant in every state of the world.

4.4 Verifiable Differences Between the Projects

Finally, imagine that the parties can describe the different project versions ex ante clearly enough that the court is able to check which project has been traded (i.e., information partition $\mathcal{I}^*$ applies). In this case, an enforceable ex-ante contract can be made contingent on the three different events 'no trade', 'trade of the standard good' and 'trade of the innovation'. The corresponding contract is denoted (p_0, p_1, p_2).

Ex-post Decisions

We start with a characterization of the ex-post equilibrium outcomes under at-will contracting.[44]

Proposition 6: *Under at-will contracting, the equilibrium outcome is identical to Proposition 1 for cases B, C and D (where p_t is replaced by p_i if i is valuable). Accordingly, if at most one of the goods is valuable, there exists a unique undominated SPE which is ex-post efficient. In case A where both projects are valuable, however, an ex-post efficient equilibrium is not feasible if $p_2 - p_0 > v_2$ and $\bar{v}_1 \geq p_1 - p_0 \geq c_1$. For these ex-ante prices, there exists a unique equilibrium, in which the standard project is inefficiently traded. Finally, if $p_2 - p_0 > v_2$ and $p_1 - p_0 < c_1$, or alternatively $p_2 - p_0 < c_2$ and $p_1 - p_0 > \bar{v}_1$ in case A, there is coexistence of an efficient equilibrium where the innovation is traded, and an inefficient equilibrium where the standard project is realized.*

Proof: See appendix; equilibrium prices are summarized in Corollary 4.

The existence of multiple equilibria is motivated by the same reasoning as in Proposition 1: If either party prefers trade of exactly one of the goods to no trade, but these goods differ, any trade requires renegotiation. Depending on who submits an offer, either the standard or the innovative project is finally realized in a state of the world where both

[44] A full characterization of the ex-post equilibria of option contracts will not be provided; see, however, the proof of Proposition 6 in the appendix.

goods are valuable. The existence of unique inefficient equilibria in case A and for some combinations of initially contracted prices, however, is quite surprising. It rests on the fact that, under the corresponding ex-ante contracts, the innovation cannot be traded unless the seller submits an offer, so that her best offer would make the buyer indifferent between trade of x_2 and no trade. Since the buyer prefers trade of x_1 to this outcome, he will prevent efficient trade by submitting a 'destructive' offer p_2^B (see appendix). Note that the seller's first mover advantage turns out to be a disadvantage here: She would like to make the buyer indifferent between trade of x_1 at p_1, and trade of x_2. But, if the seller buyer submits no offer p_2^B which renders trade of the innovation impossible, the seller's best response is a message which fixes p_2 at $p_0 + v_2$, and hence leaves no surplus for the buyer.

Ex-ante Decisions

For ex-ante contracts allowing for an ex-post efficient equilibrium, and confining attention to efficient equilibria if multiple SPE exist, the agents' optimization programs at date 1 coincide with those in section 4 (under the modification that the final prices are replaced by the equilibrium values characterized in Corollary 4; see appendix). Accordingly, (15) and (16) are still necessary and sufficient for efficient investments.

Analyzing these efficiency conditions, we obtain the following result:

Proposition 7: *Under at-will contracting, a first-best result is always feasible if only one-sided investments are relevant. In case of both-sided investments, efficiency can possibly be induced for $q > 0$. Thereby, the parameter scope $\Sigma(q)$ which supports a first-best result under at-will contracting is strictly larger when the project designs are verifiable. Under option contracts, a first-best result can always be achieved.*

Proof: See appendix.

These statements should come at no surprise. Adding one more decision variable increases the flexibility of choice and hence makes it easier to induce the first best. On the other hand, a general efficiency result for at-will contracts cannot be expected. As under the coarser information partition assumed in our basic setting, there is an interplay between situations of overinvestment and underinvestment.

It is interesting to note that this result qualitatively carries over to a setup where no standard project exists, but where the innovative project can verifiably be traded with a third party: In this interpretation, p_1 represents a breach payment from the seller to the buyer if the good is traded with another buyer, whose valuation is v_1 (where $v_1 < v_2$, since the project is not tailor-made for the demands of the alternative buyer). If the initial contract does not distinguish between no trade and trade with a third party, i.e. $p_1 = p_0$, the buyer locally overinvests in states of the world where the seller's outside option becomes relevant, while this overinvestment ceteris paribus decreases in p_1 (symmetrically, the seller's investments increase). Therefore, by an appropriate choice of prices, first-best investments under at-will contracting may be feasible even in this modified setup.[45]

In contrast to at-will contracts, option contracts always implement the first-best in situations where the court can distinguish between the projects.[46] Consider a seller's option: If the initial contract specifies $p_1 - p_0 < c_1$, the seller will never exercise her option to deliver the standard good. Accordingly, the price difference $p_2 - p_0$ can be specified so as to give the seller the correct marginal incentives to invest, while the buyer endogenously holds the whole bargaining power in renegotiations. Hence, the efficiency result of Nöldeke-Schmidt (1995) is restored.

5 Concluding Remarks

This paper investigates the holdup problem in a setting with multiple, nonverifiable project designs. It is motivated by the frequent occurence of quality choice problems in economic situations where only incomplete contracts can be written.

The paper advocates the use of at-will contracting in environments of that kind. Surprisingly, these contractual arrangements potentially resolve the holdup problem. This outcome contrasts the main result of Hart-Moore (1988), who showed that underinvestment cannot be avoided if the 'innovation' is the unique trade opportunity. Their inefficiency result carries over to our multi-goods setup as long as trade of alternative projects within the relationship is never valuable. In our setting where the realization of a a lower-quality standard project is sometimes efficient, however, it may be feasible to induce first-best investments of both parties.

Under at-will contracting, voluntary trade ensures that each party can costlessly (up to a constant) step back from trade. Hence, the paper demonstrates that the renunciation of individual breach penalties is attractive in situations where different unverifiable project versions are present. It should be emphasized that at-will contracts are very modest with respect to verifiability requirements: The court only has to observe whether trade occured

[45] A similar framework has been examined by McLeod-Malcomson (1993). In this article, the authors attain a first-best result in the special case that trade inside the relationship is always efficient, and under the additional assumption that the values of trade inside the relationship and with outside parties are independent of the specific investments; see Proposition 5 of their paper.

[46] For a sketch of proof, see the proof of Proposition 7 in the appendix.

or not. In particular, at-will contracts do not rely upon the verifiability of the parties' delivery or acceptance choices.

Allowing for this additional information does not improve the outcome if only simple mechanisms are considered: The utilization of realistic contracts which include individual breach penalties (as option contracts) cannot be recommended in situations where the court is unable to tell the different project designs apart. Rather, we find that under option contracts the seller will never invest in relationship-specific assets.

The article also extends the renegotiation game developed by Hart-Moore (1988) to incorporate bargaining over multiple project versions. Our analysis demonstrates that the main feature of this renegotiation process, namely that the bargaining power rests with the party which agrees to efficient trade under the initial contract, carries over to our extended setup. On the other hand, the seller's disagreement payoff may now increase if both project versions are valuable, an outcome which bears resemblance with the 'outside option principle' found in the bargaining literature. Moreover, for some initial contracts, multiple (even inefficient) equilibria now exist, and no ex-post efficient equilibrium at all may be found if the projects are distinguishable for the court.

Appendix

Proof of Proposition 1:

A. Dispute Game

The first part of the proof provides an equilibrium analysis of the dispute (court revelation) game at date 5. At this date, the allocative decisions have already been taken. Hence, the only issue at stake is a dispute on the correct payments after good $i \in \{0, 1, 2\}$ has been traded at date 4.

Given any allocative outcome at date 4, the parties face a zero-sum game. Accordingly, the minmax-theorem implies that all possible Nash-equilibria of the court revelation game have the seller's maximin value as unique equilibrium outcome.

Let us consider the following subcases:

1. Just one of the agents submitted a revision offer at date 3.

Then, we can state the following result:

Lemma 1: *If only one of the parties submitted a renegotiation offer at date 3, the following unique equilibrium prices are attained in the court revelation game after trade:*

1. *After an unconditional offer was submitted, the equilibrium price is*

$$p_t^e = \begin{cases} max\{p_t^B, p_t\} & \text{if} \quad B \text{ submitted an offer} \\ min\{p_t^S, p_t\} & \text{if} \quad S \text{ submitted an offer.} \end{cases}$$

2. *After a conditional V_i-offer (or a V_{ij}-offer) was submitted, the equilibrium price is*

$$p_t^e = \begin{cases} max\{p_i^B, p_t\} & \text{if} \quad B \text{ submitted an offer and } i \text{ was traded} \\ p_t & \text{if} \quad B \text{ or } S \text{ submitted an offer and } j \neq i \text{ was traded} \\ min\{p_i^S, p_t\} & \text{if} \quad S \text{ submitted an offer and } i \text{ was traded.} \end{cases}$$

After a no-trade outcome, the unique equilibrium price is as under 1., where the index t is replaced by 0.

Proof: First, assume the submission of an unconditional offer (without ex-post verification). In this case, the receiver of the offer is free to reveal the message to the court, and he will do so if this (at least weakly) increases his payoff compared to the initially contracted price. Second, assume that the offer included a verification element, i.e. a complete physical description of the good it referred to; as stated before, this description is denoted V_i where $i \in \{1, 2\}$. Remember that any V_i-offer is relevant in the dispute game only if good i has really been traded at date 4; otherwise, the offer is treated as non-existing in case of revelation. Hence, the unique equilibrium price after a buyer's message is $p_i^e = \max\{p_i^B, p_t\}$ if good i was traded, and p_t otherwise. If the seller submitted the message, we obtain $\min\{p_t, p_i^S\}$ if i was traded, and p_t otherwise. □

2. Both parties submitted offers at date 3.

I will start by a series of auxiliary results for the case where both parties tendered unconditional offers. Let us first consider opposite directions of deviation from the initially contracted trade price p_t (in the following, I will skip the no-trade situation p_0 for convenience). In this case, the initially contracted price turns out to be the unique equilibrium outcome.

Lemma 2: If $p_t^k \leq p_t \leq p_t^l,\ k,l \in \{B,S\}$ the unique equilibrium price after trade is $p_t^e = p_t$,

Proof: Assume $p_t^B > p_t$: In this case, the weakly dominant strategy of the seller is to reveal p_t^B and to obtain at least p_t (if she does not reveal the buyer's offer, she will get at most p_t). Given the seller's revelation, the buyer also reveals, so that the initial trade price is enforced. Of course, the case $p_t^B < p_t$ is symmetric.

Given the set of offers stated above, the equilibrium outcome can be attained as a pure-strategy equilibrium. If the revision offers of both parties deviate to the same direction relative to the initial trade price, however, a pure-strategy equilibrium of the court revelation game does not exist. The reason is simple: If, for example, $\min\{p_t^S, p_t^B\} \geq p_t$, it is profitable for the seller to reveal p_t^B to the court if and only if the buyer does not reveal p_t^S at the same time - and vice versa. Hence, the parties' minimax (respectively maximin) values are obtained by playing the mixed strategy combination (σ^*, β^*), where σ and β denote the probabilities with which buyer and seller reveal renegotiation offers to the court. The following lemmata characterize the equilibrium outcomes in these cases:

Lemma 3: If $\min\{p_t^B, p_t^S\} > p_t$, the unique equilibrium outcome after trade is in the interval $p_t \leq p_t^e \leq \min\{p_t^S, p_t^B\}$.

Proof: First, suppose $p_t^B \geq p_t^S > p_t$. Imagine a seller's maximin-strategy inducing $p_t^e > p_t^S$. Such a strategy cannot exist, since the buyer can guarantee $p_t^e \leq p_t^S$ by a response $\beta = 1$. If $p_t^S \geq p_t^B > p_t$, $p_t^e > p_t^B$ cannot be supported as outcome of the seller's maximin-strategy, since the buyer can ensure $p_t^e \leq p_t^B$ by a strategy $\beta = 0$. Finally, we have $p_t^e \geq p_t$ for all possible strategy combinations.

A corresponding result characterizes the equilibrium outcome for the case that both parties' offers are below the initial trade price:

Lemma 4: If $\max\{p_t^B, p_t^S\} < p_t$, the unique equilibrium outcome after trade is $p_t \geq p_t^e \geq \max\{p_t^S, p_t^B\}$.

Proof: Symmetrical to the proof of Lemma 2.

Lemma 3 implies that the equilibrium price must be weakly lower than the smaller offer if both parties submitted "high" renegotiation offers. To the contrary, if both offers are below the precontracted trade price, the equilibrium price must be (weakly) higher than the maximum of these values (Lemma 4). We will utilize these outcomes when investigating the equilibria of the revision game at date 3.

While the equilibrium price is insensitive to the type of the good which was traded after the parties submitted no V-offers (or if, in a different interpretation, conditional offers are not feasible), this does not hold if at least one of the parties submitted a conditional offer at date 3. The following lemmata deal with this case. Assume V_i-offers (p_i^k, V_i) of party $k \in \{B, S\}$, and imagine that good i has been (or has not been) traded at date 4 (alternatively, imagine a V_{ij}-offer, possibly followed by trade of i or j). In both cases, Lemmata 1-4 can immediately be applied. Let us first state a definition:

Definition 1: An offer including (p_i^k, V_i) is called "consistent" ("inconsistent") if it is (not) supported by trade of i at date 4. An unconditional offer p_t^k is consistent if any trade is realized.

Now, we have the following result:

Lemma 5: *In the equilibrium of the court renegotiation game, inconsistent offers are strategically identical to no offers at all; hence, only consistent offers matter. If party k submitted a consistent V-offer at date 3, while l submitted either an inconsistent V-offer or no offer at all, Lemma 1 can be applied. If l submitted either a consistent V-offer or an unconditional offer, Lemmata 2-4 are applicable. Finally, if both parties submitted inconsistent V-offers, the initially contracted trade price is implemented.*[47]

Proof: Immediate from the court's decision rules.

B. Trade Stage

Remember the sequential structure which was introduced in subsection 2.3: First, the seller can produce one of the goods and deliver it to the buyer. Thereupon, the buyer has to make the once-and-for-all decision whether to accept delivery, in which case trade is realized.

Given this sequencing, the parties' equilibrium strategies are as follows: Anticipating the subgame-perfect continuation of the game, that is the final equilibrium prices p_i^e if good i has been traded, the buyer accepts delivery of i if and only if his net utility from trade exceeds the (negative) no-trade payment, which implies

$$a_i = 1 \Longleftrightarrow v_i - p_i^e \geq -p_0^e \tag{18}$$

where $a_i \in \{0, 1\}$ denotes the buyer's acceptance strategies after i was supplied.

The seller, on the other hand, delivers good i, i.e., $d_i = 1$, if and only if the following conditions apply:

$$d_i = 1 \iff p_i^e - c_i \geq p_0^e \text{ and there exists no } j: \quad v_j + p_0^e \geq p_j^e > p_i^e + c_j - c_i, \;\; i, j \in \{1, 2\}. \tag{19}$$

[47] Since it turns out only at date 4 whether any V-offer is inconsistent, conditional offers can - and will - influence the equilibrium allocation. In the dispute game, however, inconsistent V-offers have no effect on equilibrium prices.

The latter condition implies that the seller cannot increase her payoff by delivering good j instead of i while j will be accepted by the buyer. As will become clear, this constraint may bear strategic importance, since the seller has an inherent incentive to deliver the cheaper standard design to the buyer.

C. Revision Game

At date 3 the parties can simultaneously submit revision offers (possibly including a verification element) to each other. I analyze which offers will be tendered given the subgame-perfect continuation of the game at dates 4 and 5.

Case D - No Valuable Good
Note that there exist no equilibrium prices under which both parties would be willing to trade. Accordingly, the parties face a zero-sum game at date 3, and renegotiation will not occur in equilibrium.

Cases B and C - One Valuable Good
In the corresponding states of the world, the analysis is equivalent to the one in Hart-Moore (1988) (to be precise, I will analyze the Nöldeke-Schmidt (1995) version of this game; there is a strategic difference to this model at stage 3 and 4 - but not at stage 5 - since their paper is concerned with option contracting). Notice first that, without loss of generality, we can neglect any V-offers since only one of the goods can successfully be traded in any equilibrium under at-will contracting.

Indicate i as the valuable good. If $v_i \geq p_t - p_0 \geq c_i$, the valuable good can be traded under initial prices. Hence, both parties can make sure of net payoffs $U^B \geq v_i - p_t$ and $U^S \geq p_t - c_i$, respectively, which implies that the unique equilibrium price is p_t.

Now, we consider situations where one of the parties is not willing to trade good i given initial prices. Imagine, for example, $p_t - p_0 < c_i < v_i$ (the case $p_t - p_0 > v_i > c_i$ is symmetric). In this case, the seller is not willing to trade i at the price p_t. We start by the following lemma:

Lemma 6: *If one of the parties credibly rejects efficient trade under the initial prices, there is no trade unless the other party submits a renegotiation offer.*

The intuition for this result is quite obvious. Imagine that in the situation above the buyer submits no renegotiation offer to the seller. Then, either the seller also submits no offer, which trivially prevents trade, or she submits an offer. But, by Lemma 1, after trade the buyer will reveal this offer to the court if and only if $p_t^S \leq p_t$. Hence, the equilibrium trade price cannot exceed the initial price p_t.

Accordingly, assume the buyer submits an offer p_t^B. From Lemmata 1 - 4, we know that the equilibrium trade price cannot exceed $\max\{p_t, p_t^B\}$. Consider first the lowest possibly successful offer $p_t^B = p_0 + c_i$, which makes the seller indifferent between trade and no trade. Note that - given the buyer's offer - the seller cannot submit any counteroffer guaranteeing a higher trade price (by Lemma 3). Hence, she will submit either no or an identical counteroffer, and i is traded at the price proposed by the buyer. As a result, we found a SPE of the renegotiation game.

Now, the question arises if this equilibrium outcome is unique. Consider any offer of the seller $p_t^S > p_t$ (the opposite case can be neglected since, by Lemmata 2 and 4, the equilibrium price cannot exceed p_t in this case.). By Lemma 6, we know that trade requires a counteroffer of the buyer which, by Lemma 3, must weakly exceed $p_0 + c_i$. Imagine first an identical counteroffer of the buyer, i.e. $p_t^S = p_t^B$. In this case, $p_t^e = p_t^S = p_t^B$, which is the highest possible trade price the seller can accrue in equilibrium for any p_t^S. Can these messages be equilibrium-offers? By the following reasoning, the answer is negative: Given any $p_t^S > p_0 + c_i$, the buyer can respond by a counteroffer $p_t^B \geq p_0 + c_i$ which yields an equilibrium trade price $p_t^e = p_0 + c_i$ in mixed strategies. To see this, observe that p_t^e is monotonically increasing in p_t^B for any given p_t^S. By choosing $p_t^B = p_t$, the equilibrium price after trade would be p_t, while $p_t^B = p_t^S$ yields $p_t^e = p_t^S = p_t^B$. Hence, there always exists an intermediate value inducing $p_t^e = p_0 + c_i$. Given the buyer's offer, however, the seller's best response is to submit an identical counteroffer. This process reaches a fixed point if and only if $p_t^B = p_0 + c_i$, which implies that the equilibrium trade price is unique.

For completeness, the existence of an additional no-trade equilibrium should be mentioned: Imagine a seller's offer $p_t^S < p_0 + c_i$. By Lemmata 1-4, the buyer cannot submit any counteroffer which could induce trade. Given a buyer's counteroffer $p_t^B < p_0 + c_i$, it is easy to verify that this strategy combination generates a second, no-trade, equilibrium at the initial price p_0. Since both parties (weakly) prefer trade, however, this inefficient outcome is pareto-dominated. Accordingly, it seems reasonable to restrict attention to the unique undominated and efficient trade equilibrium. By symmetry, the opposite case $p_t - p_0 > v_i > c_i$ yields a unique equilibrium trade price $p_t^e = p_0 + v_i$ implemented after the seller's renegotiation offer. To summarize, the outcome is equivalent to Proposition 1 in Hart-Moore (1988), who derived it in a more complicated sequential-offers framework.[48] Note that, in a situation where only one of the goods is valuable, the relevant strategy spaces of the parties are identical to those in a one-good world. This equivalence rests on the fact that a non-valuable good can never be traded under at-will contracting. As a consequence, the possibility of ex-post verification does not influence the parties' equilibrium strategies (as will become clear, this equivalence does not hold under option contracts).

Remark Consider option contracting in a one-good world, which is the main focus of Nöldeke-Schmidt (1995). Following the line of our arguments, the existence of a unique undominated and efficient equilibrium outcome carries over to this contract type. To see this, note that p_t denotes the price to be paid if the seller delivered ($d = 1$) the good at date 4. Hence, if $d = 1$ in the one-good case, the court enforces p_t independent of the acceptance decision of the buyer (since $v > 0$ by assumption, the buyer will never refuse trade after delivery). Moreover, the

[48] As Nöldeke-Schmidt (1995) convincingly argued, however, the renegotiation game in the original article is not well-defined (see also fn 17, subsection 2.3).

outcome of the dispute game is identical to the one under at-will contracting, although the parties' equilibrium strategies in the revision game will be different: If $p_t - p_0 \geq c$, the seller will exercise her option so that there is trade without renegotiation. If $p_t - p_0 < c$, the buyer submits a revision offer $p_t^B = p_0 + c$ which coincides with the equilibrium trade price.[49] It is easy to verify that these efficient equilibrium outcomes of the renegotiation game under option contracting are unique. In particular, the seller cannot force a trade price higher than $p_0 + c$ in cases where he does not exercise her option given initial prices; for any $p_t^S > p_0 + c$, the buyer's best response makes the seller indifferent between trade and no-trade. Since this result proves the uniqueness of undominated equilibria, it clarifies Nöldeke-Schmidt's claim that there exist multiple subgame-perfect equilibrium outcomes in the Hart-Moore renegotiation game.

Case A - Both Goods are Valuable

By Assumption 1, trade of the innovation is ex-post efficient. Now, we have to be aware of the seller's incentive to deliver the standard good instead of the innovation, which may give rise to inefficient equilibrium outcomes. We will calculate the equilibrium strategies for each possible initial contract (p_0, p_t).

$p_t - p_0 < c_1$. In this case, the seller is not willing to deliver even the standard project. By Lemma 6, trade requires a buyer's offer. Consider his 'optimal' offer $O^B = (p_2^B = p_0 + c_2, V_2)$. If the seller does not submit a counteroffer, p_2^B is the equilibrium price (Lemma 1) , and x_2 is efficiently traded. This outcome maximizes the buyer's utility under the constraint that the seller weakly prefers delivery to no-trade. Imagine the seller can submit a counteroffer guaranteeing him a payoff higher than her no-trade utility. By Lemma 3, the trade price of the innovation cannot exceed p_2^B, implying that any counteroffer inducing trade of x_2 cannot be profitable for the seller. Moreover, Lemma 5 states that the buyer's offer is irrelevant if the standard good has been traded at date 4. Hence, after trade of x_1, Lemma 1 must be applied and the equilibrium price in the dispute game would be $p_1^e = \min\{p_t, p_t^S\} = p_t$. Accordingly, for all possible counteroffers, trade of the standard good is not feasible in equilibrium. Hence, there is no profitable counteroffer the seller can make which proves the existence of an efficient equilibrium at a price $p_2^e = p_0 + c_2$. To show that this outcome is the unique efficient trade-equilibrium, imagine any offer p_t^S submitted by the seller.[50] If $p_t^S \geq p_0 + c_1$, and by Lemmata 2 and 3, any such offer is answered by a buyer's counteroffer inducing trade of the innovation (if $p_t^S \geq p_0 + c_2$), or trade of the standard good (if $p_t^S < p_0 + c_2$). Moreover, if i is traded, the unique equilibrium price is $p_i^e = p_0 + c_i$. For $p_t^S < p_0 + c_1$, on the other hand, it is obvious that trade cannot be realized. Hence, for all possible offers p_t^S, the seller's equilibrium payoff is identical to her no-trade payoff p_0. In the following, we will restrict our attention to equilibria which are not pareto-dominated, in which

[49] As under at-will contracting, there also exists a pareto-dominated no-trade equilibrium induced by the seller's renegotiation offer $p_t^S < p_0 + c$ in cases where the seller does not exercise her option.

[50] The reader may check that the following arguments remain valid if the seller submits any conditional offer.

case the efficient equilibrium above is unique.

$c_1 \le p_t - p_0 \le v_1$.

First, note that the seller can make sure of getting a utility of $U^S = p_t - c_1$ by submitting an offer $O^S = (p_1^S = p_t, V_1)$. Given this offer, she can always successfully deliver x_1 to the buyer (by Lemma 2, $p_1^e = p_t$ independent of the buyer's possible counteroffer). Hence, in every equilibrium his utility must weakly exceed this level. For this reason, consider a buyer's counteroffer $O^B = (p_2^B = p_t + F, V_2)$. By arguments similar to the ones above, this offer induces an equilibrium allocation where x_2 is traded and $p_2^e = p_t + F$.[51] It is easy to verify that this efficient outcome yields the unique undominated equilibrium.

$c_2 > p_t - p_0 > v_1$.

In this case, the seller agrees to deliver the standard project under the initial prices, but the buyer rejects its acceptance, and *vice versa* for the innovative good. Hence, by Lemma 6, trade of x_1 requires an offer of the seller, while efficient trade of the innovation requires an offer submitted by the buyer. I will show that this constellation gives rise to two undominated equilibria: First, assume a buyer's offer $O^B = (p_1^B > p_0 + v_1, V_1, p_2^B = p_0 + c_2, V_2)$. Given this offer, the seller knows that the standard good cannot be traded in equilibrium since $p_1^e \ge p_1^B$ (Lemmata 1-4). Moreover, since $p_2^e \le p_2^B$ by Lemma 3, any counteroffer is not profitable for the seller, so that the equilibrium price is $p_2^e = p_0 + c_2$. Second, consider a seller's offer $O^S = (p_1^S = p_0 + v_1, V_1, p_2^S < p_0 + c_2, V_2)$. In this case, the innovation cannot be traded (Lemmata 1-4), and the buyer cannot tender an offer which forces the trade price of the standard good below the price proposed by the seller (Lemma 4). Accordingly, there exists an inefficient equilibrium of the renegotiation game in which the standard good is traded at a price $p_1^e = p_0 + v_1$. Note that, in contrast to the inefficient equilibria in the previous price intervals, this equilibrium is not pareto-dominated: While the buyer gets the whole net value of the innovation in the efficient equilibrium, the seller's payoff in the inefficient one is equal to the standard good's net value.[52]

$v_2 \ge p_t - p_0 \ge c_2$.

If $c_2 > v_1$ (which always hold if $\underline{c}_2 > \bar{v}_1$), the buyer can ensure efficient trade and a payoff $U^B = v_2 - p_t$ by submitting an offer $O^B = (p_2^B = p_t, V_2)$. Since the efficient allocation can be attained at the initial trade price, the unique equilibrium outcome is trade of x_2 and $p_2^e = p_t$. If $\underline{c}_2 < \bar{v}_1$, however, it can happen that $c_2 < p_t - p_0 \le \bar{v}_1$. In this case, the seller can guarantee himself a surplus $U^S = p_t - c_1$ by submitting an offer $O^S = (p_1^S = p_t, V_1)$ and successfull delivery of x_1 (Lemmata 1,2). To guarantee efficient trade, the buyer will submit a counteroffer

[51] To see that the seller's offer is necessary to support this equilibrium outcome, imagine that the seller abstains from submitting his message. Given this strategy, the buyer's best response is $O^B = (p_1^B > p_0 + v_1, V_1, p_2^B = p_0 + c_2, V_2)$. This offer precludes trade of x_1 (by Lemma 1, $p_1^e > p_0 + v_1$ such that the buyer rejects the acceptance), and guarantees efficient trade at the buyer's most preferred price $p_2^e = p_0 + c_2$.

[52] When investigating the investment decisions, we will confine our attention to the SPE in which the efficient good is traded. It should be mentioned, however, that the ex-ante results of the global game are unaffected by this restriction to the efficient equilibrium.

$O^B = (p_2^B = p_t + F, V_2)$, which makes the seller indifferent between trade of x_1 at p_t, and efficient trade of the innovation at the equilibrium price $p_2^e = p_t + F$.

$p_t - p_0 > v_2$.

The equilibrium is symmetric to the first price interval $p_t - p_0 < c_1$. Here, the seller will submit an offer $p_t^S = p_0 + v_2$, which guarantees efficient trade at the proposed price in the unique undominated equilibrium. Note that given this offer, the buyer cannot make any counteroffer which guarantees him a payoff higher than his no-trade utility.

The following corollary summarizes the (undominated) equilibrium outcomes:

Corollary 1: *Ex-post efficiency is a subgame-perfect equilibrium outcome of the renegotiation game under at-will contracting. This equilibrium is characterized by the following final prices:*

(A) Both Goods Valuable $\quad v_2 - c_2 > 0,\ v_1 = \bar{v}_1 \quad \Longleftrightarrow \quad x_2 = x_2^* = 1$

$$p_2^e = \begin{cases} p_0 + c_2 & \text{if } \ p_t - p_0 < c_1 \\ p_t + F & \text{if } \ \bar{v}_1 \geq p_t - p_0 \geq c_1 \\ p_0 + c_2 & \text{if } \ c_2 \geq p_t - p_0 \geq \bar{v}_1 \\ p_t & \text{if } \ v_2 \geq p_t - p_0 \geq max\{c_2, \bar{v}_1\} \\ p_0 + v_2 & \text{if } \ p_t - p_0 > v_2 \end{cases}$$

(B) InnovationValuable $\quad v_2 - c_2 > 0,\ v_1 = \underline{v}_1 \quad \Longleftrightarrow \quad x_2 = x_2^* = 1,$

$$p_2^e = \begin{cases} p_2 & \text{if } \ v_2 \geq p_t - p_0 \geq c_2 \\ p_0 + c_2 & \text{if } \ p_t - p_0 < c_2 \\ v_2 + p_0 & \text{if } \ p_t - p_0 > v_2 \end{cases}$$

(C) Standard Project Valuable $v_2 - c_2 < 0,\ v_1 = \bar{v}_1 \quad \Longleftrightarrow \quad x_1 = x_1^* = 1,$

$$p_1^e = \begin{cases} p_1 & \text{if } \ \bar{v}_1 \geq p_t - p_0 \geq c_1 \\ p_0 + c_1 & \text{if } \ p_t - p_0 < c_1 \\ \bar{v}_1 + p_0 & \text{if } \ p_t - p_0 > \bar{v}_1 \end{cases}$$

(D) $\quad v_2 - c_2 < 0, v_1 = \underline{v}_1 \quad \Longleftrightarrow \quad x_0 = x_0^* = 1,\ p_0^e = p_0$

where p_i^e denotes the equilibrium price of good i. Moreover, ruling out pareto-dominated equilibria, the above equilibrium outcomes are unique unless $\bar{v}_1 < p_t - p_0 < c_2$ in case (A). In this interval, there exists a second and inefficient equilibrium where x_1 is traded at a price $p_1^e = p_0 + \bar{v}_1$.

Proof of Proposition 2: Assume $p_t - p_0 < c_1$. In this case, $p_1^{(vii)} = p_0 + c_1$, $p_2^{(i)} = p_2^{(ii)} = p_2^{(iii)} = p_2^{(iv)} = p_0 + \underline{c}_2$ and $p_2^{(v)} = p_2^{(vi)} = p_0 + \bar{c}_2$. Inserting these prices into (16), we obtain $B = B^*$ which proves part (b) of the proposition. (Inserting the equilibrium prices into (12), we immediately observe that the seller's investment incentives are zero for these initial contracts.)

Now, assume $\bar{v}_2 \geq p_t - p_0 \geq \bar{c}_2$, inducing the equilibrium prices $p_1^{(vii)} = \bar{v}_1 + p_0,\ p_2^{(i)} = p_2^{(ii)} = p_2^{(v)} = p_2^{(vi)} = p_t$ and $p_2^{(iii)} = p_2^{(iv)} = p_0 + \underline{v}_2$. Inserting into (15), we observe that $A = A^*$, so that the seller's investments are welfare-optimal. It can easily be checked that efficient investments of the seller are still attained for prices $p_t - p_0 > \bar{v}_2$, since the seller is now residual claimant in every state of the world. In this latter interval, the buyer's incentives are zero. □

Proof of Proposition 3: Assume an initial contract characterized by $\bar{v}_2 \geq p_t - p_0 \geq \bar{c}_2$, inducing the equilibrium prices $p_1^{(vii)} = \bar{v}_1 + p_0,\ p_2^{(i)} = p_2^{(ii)} = p_2^{(v)} = p_2^{(vi)} = p_t$ and $p_2^{(iii)} = p_2^{(iv)} = p_0 + \underline{v}_2$. Inserting into (15), we observe that $A = A^*$ such that the seller's investments are welfare-optimal. After some easy steps, the efficiency condition of the buyer's investments (16) becomes

$$(p_t - p_0)^* = \rho(e^*)\underline{v}_2 + (1 - \rho(e^*))[\bar{c}_2 + q(\bar{v}_1 - c_1)]. \tag{20}$$

Accordingly, a necessary and sufficient condition for efficient two-sided investments is the validity of the inequalities

$$\bar{c}_2 \leq (p_t - p_0)^* = \rho(e^*)\underline{v}_2 + (1 - \rho(e^*))[\bar{c}_2 + q(\bar{v}_1 - c_1)] \leq \bar{v}_2. \tag{21}$$

By (10), this optimal price difference must be smaller than $\bar{v}_2$ if we assume an interior efficient solution of the buyer's investments. Accordingly, the second inequality in (20) will always hold for interior solutions of the efficient investments and can therefore be neglected. The optimal price difference is a convex combination of two constants, $\underline{v}_2$ and $\bar{c}_2 + q(\bar{v}_1 - c_1)$. We require this convex combination to be as least as large as $\bar{c}_2$. Hence, for all interior solution $\rho(e^*) > 0$, $q > 0$ is a necessary condition for efficient investments. Next, let us show that there can always be found a state space $\mathcal{S}$ such that efficient investments can be attained for any $q > 0$. This claim can easily be proved: Choose $\underline{v}_2 = \bar{c}_2 - \epsilon,\ \epsilon \to 0, \epsilon > 0$ which clearly is compatible with assumption 1. Now, for any positive q, the convex combination exceeds $\bar{c}_2$ which establishes the result.

Let now $\Sigma(q) = \{\mathcal{S} : \exists (p_t - p_0)^* : e^N = e^*, a^N = a^*\}$ be the partition of possible sets of sample points $\mathcal{S}$ under which a first-best result can be attained. We demonstrate that $\Sigma(q)$ is strictly increasing in q. In order to proof this claim, we must show that the derivative of the optimal price difference with respect to q is strictly increasing, i.e.

$$\frac{d(p_t - p_0)^*}{dq} = (1 - \rho(e^*(q)))[\bar{v}_1 - c_1] - \rho'(e^*(q))\frac{de^*}{dq}[\bar{c}_2 - q(\bar{v}_1 - c_1)] > 0. \tag{22}$$

The first term of this derivative is positive. Accordingly, a sufficient condition for (21) is

$$\frac{de^*(q)}{dq} = \frac{W_{ea}W_{aq}}{W_{ee}W_{aa} - W_{ea}W_{ae}} \leq 0, \tag{23}$$

where the expression for de^*/dq has been derived by totally differentiating the first-order efficiency conditions (9) and (10). It is easy to show that the numerator of this derivative is positive. Moreover, the denumerator is also positive, since its coincides with the determinant of the Hessian requires a positive sign to ensure the validity of the first-order conditions (9) and (10) for a maximum. Consequently, (21) holds, such that $(p_t - p_0)^*$ is strictly increasing in q. Finally, consider a set of states of nature under which $(p_t - p_0)^* = \bar{c}_2 - \epsilon$, $\epsilon > 0, \epsilon \to 0$. By (22), a marginal increase in q shifts $(p_t - p_0)^*$ upwards to obtain $(p_t - p_0)^* \geq \bar{c}_2$, given $\mathcal{S}$. Accordingly, increasing q induces a strict enlargement of the set Σ for which efficient investments are feasible. □

Proof of Proposition 4: Assume the parties have written an option contract (p_0, p_t) at date 0, which prescribes a price p_t if the seller delivers a good. Note that the buyer cannot profitably refuse the acceptance of a good which is delivered by the seller under the precontracted trade price p_t. Assume $\bar{v}_1$ is drawn by nature. If trade of x_1 is efficient (i.e. in case C), the following (unique) equilibrium trade prices are attained (see Nöldeke-Schmidt (1995)) and the remark in the proof of Proposition 1):

$$p_1^e = \begin{cases} p_t & \text{if } \; p_t - p_0 \geq c_1, \\ p_0 + c_1 & \text{if } \; p_t - p_0 < c_1 \end{cases}$$

The reason is simple: If $p_t - p_0 \geq c_1$, the seller exercises his option, so that there is efficient trade without renegotiation. If $p_t - p_0 < c_1$, however, the buyer must submit a renegotiation offer to make trade possible (Lemma 6). By our previous arguments, he holds all the renegotiation power in this case. In D where no trade is efficient, there is an upward revision of the no-trade price submitted by the buyer if the seller otherwise would exercise her option. Hence,

$$p_0^e = \begin{cases} p_0 & \text{if } \; p_t - p_0 < c_1, \\ p_t - c_1 & \text{if } \; p_t - p_0 \geq c_1. \end{cases}$$

Now suppose that cases A or B emerge, where trade of the innovation is efficient. Suppose first that V-offers are not feasible. Since the seller prefers trade of the standard good at any given price (precontracted or renegotiated), an ex-post efficient result is not feasible. Hence, there is equilibrium trade of x_1 in case A (at the same prices as in case C), or no trade in case B (at an equilibrium no-trade price as in D).

If V-offers are allowed, Lemma 6 and our previous arguments imply that the buyer has to tender a revision offer for trade of the innovation. Accordingly, he submits an equilibrium offer $O^B = (p_2^B = \max\{p_0 + c_2, p_t + F\}, V_2)$, iunducing efficient trade in the unique undominated equilibrium. Consequently, the seller's net surplus is $U^S = \max\{p_0, p_t - c_1\}$ in every state of the world. Since her utility does not depend on her specific investments, the no-investment result follows. □

Proof of Proposition 6: First, the reader will check that cases B, C and D, where at most one of the goods (good i, say) is valuable, are identical the case of unverifiable designs (replace p_t by p_i); see Lemma 1.

Hence, let us investigate case A, where x_2 is efficient, but both goods are valuable.

1. Assume $p_1 - p_0 < c_1$. We must distinguish between the following subcases:
$p_2 - p_0 < c_2$.
Since the seller does not agree to trade of any good under the initial prices, the unique (undominated) SPE yields trade of x_2 and $p_2^e = p_0 + c_2$, attained by the buyer's renegotiation offer.
$v_2 > p_2 - p_0 \geq c_2$.
There exists a unique and efficient equilibrium where x_2 is traded at the initial trade price p_2. Note that, in case that the buyer prefers trade of x_1 at a price $p_0 + c_1$ to the efficient outcome, this equilibrium requires a seller's offer $p_1^S \leq p_0 + c_1$ which makes trade of x_1 impossible (Lemmata 2,3).
$p_2 - p_0 > v_2$.
In this case, any project can only be realized only if either the seller (for trade of the innovation) or the buyer (for trade of the standard good) submits a renegotiation offer (Lemma 6). As in the corresponding situation when projects are unverifiable, this fact induces the existence of two undominated SPE: First, assume that the seller submits a renegotiation offer ($p_1^S < p_0 + c_1, p_2^S = p_0 + v_2$). By Lemmata 1-4, this offer precludes trade of x_1. The corresponding equilibrium $x_2 = 1$, $p_2^e = p_0 + v_2$ is efficient. Symmetrically, assume that the buyer submits an offer ($p_1^B = p_0 + c_1, p_2^B > p_0 + v_2$). By equivalent reasoning, this offer induces an equilibrium outcome $x_1 = 1, p_1^e = p_0 + c_1$. Note that these two equilibria cannot be pareto-ranked.

2. Assume $p_1 - p_0 > \bar{v}_1$.
$p_2 - p_0 < c_2$
Again, there exist two undominated trade-equilibria, an efficient one characterized by the buyer's revision offer ($p_1^B > p_0 + v_1, p_2^B = p_0 + c_2$), and an inefficient one in which the seller proposes ($p_1^S = p_0 + v_1, p_2^S < p_0 + c_2$).
$v_2 \geq p_2 - p_0 \geq c_2$
In the unique equilibrium, there is efficient trade of x_2 at $p_2^e = p_2$ (note that this equilibrium possibly requires an offer $p_1^B > p_0 + v_1$ to preclude trade of x_1).
$p_2 - p_0 > v_2$
Obviously, trade of any good requires an offer submitted by the seller (Lemma 6), so that $x_2 = 1$ and $p_2^e = p_0 + v_2$ in the unique undominated equilibrium.

3. Finally, let us consider initial contracts characterized by $\bar{v}_1 \geq p_1 - p_0 \geq c_1$. Note that the seller can always make sure of a payoff $U^S = p_1 - c_1$ by submitting an offer $p_1^S = p_1$ (Lemma 2), and delivering the standard project.
$p_2 - p_0 < c_2$.
There exists a unique undominated equilibrium outcome which is efficient, attained by equilibrium offers $p_1^S = p_1$ (see above) and $p_2^B = p_1 + F$. Given these messages, $x_2 = 1$ and $p_2^e = p_1 + F$.
$v_2 \geq p_2 - p_0 \geq c_2$.
In the subcase $p_2 - p_0 < p_1 + F$, the equilibrium strategies (as the outcome) are identical to the previous case. In the situations above, the seller enjoys a first-mover advantage since she can

always credibly threat to deliver the standard good. If $p_2 - p_0 \geq p_1 + F$, there is efficient trade without renegotiation in the unique SPE of the game.

$p_2 - p_0 > v_2$.

This case deserves special interest because there exists no efficient SPE at all. Note first that the buyer can guarantee trade of the standard good and make sure of getting $U^B = v_1 - p_1$ by submitting an offer $O^B = (p_1^B = p_1, p_2^B > p_0 + v_2)$. Given this offer, he precludes trade of the innovation (by Lemmata 1,2 and 4). Note that p_2^B is a necessary element of the buyer's offer to overcome the seller's first-mover advantage. To see that this offer is made in the unique equilibrium, imagine that the seller submits a renegotiation offer $p_2^S = v_2 - (v_1 - p_1)$. Given this offer, the buyer would be indifferent between trade of the innovation and trade of x_1 at p_1. However, trade of x_2 at this renegotiated trade price requires either an identical counteroffer by the seller, or no counteroffer at all. If one of these strategies is pursued by the buyer, however, the seller's best response is to submit an offer ensuing a trade price $p_2^e = p_0 + v_2$ after trade of the innovation. Consequently, the unique SPE of the game is characterized by inefficient trade of the standard good at a price $p_1^e = p_1$. Importantly, the seller suffers from being the first mover at the trade stage, which turns out to prevent efficient trade and the realization of a higher joint payoff.

The following corollary summarizes our discussion:

Corollary 4: *When the court's information partition is $\mathcal{I}^*$, the following undominated subgame-perfect equilibrium outcomes are attained in the renegotiation game under at-will contracting:*

(A) $v_2 - c_2 > 0,\ v_1 = \bar{v}_1$

1. *In the intervals specified below, there exists a unique undominated and efficient SPE, which is characterized by the equilibrium trade prices*

$$p_2^e = \begin{cases} p_0 + c_2 & \text{if} \quad p_2 - p_0 < c_2 \text{ unless } \bar{v}_1 \geq p_1 - p_0 > c_1 \\ p_1 + F & \text{if} \quad p_2 - p_0 < c_2 \text{ and } \bar{v}_1 \geq p_1 - p_0 > c_1 \\ max\{p_2, p_1 + F\} & \text{if} \quad v_2 \geq p_2 - p_0 \geq c_2 \text{ and } \bar{v}_1 \geq p_1 - p_0 \geq c_1 \\ p_2 & \text{if} \quad v_2 \geq p_2 - p_0 \geq c_2 \text{ unless } \bar{v}_1 \geq p_1 - p_0 \geq c_1 \\ v_2 + p_0 & \text{if} \quad p_2 - p_0 \geq v_2 \text{ unless } \bar{v}_1 \geq p_1 - p_0 \geq c_1 \end{cases}$$

2. *In the following intervals, there additionally exists an inefficient SPE, in which x_1 is traded at the following equilibrium prices:*

$$p_1^e = \begin{cases} p_0 + c_1 & \text{if} \quad p_2 - p_0 > v_2 \text{ and } p_1 - p_0 < c_1 \\ p_0 + \bar{v}_1 & \text{if} \quad p_2 - p_0 < c_2 \text{ and } p_1 - p_0 > \bar{v}_1 \end{cases}$$

3. *In the price interval specified below, there exists a unique SPE characterized by inefficient trade of x_1 and an equilibrium trade price:*

$$p_1^e = p_1 \quad \text{if} \quad p_2 - p_0 \geq v_2 \quad \text{and} \quad \bar{v}_1 \geq p_1 - p_0 \geq c_1.$$

(B) $\quad v_2 - c_2 > 0, v_1 = \underline{v}_1 \quad \Longleftrightarrow \quad x_2 = x_2^* = 1,$

$$p_2^e = \begin{cases} p_2 & \text{if} \quad v_2 \geq p_2 - p_0 \geq c_2 \\ p_0 + c_2 & \text{if} \quad p_2 - p_0 < c_2 \\ v_2 + p_0 & \text{if} \quad p_2 - p_0 \geq v_2 \end{cases}$$

(C) $v_2 - c_2 < 0, \; v_1 = \bar{v}_1 \quad \Longleftrightarrow \quad x_1 = x_1^* = 1,$

$$p_1^e = \begin{cases} p_1 & \text{if} \quad \bar{v}_1 \geq p_2 - p_0 \geq c_1 \\ p_0 + c_1 & \text{if} \quad p_2 - p_0 < c_1 \\ \bar{v}_1 + p_0 & \text{if} \quad p_1 - p_0 > \bar{v}_1 \end{cases}$$

(D) $\quad v_2 - c_2 < 0, v_1 = \underline{v}_1 \quad \Longleftrightarrow \quad x_0 = x_0^* = 1, \; p_0^e = p_0.$

Proof of Proposition 7: First, observe that by choosing $p_1 - p_0 \geq \bar{v}_1$ and $\bar{v}_2 \geq p_2 - p_0 \geq \bar{c}_2$, the efficiency outcome of Theorem 1 is replicated: Under these price differences, we have $p_1^{(vii)} = \bar{v}_1 + p_0, \; p_2^{(i)} = p_2^{(ii)} = p_2^{(v)} = p_2^{(vi)} = p_2$ and $p_2^{(iii)} = p_2^{(iv)} = p_0 + \underline{v}_2$. Plugging into (15), one immediately obtains the validity of $A = A^*$ implying efficient investment incentives of the seller. Moreover, inserting into (16) and rearrangging terms yields the price difference generating efficient incentives of the buyer

$$(p_2 - p_0)^* = (1 - \rho(e^*))[\bar{c}_2 + q(\bar{v}_1 - c)] + \rho(e^*)\underline{v}_2. \tag{24}$$

Again, this solution is only valid if it is compatible with the $(p_2 - p_0)^* \geq \bar{c}_2$.

To verify that there are still other possibilities to reach a first-best, consider now initial prices $p_1 - p_0 < c_1$. Accordingly, sing Proposition 6, $p_1^{(vii)} = p_0 + c_1$ and the condition for efficient investments of the buyer (16) can be written as

$$\bar{c}_2 = qp_2^{(v)} + (1-q)p_2^{(vi)} - p_0 - \frac{\rho(e^*)}{1 - \rho(e^*)}[q(p_2^{(iii)} - p_2^{(i)})) + (1-q)(p_2^{(iv)} - p_2^{(ii)})]. \tag{25}$$

We characterize price differences $p_2 - p_0$ for which the term in square brackets vanishes. Let us first find conditions for $p_2^{(iii)} = p_2^{(i)}$. By Proposition 6, this occurs if either $\underline{v}_2 \geq p_2 - p_0 \geq \underline{c}_2$ in which case $p_2^{(i)} = p_2^{(iii)} = p_2$ or if $p_2 - p_0 < \underline{c}_2$ where $p_2^{(i)} = p_2^{(iii)} = p_0 + \underline{c}_2$. Next, we require $p_2^{(iv)} = p_2^{(ii)}$, which is realized for the same ex-ante prices. Assume that $p_2 - p_0 \leq \underline{v}_2$, so that the term in brackets is zero. Now, we check under which circumstances

$$\bar{c}_2 = qp_2^{(v)} + (1-q)p_2^{(vi)} - p_0 \tag{26}$$

applies. This can be guaranteed if and only if $p_2 - p_0 \leq \bar{c}_2$ in which case $p_2^{(v)} = p_2^{(vi)} = p_0 + \bar{c}_2$. We immediately observe that this requirement is compatible with $p_2 - p_0 < \underline{v}_2$, so that $B = B^*$ under initial prices $p_1 - p_0 < c_1$, and $p_2 - p_0 \leq \underline{v}_2$.

Let us turn to the condition for efficient incentives of the seller (15). Under our initial assumption $p_1 - p_0 < c_1$, this condition can be rewritten as

$$\underline{v}_2 - q(\bar{v}_1 - c) = qp_2^{(iii)} + (1-q)p_2^{(iv)} - p_0 - \frac{\mu(a^*)}{1-\mu(a^*)}[q(p_2^{(i)} - p_2^{(v)}) + (1-q)(p_2^{(ii)} - qp_2^{(vi)})]. \quad (27)$$

From our preceding discussion, we know that $p_2 - p_0 < \underline{v}_2$ $[< \bar{c}_2]$ guarantees efficient investments of the buyer. Examining the terms in brackets, we obtain $p_2^{(i)} = p_2^{(ii)} = p_2$ as long as $\bar{v}_2 \geq p_2 - p_0 \geq \underline{c}_2$. Assuming the subinterval $\bar{c}_2 \geq p_2 - p_0 \geq \underline{c}_2$, we have $p_2^{(v)} = p_2^{(vi)} = p_0 + \bar{c}_2$. Inserting these prices into the efficiency condition (15) and rearranging terms yields

$$(p_2 - p_0)^* = (1 - \mu(a^*))(\underline{v}_2 - q(\bar{v}_1 - c)) + \mu(a^*)\bar{c}_2. \quad (28)$$

Of course, this solution is only valid if $\underline{c}_2 \leq (p_2 - p_0)^* < \underline{v}_2$. Since $\underline{v}_2 < \bar{c}_2$, we observe again that efficient investments require $q > 0$. Unless $q = 0$, however, one can find parameter values for which $(p_2 - p_0)^*$ induces first-best investments of both parties. Accordingly, the set $\Sigma(q)$ strictly increases if the projects are verifiable ex ante.

Finally, consider option contracting and initial prices $p_1 - p_0 < c_1$. Under these prices, the seller will never deliver the standard good unless renegotiation occurs. Moreover, the existence of a standard project does not influence her bargaining power in states where the innovation should be traded (A and B). For this reason, it is easy to check that $p_2^e = \max\{p_0 + c_2, p_2\}$ in A and B, $p_1^e = \max\{p_0 + c_1, p_2 - F\}$ in C and $p_0^e = \max\{p_2 - c_2, p_0\}$ in D. Note that the seller's ex-post utility is $\max\{p_2 - c_2, p_0\}$ in every state of the world, so that her investment incentives monotonically increase in $p_2 - p_0$. Since she overinvests relative to the first-best if $p_2 - p_0 > \bar{v}_2$ (see Nöldeke-Schmidt (1995)), the optimal price difference is strictly smaller than this value. Moreover, and as in Nöldeke-Schmidt, the buyer maximizes the whole surplus minus a constant, so that first-best investments are induced. □

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