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RELATIONSHIP-SPECIFIC INVESTMENT AND MULTIPLE INTERESTED PARTIES*

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This paper proposes a solution to the hold-up problem for situations where a seller interacts with several parties who have a common interest in inducing the seller to make a quality-enhancing investment. Since parties can observe purchase decisions, they are able to add a clause to the contract specifying that an extra payment should be made to the seller, conditional on verifiable previous purchases. Since previous purchases depend on observable but not verifiable quality, this 'conditional multilateral contract' provides correct incentives to restore efficiency, and is feasible in the context of both, complete and incomplete information.

1 Introduction

In its classic version, a hold-up problem arises when a relationship-specific investment increases the value of the transaction among parties, but parties are unable to specify a complete contract defining the division of the returns from the investment. Anticipating that future negotiations may confer parts of the benefit from the customized investment to the non-investing party, the investing party will under-invest in comparison to the social optimum (Williamson, 1985; Holmström and Roberts, 1998; Hart and Moore, 1999).

This paper proposes a solution to the hold-up problem for situations where a seller interacts—and potentially trades—with several parties who have a common interest in inducing the seller to make a quality-enhancing investment. The quality of the product is observable for the buyer(s) before purchase, but not verifiable. Thus, contracts contingent on quality are infeasible. Also, the level of the quality-enhancing investment is not verifiable, implying that contracts contingent on the investment level are not feasible, either. However, previous trades are observable *and* verifiable. This allows parties to agree on contracts that take advantage of the presence of multiple buyers and the sequence of purchase decisions. Specifically, parties are able to solve the hold-up problem, by making transfers paid by some party contingent on the verifiable purchase decision of other buyer(s).

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Since previous purchases depend on observable but unverifiable quality, this form of conditional multilateral contract provides correct incentives to restore efficiency, and is feasible in the context of both, complete and incomplete information.

Numerous potential applications exist for such contracts. Abstracting from competition, the seller may be any company developing customized products, while the buyers may be end-consumers, firms operating in different markets or industries, or companies in the research sector.[1] Including competition among the buyers expands the field of application to any group of suppliers facing a hold-up problem. Competition among several buyers has no effect on contracting, a priori. The impact of contracting on the competitive position—or on the incentives of the competing firms—may be captured by allowing buyers to have different, possibly private valuations, for the products. This case is investigated in Section 3.[2]

The involvement of a second buyer is not a prerequisite. The contract may also specify that the transfer exchanged, conditional on the purchasing decision, is paid for by an outside party (a financier), taking advantage of the transformation of an unverifiable state of quality/investment into a verifiable purchasing decision.

Multilateral contracts are not uncommon, though the purpose is often different from that of solving the hold-up problem. One example is Pledgebank, a website structuring crowdfunding projects. Among others, it runs pledges consisting of a promise by one party to pay a premium to an entity upon a certain number of others donating money.[3]

Such pledges have a formal structure that is similar to the conditional multilateral contract proposed here, except that their aims are different. Specifically, pledges have been used to increase voluntary contributions towards a public good or to solve coordination problems, and not as remedies against the hold-up problem (although, in principle, they could be remedies,

[1]More specific examples include SAP, developing software for firms operating in different industries, such as E.ON SE, one of the largest private energy companies in Europe, or B. Braun, one of the world's leading health-care suppliers (SAP, 2013). Air force authorities from different countries wishing to buy the Lockheed Martin F-35 Lightning II may sign a conditional multilateral contract as proposed here (GlobalSecurity.Org, 2011). Another example is Gore-Tex® supplying materials to distributors targeting different audiences, such as Black Diamond Equipment or Burton (Gore-Tex®, 2013a, 2013b).

[2]The question might arise whether such a contract is in line with competition laws or not. Since the contract (i) leads to increased overall welfare due to efficient investment and (ii) evidently does not harm consumers, it is in line with regulations both in the EU and in the US (EU: paragraph 101/102 of the EU Competition Law; US: the Sherman Act, the Federal Trade Commission Act and the Clayton Act).

[3]For example, Ronald Ramo pledges to 'donate $500 to the Ron Paul Presidential Campaign, but only if 200 […] people will donate at least $20'; Shirley Salmeron pledges to donate '$1000 to Catalytic Communities, […] but only if 30 […] friends of CatComm will pledge $50 or more'; and Serena Blanchflower pledges '£250 to MERGE, […] but only if 25 other people will give £ 10 each' (all pledges see pledgebank.com, 2006/2007).

since pledges of the form 'I pay *w* to *x* if *y* number of people buy *z*' are feasible). A second example of successful crowdfunding through a contract similar to the proposed multilateral one is the development and production process of the fitness e-watch Pebble. While no party promised to pay a premium upon others purchasing the product, the purchase decision of each buyer (and the production decision of the firm) was conditional upon a sufficient number of supporters placing a pre-order. As a result, the campaign raised $10 million in 2012 (kickstarter.com, 2012; Forbes.com, 2012; Money, 2013). As in the previous example, the form of the contract was similar to the one proposed here, although the purpose of the latter is different.

Finally, certain forms of multi-sided markets (Rochet and Tirole, 2003, 2006) are also similar in structure to the one proposed here, such as video game platforms or any kind of media supported by advertising. No multilateral contract is involved—not even a contract conditional on the behaviour of other parties—and the incentives for one side to pay a premium are related to a consumption externality, rather than to a signal of the quality of the good. Yet, the two settings share an important characteristic. Both, in the case of multi-sided markets as in the proposed contract, only after sufficient (end-)customers from one side buy a unit, customers from the other side (game producers or advertisers) will be willing to pay (more) for a unit of the good.[4] Even among multi-sided markets, there are cases in which parties sign contracts which specify a premium that the company pays to the platform, conditional on the behaviour of other parties. Facebook, e.g. offers advertisement contracts where the advertiser pays, conditional on the number of views and clicks generated by the users. Similarly, one may find evidence in editorial contracts in which the publisher starts paying royalties to the author of a book, but only when sales cross a certain threshold.

In the model presented here, relation-specific investment generates direct benefits only to the seller's trading partners and not to the seller himself. Che and Hausch (1999) call such investments 'cooperative', to distinguish them from investments that benefit only the investor, which are called selfish. Che and Hausch find that contracting creates additional value to the parties when investment is cooperative, and committing not to renegotiate is possible. If renegotiation cannot be ruled out, Maskin and Moore (1999) and Segal and Whinston (2002) have shown that the first-best outcome cannot be attained. Hence, the question arises whether it is possible or not to commit not to renegotiate. One possibility to achieve such a commitment is to include a third party who is able to observe quality and may act as an

[4]While in the classic definition of multi-sided markets the purchase decision of some buyers directly influences the valuation of the good by other buyers, the multilateral contract presented here does not rely on such externalities. The purchase decision of other buyer(s) only creates a signal of quality. Complementarities to both sides of the market do not have to be excluded, yet, they are not the focus.

intermediary or arbitrator, threatening to punish renegotiators (Dixit, 2004). In the contract presented here, renegotiation is not an issue since the contract is incentive compatible. The purchase decision of buyer one translates the unverifiable state of quality into a verifiable event, and the transfer paid by the second buyer (the 'third party') is contingent on this event. Renegotiating the price of the good cannot improve the positions of the respective parties.

Hence, the question whether the contract is feasible or not transforms into a question of whether collusion can be ruled out or not (Hart and Moore, 1999; Maskin and Tirole, 1999). Collusion is a potential problem here and needs to be ruled out, so that the solution holds. This latter property might be considered a major drawback. However, if the number of buyers is large, and / or the buyers are unable or unwilling to communicate (for instance, because they are firms in the same industry that respect the cartel law), then the assumption of 'no collusive behaviour' seems less problematic.

The present paper does not rely on other means that typically have been employed to remedy the hold-up problem. Demski and Sappington (1991) consider a moral hazard problem, where efforts of a principal and an agent are not verifiable, yet the principal observes the agent's efforts. Efficient effort levels can be induced by means of an option contract that specifies a price for which the principal can sell his firm to the agent. This paper proposes a solution that does not involve possible changes in asset ownership. Overall, no (vertical) integration or restructuring of firm boundaries is required (see also Klein *et al.*, 1978; Grossman and Hart, 1986; Baker *et al.*, 2002). In addition, the contract does not rely on repeated interactions with the same agent or within a group (Radner, 1981; Kandori, 1992; Dixit, 2003). The one-time interaction among the agents involved in the transaction suffices to induce efficient incentives.

Other papers have considered dynamic hold-up problems, as well. In Nöldeke and Schmidt (1998), a buyer and a seller sequentially invest cooperatively, both facing a hold-up problem. Giving the buyer the option to acquire the investing firm at a predetermined price at some later date induces efficient investment and explains the use of contingent ownership structures in joint ventures. Also, in the work of Pitchford and Snyder (2004), sequential investments by the seller and sequential payments by the buyer lead to efficiency. However, the present setting requires more than one interested party, which, however, implies that the downstream parties do not collude, that is they do not act as one player.

A paper related to the transformation of a non-verifiable event into a verifiable one is Nöldeke and Schmidt (1995). Focusing on investment that only directly affects the investor, they show that when the supply of the seller is observable, an option contract remediates the hold-up problem. In my model, while trade has to be verifiable, if no trade takes place, there is no need to distinguish between whether the seller refuses to supply or not and whether the buyer refuses to accept delivery or not.

The remaining part of the paper is organized as follows. Section 2 introduces the basic model under complete information. Section 3 extends the model to incomplete information. Section 4 concludes the paper.

2 Model

2.1 Introduction Model

There are three players, a seller S and two buyers, B_1 and B_2.[5] S produces two units of a good. The cost of producing a unit is normalized to zero. The two units are of the same quality, and quality depends on level e of a quality-enhancing investment chosen by S. Investment is costly for S and the investment cost, denoted as $c(e)$, is a strictly increasing function. For the sake of simplicity, I assume a binary relationship between investment and quality, in that there exists an investment level e^* such that for any $e < e^*$ the product is of low quality and for $e \geq e^*$ the product is of high quality.[6] Each unit of the good can be sold either to one of the potential buyers (each is interested in at most one unit), or potentially to the market. The price in the market is exogenously given, and might depend on quality (but does not necessarily have to). Specifically, a unit of low-quality yields $m_l \geq 0$ and a unit of high quality yields $m_h \geq m_l$ in the market. The two (potential) buyers B_1 and B_2 both have valuations of zero for the low quality product[7] and a strictly positive valuation for the high quality product. Let the valuation for a unit of the high quality product be v_i, with $v_i > m_h$ for $i = 1,2$. Furthermore,

$$v_1 + v_2 - 2m_l \geq c(e*) > 2m_h - 2m_l \geq 0;$$

the first part of this condition states that the cost of the investment is not higher than the additional value created by the high quality over the low quality for the two buyers—otherwise, investing would never be efficient. The second part states that the cost of investment is higher than the additional value created by high quality over low quality in the market—otherwise, no hold-up problem would exist.

All players are risk neutral and their utility payoffs are just the material payoffs. There are no transaction costs.

The timing of the game is shown in Fig. 1. At time $t = 0$, partners decide upon the terms of the contract. At $t = 1$, S chooses the level of investment, and production occurs. At $t = 2$, the two buyers B_1 and B_2 sequentially

[5]For the sake of simplicity, in the rest of the paper, I will concentrate on two buyers. The extension to more than two buyers and the extension to one buyer and one investor is straightforward.

[6]Appendix B presents a cleaner, continuous version of the relationship, where an increase in e increases the probability that the good is of high quality.

[7]While this is not necessary for the result to go through, it simplifies the analysis greatly. Furthermore, it seems very natural in many transactions involving relationship-specific investment or customized products (Lülfesmann, 2012).

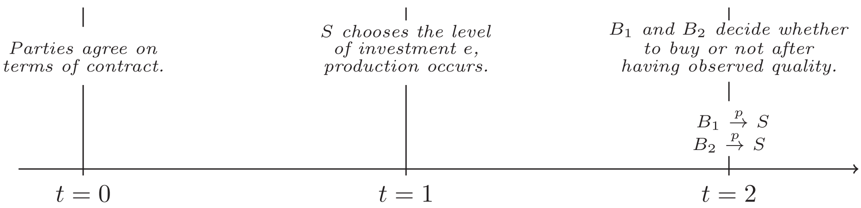

FIG. 1. Timeline Two Independent Contracts

decide whether to buy or not to buy at a price p, after having observed the quality of the good.[8]

If investment was verifiable, but quality was not, an efficient outcome could be reached that guarantees each party at least the reservation payoff, e.g. by a contract that specifies an investment $e = e^*$ and a price $p \in [\frac{1}{2}c(e*), v_i]$. Also, if investment was not verifiable, but quality was, there exist incentive compatible contracts which induce efficient outcomes. Any contract which specifies a pair of prices (p_{h_i}, p_{l_i}) such that $p_{h_i} - p_{l_i} = v_i$, for $i \in \{1,2\}$ and lump sum transfers $\tau \in R_+$ to distribute profits induces an efficient outcome.

If neither quality nor investment is verifiable, a contract that specifies a price independent of the realized quality of the good does not induce an efficient level of investment, since S has no incentive to produce high quality. An option contract, which specifies a pair of prices with $p_h > m_h$ (and $p_l \geq 0$) is not self-enforcing, and therefore, parties cannot provide the seller with enough incentives to invest e^*.

2.2 *Multilateral Contract*

A multilateral contract leads to an efficient level of investment if neither quality nor investment is verifiable. The contract is the following: B_1 and B_2 each has the option to buy one unit of the good once they have observed its quality. B_1 has the option to buy a unit at price $p = m_h \geq 0$; if B_1 buys, then B_2 is required to pay ρ to S. Once B_1 has taken his decision, B_2 has the option to buy a unit at price $p = m_h$. The timing is summarized in Fig. 2.

In case the good is of high quality, B_1 and B_2 execute the option and S obtains a payoff of $2p + \rho$. The payment ρ can be specified such that S has an incentive to participate in the contract and to invest e^*. B_1 and B_2 pay no more for the good than they would pay if S sold it to the market. B_2 is required to pay ρ contingent on B_1 buying the good. Depending on B_2's valuation v_2, the fact that he has to pay ρ may require B_1 to compensate B_2 so

[8]All parties involved bargain simultaneously over the contract, deciding which of the buyers purchases first. Without loss of generality, assume B_1 buys first.

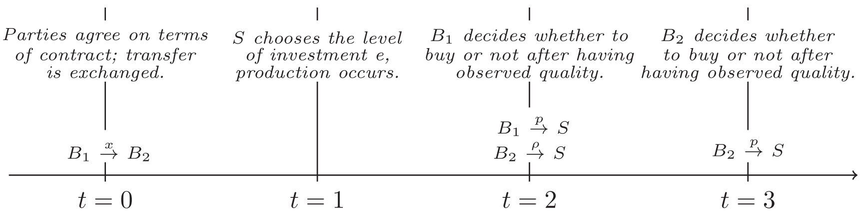

FIG. 2. Timeline Multilateral Contract

that his participation constraints are fulfilled. x denotes the payment that B_1 makes to B_2 upon signing the contract.

The timing of the game is crucial. Incentive compatibility is assured only by making payments conditional on prior transactions. Note that the sequential arrangement does not provide additional information—quality is observable at all times. Instead, it generates a verifiable variable (i.e. whether B_1 bought the good or not), which is perfectly correlated with quality.

Proposition 1 A multilateral contract that specifies $\{p = m_h, \rho \in [c(e*) - 2m_h + 2m_l, v_1 + v_2 - 2m_h] \text{and} \rho + m_h - v_2 \leq x \leq v_1 - m_h\}$ is self-enforcing and induces the optimum level of investment.

Proof First, consider incentive compatibility. Suppose the contract has been signed and quality of the good is high. Both buyers have the possibility to refuse to buy from S. In this case, S can sell the two units to the market at a price m_h. Since there are zero transaction costs, if there is a market, B_1 and B_2 can then buy each at a price m_h from the market. Once quality is observable, B_i will buy from S as long as his payoff is not lower than what he gets while buying from the market,

$$v_i - p \geq v_i - m_h \, \forall \, i \in \{1, 2\}. \tag{1}$$

Also, B_i will not buy a unit of the low-quality good if the price is not less than the value created. Since the value that a low quality good creates is zero, this implies that B_i will not buy a low-quality good as long as

$$p \geq 0. \tag{2}$$

With $p = m_h$, inequalities (1) and (2) are satisfied for $i \in \{1,2\}$.

Knowing that she receives $2p$ and ρ if the good is of high quality, S will invest e^* as long as her payoff from selling two units of the high quality good is not lower than her payoff from not investing,[9]

[9]I assume that parties do not collude (see below). As long as the first buyer does not receive a share of ρ for claiming that the good is of high quality when it is of low quality, he does not have an incentive to do so. Therefore, the seller's payoff from not investing is only the payment she receives for two low quality goods.

$$2p + \rho - c(e*) \geq 2m_l. \tag{3}$$

With $p = m_h$ and $\rho \in [c(e*) - 2m_h + 2m_l, v_1 + v_2 - 2m_h]$, inequality (3) is satisfied.

Second, consider individual rationality. S will only participate in the contract as long as inequality (3) is fulfilled. If the contract is not signed, S will not invest e^*, and no high quality good will be produced. A unit of low quality has a value of 0 for B_1 and B_2, hence the expected value of not signing the contract is 0 for each buyer. Having to pay x to B_2 upon signing the contract, B_1 participates in the contract if his expected value is not lower than not partaking:

$$-x + v_1 - p \geq 0. \tag{4}$$

Similarly, receiving x upon signing the contract, B_2 will participate as long as

$$x + v_2 - p - \rho \geq 0. \tag{5}$$

With $p = m_h$, $\rho \in [c(e*) - 2m_h + 2m_l, v_1 + v_2 - 2m_h]$, and $\rho + m_h - v_2 \leq x \leq v_1 - m_h$, inequalities (4) and (5) are fulfilled.

The contract is individual rational, but not immune to collusion between B_1 and B_2. Obviously, the two buyers together would prefer to pay $2p$ instead of $2p + \rho$ for two high quality goods. However, as already mentioned in the introduction, if one regards B_1 as representing a large number of buyers, or assumes that B_1 and B_2 are unable or unwilling to collude (because of collusion entailing breaking competition laws, for example) then this property seems less problematic.

A related problem is collusion between S and B_1 at B_2's expense: when S produces low quality and B_1 certifies the good as having high quality, S receives ρ from B_2. Hence, S may transfer an amount $\tau \leq \rho$ to B_1 for certifying high quality. Note, however, that for $\tau \leq v_1 - p$, B_1 is better off with a high quality good than with low quality plus a transfer of τ. With

$$\rho \leq v_1 - p, \tag{6}$$

B_1 is better off with high quality even if S transfers the whole amount ρ. Hence, under this condition, B_1 has an incentive to commit ex ante not to collude with S, if a commitment technology is available.

The exact specification of ρ and x depends on the cost of investment, the additional profit created and the distribution of profits. As long as the relationship creates no additional surplus (i.e. $v_1 + v_2 - c(e^*) = 2m_l$) the only possible contract specifies $\rho = v_1 + v_2 - 2m_h$ and $x = v_1 - m_h$. In this case, the overall profit for S equals her outside option (i.e. the profit when the contract does not materialize), $2m_l$. Also, for B_1 and B_2, profits equal their outside options, which is a payoff of zero.

The contract will generate a positive surplus (to be distributed among the participating parties) only if $v_1 + v_2 - 2m_l > c(e^*)$. How the surplus is distributed depends on the bargaining shares of the parties, which are implicitly defined by the transfers ρ and x, and assumed to be exogenously given (Edlin and Reichelstein, 1996; Che and Hausch, 1999). With $\rho = c(e^*) - 2m_h + 2m_l$, all surplus goes to the buyers (they may divide the surplus by specifying x accordingly).[10] For illustrative reasons, consider the case when all additionally generated surplus goes to the seller: $\rho = v_1 + v_2 - 2m_h$, $x = v_1$, and hence her payoff is $v_1 + v_2 - c(e^*)$. Obviously, other distributions of extra surplus are feasible.

2.3 *Premium Contract*

Under some circumstances—with v_2 large enough—efficiency can be achieved by means of bilateral contracts that do not entail any contractual relationship or payment between B_1 and B_2. In this situation, the contract obliges B_2 to pay a premium, conditional on other buyer(s) purchasing a unit of the good. The contract is similar to the one proposed. Yet, it resembles better examples in which firms contract less directly as a group, e.g. when the number of buyers B_1 is large.

Again, B_1 and B_2 have the option to each buy one unit of the good once they have observed its quality. B_1 has the option to buy a unit at price $p = m_h$. If B_1 buys, then B_2 is required to pay ρ to S. Once B_1 has taken his decision, B_2 has the option to buy a unit at price $p = m_h$. In case the good is of high quality, B_1 and B_2 execute the option and S obtains a payoff of $2m_h + \rho$. Without loss of generality, assume B_2 has a 'high' valuation: he values one unit of the high quality good not less than its market price plus the payment S needs to receive to invest efficiently:

$$v_2 \geq m_h + \rho.$$

Hence, B_2 does not need to be compensated to participate in the contract, and firms can contract bilaterally. Incentive compatibility constraints are given by the inequalities (1)–(3), and participation constraints are given by the inequalities (3)–(5), where in the latter two inequalities $x = 0$. With $p = m_h$, $\rho \in [c(e*) - 2m_h + 2m_l, v_1 + v_2 - 2m_h]$, all constraints are satisfied, and S and B_2 condition the exchange of a payment ρ on the external event that B_1 buys the good. In this case, the payment ρ is a kind of premium, which may honour the effort of the seller to attract other buyer(s).

[10]With $x = v_1 - m_h$, the payoff of B_1 is zero, while B_2 captures all created surplus. Hence, his payoff is $v_1 + v_2 - c(e^*) - 2m_l$. With $x = c(e^*) + 2m_l - m_h - v_2$, B_1 captures all additional surpluses, and his payoff is $v_1 + v_2 - c(e^*) - 2m_l$, while B_2 receives zero. With $x = \frac{1}{2}(v_1 - m_h - c(e*) - 2m_l + m_h)$, profits are divided equally among the buyers, and each receives $\frac{1}{2}(v_1 + v_2 - c(e*) - 2m_l)$.

3 Incomplete Information

Consider the case that the own valuation of a unit of the high quality good is private information to each buyer; an assumption which is straightforward to include, to take the model closer to reality. In such a case, ρ and x may be made conditional on the declared types. As will be shown in the following, allowing for this type of private information does not change the results and the suggested contract induces truthful revelation of private information.

Assume that there are two buyers who, at the time of writing the contract, privately observe their type $v^k, k \in \{H,L\}$ with $v^H \geq v^L > m_h$ (and, as before, $m_h \geq m_l \geq 0$). The types v^H and v^L are identically and independently distributed, with $\Pr\{v_i^k = v^H\} = q \in [0,1]$, the distribution being common knowledge. Let

$$2v^L - 2m_l \geq c(e*) > 2m_h - 2m_l. \tag{7}$$

The first part of this condition states that the cost of the investment is not higher than the additional value created by the high quality over the low quality for the two buyers, when both buyers have low valuations of the high-quality unit. The second part states that the cost of investment is higher than the additional value created by high quality over low quality at the market.[11]

Proposition 2 There exists a contract that induces truthful revelation of types and the optimal level of investment.

Proof See Appendix A.1.

If the additional benefit generated is minimal (i.e. $c(e^*) = 2v^L - 2m_l$) then the solution is unique: $\rho = 2v^L - 2m_h$ and $x = v^L - m_h$. In this case—as in the case of full information—the profits of the seller and the buyers are equal to their reservation utility. Each buyer's profit is independent of what the other buyer reports. When being of a high type, the buyer in question gets an informational rent while reporting truthfully, equal to the difference in valuations.

If the additional benefit generated is not minimal (i.e. $c(e^*) < 2v^L - 2m_l$), there exist a number of solutions, depending on the size of the benefit generated. In either case, both, the seller and the buyers receive at least their reservation utilities. Furthermore, again, each buyer's profit is independent of what the other buyer reports, and when being of a high type, the buyer in question gets an informational rent while reporting truthfully.

[11]If $c(e^*) = v_1 + v_2 - 2m_l$ and v_1 and / or v_2 equals v^H, and when buyers are of high types, there is not sufficient surplus to guarantee the informational rents required to truthfully report the types, see the proof in A.1. For a probabilistic version of this model with incomplete information, see Appendix C.

4 Conclusion

The presented solution to the hold-up problem applies to settings in which several parties want to incentivize a seller to make a quality-enhancing investment. More importantly, it also holds good when the outcome of investment is probabilistic, i.e. when the seller cannot be sure of producing high quality. The extension makes the contract applicable to settings of research and development, and this is illustrated in Appendix B.

The extension of the simple contract to more than two parties is straightforward. Together with the version of the multilateral contract entitled 'premium contract', such a setting best resembles the introductory example of a multi-sided market. In this case, the two (groups of) buyers may share different characteristics, which justifies the assumption of different valuations for the good—and justifies why one buyer/one group of buyers may be willing to pay a premium.

As highlighted in the introduction, contracts similar to the one proposed here have been used in many situations. Yet, the contract may not be immune to collusion among parties, even though this might be less of a problem with a large number of buyers—or in the version of the premium contract, when buyers have different valuations. If firms can exclude collusion, if they interact on just a one-time basis, or if they do not want to rely on reputational concerns, then, such a contract provides optimal means to restore efficiency. I show that inefficiencies associated with the hold-up problem can be eliminated easily with the proposed contract, with simple market transactions—there is no need to build sophisticated organizations (such as firms) to handle the problem.

APPENDIX A. PROOFS

A.1 Proof of Proposition 2

Let $\hat{v}_i$ be the reported types, $i \in \{1,2\}$. Knowing that she receives $2p$ and ρ if the good is of high quality, S will invest e^* as long as her payoff from selling two units of the high quality good is not lower than her payoff from not investing,

$$2p + \rho - c(e*) \geq 2m_l.$$

With $p = m_h$ and $\rho \in [c(e*) - 2m_h + 2m_l, \hat{v}_1 + \hat{v}_2 - 2m_h]$, S will invest.

Suppose the quality of the good is high. Once quality is observable, B_i will buy from S as long as his payoff contracting is not lower than his payoff from buying from the market,

$$v_i^k - p \geq v_i^k - m_h \, \forall \, i \in \{1,2\}, k \in \{H,L\}. \tag{8}$$

He will not buy a unit of low quality as long as what he pays for it is more than the value created,

$$p \geq 0. \tag{9}$$

With $p_i = m_h$, inequalities (8) and (9) are satisfied.

The participation and incentive compatibility constraint for S is

$$2m_h + \rho(\hat{v}_1^k, \hat{v}_2^j) - c(e*) \geq 2m_l, \forall k,j \in \{H,L\}.$$

The participation constraints for B_1 and B_2 are, respectively

$$v_1^k - m_h - x(\hat{v}_1^k, \hat{v}_2^j) \geq 0 \quad \text{and} \tag{10}$$

$$v_2^k + x(\hat{v}_1^j, \hat{v}_2^k) - m_h - \rho(\hat{v}_1^j, \hat{v}_2^k) \geq 0, \forall k,j \in \{H,L\}. \tag{11}$$

Incentive compatibility regarding the reported type in (weakly) dominant strategies requires that a strategy must exist $\hat{v}_i = v_i^k, \forall i \in \{1,2\}$ such that

$$U_i(\hat{v}_i, \hat{v}_{-i} | v_i) \geq U_i(\hat{v}_i\prime, \hat{v}_{-i} | v_i), \forall \hat{v}_i, \hat{v}_i\prime.$$

That is, for B_1 and B_2 respectively,

$$v_1^k - m_h - x(\hat{v}_1^k, \hat{v}_2^j) \geq v_1^k - m_h - x(\hat{v}_1^{-k}, \hat{v}_2^j), \quad \text{and} \tag{12}$$

$$v_2^k - m_h + x(\hat{v}_1^j, \hat{v}_2^k) - \rho(\hat{v}_1^j, \hat{v}_2^k) \geq v_2^k - m_h + x(\hat{v}_1^j, \hat{v}_2^{-k}) \tag{13}$$

$$-\rho(\hat{v}_1^j, \hat{v}_2^{-k}), \forall k,j \in \{H,L\}.$$

Again, there are many different solutions to the specifications of the contract, which all include $\rho \in [c(e*) - 2m_h + 2m_l, v_1 + v_2 - 2m_h]$ and the xs specified such that inequalities (10)–(13) are satisfied. With the values specified in Section 3, constraints are fulfilled.

APPENDIX B. PROBABILISTIC REALIZATION OF QUALITY

Assume that the level of effort influences the probability of the good being of high quality $\pi(e) \in [0,1]$, with $\pi(e)$ being an increasing function. In order to derive a closed-form solution for the model, I employ specific functional forms for the probability and cost functions.[12] Namely, assume that $\pi(e) = \min\{\eta e, 1\}$, with $\eta > 0$, and $c(e) = \frac{\alpha}{2}e^2$, with $\alpha > 0$. Moreover, assume that α is sufficiently high and η is sufficiently low to prevent S from choosing such a large investment level as to induce $\pi(e) = 1$; furthermore, assume $m_l = 0$.

The welfare-maximising level of investment e solves

$$\max_e \pi(e)(v_1 + v_2) - c(e) \tag{14}$$

$$= \max_e \eta e(v_1 + v_2) - \frac{\alpha}{2}e^2,$$

[12]The result also goes through with more general functions. However, this and particularly the section on asymmetric information benefits a lot from the functional forms for a simplified presentation of the results.

and from the first order condition the optimal level of investment follows

$$e^{FB} \equiv \frac{\eta}{\alpha}(v_1 + v_2).$$

Assume that neither quality nor investment is verifiable. Anticipating a payment of $p = m_h$ for each unit of the good, S invests

$$\begin{aligned} &\max_{e|p=m_h} U_A \\ &= \max_{e|p=m_h} \pi(e)(2p) - c(e) \\ &= \max_{e|p=m_h} \eta e 2m_h - \tfrac{\alpha}{2}e^2. \end{aligned} \tag{15}$$

Hence, the induced investment level is

$$e^{IC} \equiv \frac{\eta}{\alpha}2m_h.$$

A multilateral contract leads to an efficient level of investment in case neither quality nor investment is verifiable. Differently from the deterministic case, it may not suffice that B_1 pays a transfer x to B_2 to fulfil B_2's participation constraints, but also S has to pay a transfer. x_S and x_B denote the payments that S and B_1 make in favour of B_2 upon signing the contract for that reason.

Proposition 3 A multilateral contract that is self-enforcing and induces the optimal level of investment exists.

Proof Suppose the contract has been signed. Now S maximizes

$$\begin{aligned} &\max_{e|p=m_h\rho} U_A \\ &= \max_{e|p=m_h\rho} \pi(e)(2p + \rho) - c(e) \\ &= \max_{e|\rho} \eta e(2m_h + \rho) - \tfrac{\alpha}{2}e^2. \end{aligned} \tag{16}$$

From the first order condition, it follows that

$$\tilde{e} \equiv \frac{\eta}{\alpha}(2m_h + \rho)$$

is the optimal level of investment for S, given that the contract has been signed. For $\rho = v_1 + v_2 - 2m_h$, $\tilde{e}$ equals the optimal level of investment e^{FB}.

First, consider incentive compatibility. Suppose the quality of the good is high. Both buyers have the possibility to refuse buying from S. In this case, S can sell the two units to the market at a price m_h each. Since there are zero transaction costs, B_1 and B_2 can then buy each at a price m_h from the market. Once quality is observable, B_i will buy from S as long as his payoff contracting is not lower than what he gets when buying from the market,

$$v_i - p \geq v_i - m_h \, \forall \, i \in \{1,2\}. \tag{17}$$

He will not buy a unit of the low-quality good as long as what he paid for a low-quality good is more than the value that is created,

$$p \geq 0. \tag{18}$$

With $p = m_h$, inequalities (17) and (18) are satisfied for $i \in \{1,2\}$.

Second, consider individual rationality. If the contract is not signed, S will invest e^{IC}, and the buyers each pay m_h at the market if the good is of high quality. Hence, the expected value of not contracting computes to $\pi(e^{IC})(v_i - m_h)$ for the buyers. Having to pay x_B upon signing the contract, B_1 is willing to participate in the contract if his expected value from contracting is not lower than not partaking,

$$-x_B + \pi(\tilde{e})(v_1 - p) \geq \pi(e^{IC})(v_1 - m_h). \tag{19}$$

Similarly, B_2 will partake as long as

$$x_S + x_B + \pi(\tilde{e})(v_2 - p) - \pi(\tilde{e})\rho \geq \pi(e^{IC})(v_2 - m_h). \tag{20}$$

S partakes as long as her expected value from contracting is not lower than her reservation payoff,

$$\pi(\tilde{e})(2p + \rho) - c(\tilde{e}) - x_S \geq \pi(e^{IC})(2m_h) - c(e^{IC}). \tag{21}$$

There are many solutions to the contract. They all include $p = m_h$, $\rho = v_1 + v_2 - 2m_h$ and $x_S \leq \pi(\tilde{e})(2p + \rho) - c(\tilde{e}) - \pi(e^{IC})2m_h + c(e^{IC})$, $x_B \leq \pi(\tilde{e})(v_1 - p) - \pi(e^{IC})(v_1 - m_h)$. Inserting functional forms, the x_s become $x_S \leq \frac{1}{2}\frac{\eta^2}{\alpha}[(v_1 + v_2)^2 - 4m_h^2]$ and $x_B \leq \frac{\eta^2}{\alpha}(v_1 - m_h)(v_1 + v_2 - 2m_h)$. One possible solution is $x_S = \frac{\eta^2}{\alpha}(v_1 + v_2) - \frac{\eta}{2}(v_1 + v_2 - 2m_h)$, and $x_B \leq \frac{\eta^2}{\alpha}(v_1 - m_h)(v_1 + v_2 - 2m_h)$.

APPENDIX C. INCOMPLETE INFORMATION AND PROBABILISTIC REALIZATION OF QUALITY

The contract for the probabilistic realization of quality can also be extended to situations in which the valuation of one unit of the good is private information for each buyer. Before the contract is signed, each buyer privately observes his type $v^k, k \in \{H,L\}$, with $v^H \geq v^L \geq m_h$. The types v^H and v^L are identically and independently distributed, with $\Pr\{v_i = v^H\} = q \in [0,1]$, the distribution being common knowledge. Let $\hat{v}_i$ be the reported types, $i \in \{1,2\}$.

Proposition 4 There exists a contract that induces truthful revelation and the optimal level of investment.

Proof Knowing that while producing high quality, she receives an overall payment of $2m_h + \rho(\hat{v}_1,\hat{v}_2)$, S will maximize:

$$\begin{aligned}
&\max\nolimits_e U_A \\
&= \max\nolimits_{e|p = m_h(\hat{v}_1,\hat{v}_2)} \pi(e(\hat{v}_1,\hat{v}_2))\left[2p + \rho(\hat{v}_1,\hat{v}_2)\right] - c(e(\hat{v}_1,\hat{v}_2)) \\
&= \max\nolimits_{e|(\hat{v}_1,\hat{v}_2)} \eta e(\hat{v}_1,\hat{v}_2)[2m_h + \rho(\hat{v}_1,\hat{v}_2)] - \frac{\alpha e(\hat{v}_1,\hat{v}_2)^2}{2}.
\end{aligned}$$

This results in

$$\tilde{e}(\hat{v}_1,\hat{v}_2) = \frac{\eta}{\alpha}[2m_h + \rho(\hat{v}_1,\hat{v}_2)].$$

Assuming truthful reporting, setting $\rho(\hat{v}_1,\hat{v}_2) = (\hat{v}_1 + \hat{v}_2 - 2m_h)$ induces the efficient level of investment.

C.1 Incentive Compatibility

Suppose the quality of the good is high. Once the quality is observable, B_i will buy from S as long as his payoff contracting is not lower than his payoff from buying from the market,

$$v_i^k - p \geq v_i^k - m_h \,\forall\, i \in \{1,2\}, k \in \{H,L\}. \tag{22}$$

He will not buy a unit of low quality as long as what he pays for it is more than the value created,

$$-p \leq 0. \tag{23}$$

With $p = m_h$, inequalities (22) and (23) are satisfied.

C.2 Participation Constraints

The ex-post participation constraint of S is

$$\begin{aligned}&\pi(\tilde{e}(\hat{v}_1^k,\hat{v}_2^j))[2p + \rho(\hat{v}_1^k,\hat{v}_2^j)]\\ &-c(\tilde{e}(\hat{v}_1^k,\hat{v}_2^j)) - x_S(\hat{v}_1^k,\hat{v}_2^j) \geq \pi(e_{IC})(2m_h) - c(e_{IC}) \,\forall\, j,k \in \{H,L\}.\end{aligned}$$

Replacing functional forms, $p = m$ and $\rho(\hat{v}_1^k,\hat{v}_2^j) = (\hat{v}_1^k + \hat{v}_2^j - 2m_h)$, this is

$$x_S(\hat{v}_1^k,\hat{v}_2^j) \leq \frac{\eta^2}{\alpha}\left[\frac{1}{2}(\hat{v}^k + \hat{v}^j)^2 - 2m_h^2\right] \,\forall\, j,k \in \{H,L\}. \tag{24}$$

The participation constraints of B_1 and B_2 are, respectively:

$$\begin{aligned}&\pi(\tilde{e}(\hat{v}_1^k,\hat{v}_2^j))(v_1^k - p) - x_B(\hat{v}_1^k,\hat{v}_2^j) \geq \pi(e_{IC})(v_1^k - m_h) \quad \text{and}\\ &\quad \pi(\tilde{e}(\hat{v}_1^k,\hat{v}_2^j))[v_2^j - p - \rho(\hat{v}_1^k,\hat{v}_2^j)]\\ &\quad\quad + x_B(\hat{v}_1^k,\hat{v}_2^j) + x_S(\hat{v}_1^k,\hat{v}_2^j) \geq \pi(e_{IC})(v_2^j - m_h) \,\forall\, j,k \in \{H,L\}.\end{aligned}$$

Replacing functional forms, $p = m_h$, $\rho(\hat{v}_1^k,\hat{v}_2^j) = (\hat{v}_1^k + \hat{v}_2^j - 2m_h)$, and assuming $\hat{v}_i^k = v_i^k \,\forall\, i \in \{1,2\}, j,k \in \{H,L\}$, these are, respectively

$$x_B(\hat{v}_1^k,\hat{v}_2^j) \leq \frac{\eta^2}{\alpha}(v^k + v^j - 2m_h)(v^k - m_h) \quad \text{and} \tag{25}$$

$$x_B(\hat{v}_1^k,\hat{v}_2^j) + x_S(\hat{v}_1^k,\hat{v}_2^j) \geq \frac{\eta^2}{\alpha}\left[m_h(v^j - v^k - 2m_h) + v^k(v^k + v^j)\right] \tag{26}$$

$$\forall\, j,k \in \{H,L\}.$$

C.3 Truthful Reporting

Incentive compatibility regarding the reported type in (weakly) dominant strategies requires that there exists a strategy $\hat{v}_i = v_i^k, \forall\, i \in \{1{,}2\}$ such that

$$U_i(\hat{v}_i,\hat{v}_{-i}|v_i) \geq U_i(\hat{v}_i\prime,\hat{v}_{-i}|v_i), \forall\, \hat{v}_i,\hat{v}_i\prime.$$

That is, for B_1 and B_2, respectively,

$$\begin{aligned}
&\pi(\tilde{e}(\hat{v}_1^k,\hat{v}_2^j))(v_1^k-p)-x_B(\hat{v}_1^k,\hat{v}_2^j) \geq \pi(\tilde{e}(\hat{v}_1^{-k},\hat{v}_2^j))(v_1^k-p)-x_B(\hat{v}_1^{-k},\hat{v}_2^j) \quad \text{and}\\
&\pi(\tilde{e}(\hat{v}_1^k,\hat{v}_2^j))\left[v_2^j-p-\rho(\hat{v}_1^k,\hat{v}_2^j)\right] + x_B(\hat{v}_1^k,\hat{v}_2^j) + x_S(\hat{v}_1^k,\hat{v}_2^j) \geq\\
&\pi(\tilde{e}(\hat{v}_1^k,\hat{v}_2^{-j}))\left[v_2^j-p-\rho(\hat{v}_1^k,\hat{v}_2^{-j})\right] + x_B(\hat{v}_1^k,\hat{v}_2^{-j}) + x_S(\hat{v}_1^k,\hat{v}_2^{-j})\\
&\forall\, j,k \in \{H,L\}.
\end{aligned}$$

Replacing functional forms, $p = m_h$, $\rho(\hat{v}_1^k,\hat{v}_2^j) = (\hat{v}_1^k + \hat{v}_2^j - 2m_h)$, and assuming $\hat{v}_i^k = v_i^k\, \forall\, i \in \{1{,}2\}, j,k \in \{H,L\}$, it must hold for B_1 and B_2 respectively

$$x_B(\hat{v}_1^k,\hat{v}_2^j)-x_B(\hat{v}_1^{-k},\hat{v}_2^j) \leq \frac{\eta^2}{\alpha}(v^k-v^{-k})(v^k-m_h) \quad \text{and} \tag{27}$$

$$x_B(\hat{v}_1^k,\hat{v}_2^{-j})-x_B(\hat{v}_1^k,\hat{v}_2^j)+$$

$$x_S(\hat{v}_1^k,\hat{v}_2^{-j})-x_S(\hat{v}_1^k,\hat{v}_2^j) \leq \frac{\eta^2}{\alpha}\left[(v^{-j}-v^j)(2v^k + v^{-j}-m_h)\right] \tag{28}$$

$$\forall\, j,k \in \{H,L\}.$$

There are many solutions, which all specify $p = m_h$, $\rho(\hat{v}_1^k,\hat{v}_2^j) = (\hat{v}_1^k + \hat{v}_2^j - 2m_h)\, \forall\, j,k \in \{H,L\}$, and the transfers such that inequalities (24)–(28) are satisfied. It can easily be shown that the following set is one possible solution:

$$\begin{aligned}
x_B*(\hat{v}_1^H,\hat{v}_2^H) &= (v^H-m)^2 + (v^L-m)^2,\\
x_B*(\hat{v}_1^H,\hat{v}_2^L) &= (v^H-m)(v^H-v^L),\\
x_B*(\hat{v}_1^L,\hat{v}_2^H) &= (v^H + v^L-2m)(v^L-m),\\
x_B*(\hat{v}_1^L,\hat{v}_2^L) &= 0,\\
x_S*(\hat{v}_1^H,\hat{v}_2^H) &= 2(v^H)^2-2m^2-2(v^L-m)^2,\\
x_S*(\hat{v}_1^H,\hat{v}_2^L) &= \tfrac{1}{2}(v^H + v^L)^2-2m^2-\tfrac{1}{2}(v^H-v^L)^2,\\
x_S*(\hat{v}_1^L,\hat{v}_2^H) &= \tfrac{1}{2}(v^H + v^L)^2-2m^2-\tfrac{1}{2}(v^H-v^L)^2-2(v^L-m)^2,\\
x_S*(\hat{v}_1^L,\hat{v}_2^L) &= 2(v^L)^2-2m^2.
\end{aligned}$$

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