Opportunism and Incomplete Contracts

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Abstract

This paper formalizes the idea that contracting partners can engage in post-contractual opportunistic behavior aimed at circumventing the original intention of their agreement. We show that anticipation and observability of such behavior are typically not enough to prevent its occurrence. This is true if message games are allowed and parties renegotiate any inefficient contractual outcome. Any contractually specified incentives unavoidably have conflicting effects: they increase the likelihood of welfare improving investments and at the same time they increase the likelihood of (welfare reducing) opportunistic behavior. Thus opportunism reduces the value of contracting by limiting the effectiveness of contractual incentives. We provide conditions for the optimality of incomplete contracts, a simple characterization of the second-best contract, and some comparative statics. We demonstrate the usefulness of our framework by relating it to the property rights and transaction costs theories of the firm. (JEL D23, J41, K12, L22)

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1 Introduction

The modern theory of the firm (Williamson, 1985; Hart, 1995) takes incomplete contracts as a departing assumption. Ownership structure and organizational design arise as a response to the imperfection of such contractual arrangements. Yet our understanding of what makes the use of contracts undesirable is still imperfect.[1]

This paper develops and formalizes the idea that contracting can be costly when trading partners engage in opportunistic behavior to circumvent the original purpose of a contract. For example, a contracting partner may find a loophole in the contractual terms that allows him to fulfill the contractual obligations, but not in the way that was intended when the contract was signed (following the letter but not the spirit of the contract). The problem can also arise when a court cannot verify the fulfillment of contractual obligations, for instance when it cannot precisely say whether a widget to be exchanged satisfies the requirements laid out in the contract. We show that when trading partners can exploit verifiability problems, a contract that tries to encourage efficiency-enhancing investments can lead to costly opportunism instead.

In the classical example of General Motors and Fisher Body, the two parties signed a contract whereby GM agreed to buy closed metal automobile bodies exclusively from Fisher, at a price equal to its variable costs plus a fixed markup of 17.6% to cover the fixed costs of production. Klein (1992) argues that Fisher exploited this contractual agreement by "adopting an inefficient, highly labor-intensive technology and by refusing to locate its body-producing plants adjacent to the General Motors assembly plant." Changing the production technology in such a way can be viewed as a costly way of exploiting the above

[1] Indeed, several authors have argued that contracts can often solve the hold-up problem, which has been the main focus of the theories of the firm (Moore and Repullo, 1988; Maskin and Tirole, 1999). Moreover, even though such mechanisms can be very complex, it is often possible to have simple, more realistic contracts that achieve the same goal in specific environments (Aghion et al., 2002; Edlin and Reichelstein, 1996; and Nöldeke and Schmidt, 1995, are some examples).

contract in order to extract rents from the agreed-upon fixed markup.

When parties foresee the possibility of opportunism, they will try to mitigate its consequences.[2] Contracts between suppliers of petroleum coke (i.e. oil refineries) and their buyers (e.g. calcining firms) provide an example of how the potential for opportunistic behavior can influence contractual design. Petroleum coke contracts are typically long-term to protect the refineries' investments (see Goldberg and Erickson, 1987). Rather than specifying a fixed price (or a schedule of future prices), many contracts include a flexible price-adjustment clause which links the price to an index beyond the control of the parties. Goldberg and Erickson (1987) wonder why such seemingly inefficient price-adjustment clauses are used.[3] They suggest (without formalizing this idea) that risk-neutral firms include price-adjustment rules as they provide less incentives for opportunistic behavior. Parties who enter a contract have incentives to spend resources on gathering information about future prices, which diminishes the pie. As Goldberg and Erickson note, this wasteful search can be reduced by lowering the value of information, which is done by price-adjustment rules. Furthermore, when the contract price differs from the market price, there is an incentive for the losing party to try to avoid the implementation of the agreement.[4] Price adjustment clauses, by decreasing the gap between contract and market prices, can mitigate these ex-post incentives to behave opportunistically.[5]

[2] Indeed, Klein (1992) argues that the contract between GM and Fisher Body was designed to minimize the possibility of GM exploiting Fisher. Ex-ante, this type of opportunism seemed more likely, even though ex-post the reverse was true.

[3] In their paper, they ask: "Given that price-adjustment can be difficult and costly, why bother?"

[4] According to Goldberg and Erickson, the implementation of the agreement can be avoided by directly suffering the legal and reputational consequences of not fulfilling the contract, by insisting on strict compliance with quality standards, by performing at a slower pace, or by "working to the rules."

[5] Incentive schemes in agency relationships are also exploited. There is evidence of earnings manipulation and strategic timing of sales to reach particular performance targets (Oyer, 1998), both of which can be costly practices for the firm (Courty and Marschke, 2004). Firms also adjust their incentive schemes to minimize opportunistic behavior, even at the cost of sacrificing incentives for efficient actions. Martinez-Jerez (2007), for instance, points out that Charles Schwab pays its financial advisors the same commission for selling all financial products, despite their own products carrying higher margins. He argues that this is done to prevent overselling particular products at the expense of customers' interests, which can be seen

Sometimes, opportunism is difficult to avoid, leading transacting parties to rely on contracts that are incomplete and offer weak incentives. Infosys, an Indian IT services firm, has traditionally used time-and-materials contracts, which compensated the company for the inputs it used to provide a service. These contracts detailed very precisely all the conditions that would lead to a contractual payment. However, when Infosys started to develop more complex projects for its clients, it moved towards fixed-time/fixed-price contracts. While the company still measures all the different dimensions of performance, these measures are not used in the contract to determine any rewards or penalties.[6] Infosys does this in order to address clients' concerns about its potential to overcharge them by manipulating the metrics (see Martínez-Jerez, 2009). This shift in strategy reflects the fact that the scope for opportunistic overbillling is larger in a complex project. Martínez-Jerez further argues that the changes in Infosys are part of a larger trend towards new governance mechanisms for business-to-business transactions in high-uncertainty environments, such as the IT industry.

To model opportunism and its effects on contracting, we consider a buyer and a seller that would like to exchange a widget in the future. The seller can make an investment that increases the total value of the trade. However, she may also make a costly opportunistic investment that does not increase the welfare of the transaction. While the parties understand the nature of the trade, a court cannot verify the nature of the investment that has been made. We further assume that the parties are free to renegotiate any agreement to eliminate any ex-post inefficiencies. Under these conditions, we show that *any* contract that creates incentives for welfare-increasing investments will inevitably create incentives for socially undesirable opportunistic activities as well. The optimal contract weighs higher

as yet another form of opportunism.

[6] See Martínez-Jerez et al. (2008) for more details on this case.

efficiency-enhancing investments against the risk of opportunistic activities.[7] As a result, the first best is generally unattainable. Furthermore, when opportunism becomes very likely, the value of contracting can be very small. Indeed, it can be optimal for the parties to leave the contract incomplete, and rely on ex-post negotiations.

Our model provides a formalization of the informal arguments made in the transaction costs literature. Klein (1992) argues that the appropriate framework for studying contracting among firms is one where transacting parties observe each other's actions. He further claims that opportunistic behavior is contractually unavoidable, and is indeed exacerbated by a contract.[8] Yet when trading partners are symmetrically informed about each other's actions, it is not obvious that opportunism cannot be overcome using elaborate contracts, in a similar way that the mechanism design literature resolves the hold-up problem.[9] This paper provides a formal proof of Klein's statements. We show how opportunism conditions the form of optimal contracts, and what trade-offs are involved in designing them. Moreover, we show that opportunism induces parties to sign a more incomplete contract than they would have in the absence of such activities.

Our framework can be extended to provide an integrated theory of the firm, by showing how asset ownership affects the contractual frictions that arise endogenously in the model. Having a formal model for these contractual frictions allows us to go beyond both the property rights and the transaction costs theories of the firm. We argue that the optimal

[7] The trade-offs that arise in the model are similar to those emphasized by Klein (1992). Ex-ante, parties evaluate the likelihood of suffering opportunism, and write a contract accordingly. If this probability is sufficiently small (as Klein argues was the case in the GM and Fisher Body example), the parties would write a contract to maximize incentives, and neglect opportunism. But ex-post, the realization of the state of nature may be such that opportunism is sufficiently rewarding for the parties to withhold profitable trading opportunities. On the other hand, when the parties foresee opportunism to be a more likely possibility, the contracts adjust accordingly to curb opportunism, as in the petroleum coke case.

[8] Note that this is different from Williamson (1985), who in contrast argues that the existence of incomplete contracts creates incentives for opportunism in order to appropriate the rents that have not been allocated contractually.

[9] See Moore and Repullo (1988) and Maskin and Tirole (1999).

ownership structure is determined not only by the importance of the specific investments of each of the parties, but also by their potential opportunistic behavior. In particular, unlike in Grossman and Hart (1986), we argue that it may be optimal to withdraw assets from a party whose investments are very important for the relationship if the other party is more prone to behave opportunistically. This is so because asset ownership not only increases incentives for efficiency-enhancing investments, but also reduces opportunism. Moreover, while asset ownership has the benefit of reducing the opportunism of the asset owner, as Williamson (1985) argues, this is achieved at the cost of increasing the opportunism of the other party. As a result, in this model, vertical integration has both benefits and costs in terms of opportunism.

The paper also makes a technical contribution to the mechanism design literature. Other papers have shown that general mechanisms may offer little value when such contracts must implement an ex-post efficient outcome.[10] This is the case in complex environments (Segal, 1999, Hart and Moore, 1999), in situations where a contract cannot enforce trade unless it provides both parties with at least the payoff they can receive in renegotiations with no-trade as the disagreement point (Hart and Moore, 1988), or when efficiency-enhancing investments are cooperative or ambivalent (Che and Hausch, 1999, and Reiche, 2006).[11] In all these models the seller is restricted to one-dimensional investments, whereas we allow for different types of investments. This multidimensionality allows us to capture the idea that a contracting partner can either invest in the relationship or in rent-seeking. This feature introduces incentive compatibility constraints that link the

[10] As in these papers, we model ex-post renegotiations as a cooperative game. For the implications of alternative assumptions on ex-post renegotiation, see Maskin and Tirole (1999), Hart and Moore (1999), Aghion et al. (1994) and Evans (2008).

[11] Another fruitful branch of the literature argues that contractual incompleteness is a response to cognitive limitations or behavioral biases of contracting partners (Bolton and Faure-Grimaud, 2007; Hart and Moore, 2008; Tirole, 2008; von Thadden and Zhao, 2007). Our approach, in contrast, focuses on verifiability problems, thus stressing the importance of the cognitive limitations of the contract enforcer for understanding incomplete contracts.

two investments. As a result, a contract that is designed to increase socially desirable investments at the same time also encourages opportunistic investment.[12] The model also highlights the importance of the difficulty to contract on the nature of the good to be traded and, unlike earlier models, shows how this can make the widgets available for trade endogenous.[13]

The rest of the paper is organized as follows. Section 2 presents in a very simple example the main intuition of the paper. Section 3 presents the setup of the model. As a benchmark, we solve for the first best and no contract cases in Section 4. We derive the main results of the paper in Section 5. We discuss some extensions of the model in Section 6. In Section 7 we introduce asset ownership to the model and Section 8 concludes. The formal derivations and proofs are presented in Appendices A and B.

2 An Illustrative Example

A simple example can illustrate how the potential for opportunism can alter the value of contracting. Consider a buyer (he) that would like to purchase a widget from a seller (she), and denote this widget by R. The widget costs c_R for the seller to produce and offers value

[12] Our model is reminiscent of Holmstrom and Milgrom's (1991) multitasking model, and its recent applications to gaming of incentive schemes (see Ederer, Holden and Meyer, 2008). Nevertheless, there are substantial differences. First, unlike agency models, there is symmetric information in our framework. This opens up the possibility of a richer set of contracts that cannot be used to solve agency problems. Furthermore, the interaction between the two types of investments comes from an endogenous incentive compatibility constraint in our case, whereas the interaction between activities arises from the cost of effort (a technological link) in the multitasking model. Finally, in our model there is only one task that can create value, whereas in the multitasking model, the principal would like the agent to exert effort in multiple tasks.

[13] In Che and Hausch (1999) and Reiche (2006), the effectiveness of a contract is limited by the trade-off between the benefits of an investment (increase of the value of trade) and its disadvantage (increase in bargaining position of the opponent). By contrast, in our framework a contract that is designed to increase socially desirable investments simultaneously encourages opportunistic investments. The incomplete contract may then be optimal not because it maximizes investment, but because it minimizes the cost of opportunistic investments. To make this point we do not require the existence of a large number of trading opportunities, as in Segal (1999) or Hart and Moore (1999). Moreover, the widgets available for trade are exogenous in their setups, while they are endogenous in ours.

v_R to the buyer. To get efficiency in this transaction, it is enough to rely on an efficient negotiation between buyer and seller to agree on a spot contract.

Consider what happens if the seller can make a specific investment prior to the production of the widget to improve the value of the transaction. In particular, suppose that the seller can pay a cost of κ_I to create (invent) a new improved widget (I) with a production cost of $c_I < c_R - \kappa_I$ and a value of $v_I = v_R$.[14] Suppose, also, that inefficient outcomes resulting from a contract are renegotiated to an efficient outcome, and that the buyer has all the bargaining power. Now, a simple spot contract is not enough to induce the seller to invest in creating the new trading opportunity, since the buyer captures all the rents generated by the investment. This is the classic hold-up problem. However, the efficient investment can still be achieved through a contract. For example, consider a contract that specifies that the buyer must pay a price of $p \in [c_R, v_R]$, and the seller is allowed to produce either widget. Since this contract fixes the price for the seller, she will receive all the gains from cost reduction, and hence, will invest efficiently.

This last contract, however, can potentially perform very badly. Suppose that the seller, by investing κ_O, can create yet a third widget (O) which is useless to the buyer, but is cheap to produce ($c_O < c_I$), and a third party cannot distinguish it from I.[15] O would never be traded in a spot transaction. Nevertheless, the seller can use this widget to pretend she has an improved one, which she would be entitled to deliver to the buyer, obtaining a payoff of $p - c_O$. The buyer would then ask to renegotiate the contract, demanding the R widget be delivered. Since he has all the bargaining power, he will extract all the gains

[14] This improved widget could be thought of as an adaptation that is tailored to the specific needs of the buyer, as in Ellman (2008). Notice that the increase in welfare comes from a reduction in the production cost. Che and Hausch (1999) refer to this type of investments as selfish.

[15] Note the difference between the cost of creation (κ_I or κ_O) and the cost of production (c_I or c_O). The cost of production is only incurred when the widget is actually traded. The cost of creation, in contrast, can be thought of as the cost of developing a prototype, sample or blueprint of the product which then can be shown to the buyer and/or a third party.

from trade that have not been allocated by the contract, leaving the seller with the same payoff of $p - c_O$. As long as $\kappa_O < \kappa_I$, she will prefer to create this opportunistic widget and pretend it is the improved one. This creates an efficiency loss for two reasons. First, because the improved widget is not created. Second, because the seller pays the cost of creating O, despite this never being traded. We can therefore think of this investment as the cost of being opportunistic, in the spirit of the transaction costs literature. It can be seen as a metaphor for behavior that is aimed at extracting rents, rather than enhancing the value of the relationship. The seller pays for it, despite being inefficient, in order to increase her share of the rents.

This example shows that contracts that seem to implement efficient outcomes in a robust manner, may indeed be quite fragile when parties can affect future contingencies in a way that is not foreseen ex-ante. It is still unclear, however, how much of this inefficiency can be overcome if the parties anticipate the possibility of opportunistic behavior, and design a contract to prevent inefficient rent-seeking.

Suppose that the parties realize that the seller can either invest in the creation of an improved trading opportunity I, or an opportunistic one O, used for the sole purpose of obtaining rents from the contract. Suppose also that the seller can create at most one new widget.[16] In general, a contract can condition on parties' announcements about the nature of the widget created, and we can restrict attention to contracts that induce truthful announcements. In Section 5.2 we show that for this example any outcome arising from such a contract can also be implemented with a contract of the following form: the seller gets a price p_R if there is only one widget, and p_N if there are two.[17] In the latter case, the buyer can choose which widget to purchase. For any such contract, when $\kappa_O < \kappa_I$, either no new widget is created (if $p_N - p_R < \kappa_O$), or O is created (if $p_N - p_R \geq \kappa_O$).

[16] Creating both, I and O, may be excessively costly or impossible for technical reasons.
[17] See the proof of Proposition 2.

In particular, we cannot provide the seller with incentives to create the improved widget, and it is optimal to leave the contract incomplete, and let the parties negotiate ex-post. This way, the improved widget is not created, as the seller has no bargaining power, but the opportunistic behavior is avoided. If, on the other hand, $\kappa_O > \kappa_I$ we can obtain even first-best incentives to invest by setting $p_N = \kappa_I - p_R$. As in this setup both widgets are substitutes from the viewpoint of the seller and the improved widget is cheaper to create, no contract encourages the creation of the opportunistic widget.

In the remainder of the paper we relax the assumptions that investment costs are deterministic, and bargaining power is concentrated in the buyer. This yields the general insight that providing incentives for welfare-enhancing investments also encourage opportunistic investments. As a consequence any contract has to trade off these adverse effects. We analyze this trade-off and characterize conditions under which the incomplete contract is optimal and conditions under which the first best can be obtained.

3 The Model

We consider a trading relationship between two risk-neutral parties: a buyer, B, and a seller, S, who want to exchange one unit of a widget in the future. Initially, there is a known widget, which we call R (regular), that could be traded. This widget has a value of v_R to the buyer and it costs the seller c_R to produce.

However, before trade occurs, the seller can make an investment at a cost of κ_I to create a new widget with superior quality and/or lower production costs. If she decides to make the investment the seller can produce and trade the widget, which we call I (for improved). When this happens, we assume that it is still possible to trade the original R widget, so two trading opportunities exist. The improved widget has a value of v_I, and production costs of c_I with $v_I - c_I > v_R - c_R$.

For our model to reflect the idea that I cannot be perfectly described in any contract and consequently that there is no guarantee that I is indeed created, we assume that the seller can also decide to make an investment at a cost κ_O to create another widget O (for opportunistic widget). If the seller decides to make this investment, she can produce and trade widget O. And the contract cannot distinguish between I and O, i.e. the identities of O and I are not verifiable. Therefore, the seller can deliver O to claim the rents allocated to the buyer by the contract for the creation of I. We interpret the investment in the creation of O as an opportunistic investment in rent-seeking: there is no social benefit in having O (as we will assume shortly), but the seller may still obtain private gains from it.

Implicit in our formulation is the assumption that even when the parties may have a good idea of what the I widget could look like, or what it might achieve, they cannot perfectly describe this in a way that rules out that a different inferior widget is created as a substitute. Buyer and seller cannot foresee at the time of writing the contract how potential contractual formulations could be circumvented: what element of the description of I is not accurate, or what performance measure can be deceived, and in what way. Otherwise they could describe I in a verifiable way. Nevertheless, they understand that these contractual imperfections may occur and be exploited by the seller, and they can foresee what the payoff implications would be.

Accordingly, we assume that this opportunistic widget O has a value of v_O, and production costs of c_O and that it is inferior to the existing one R, i.e. we assume $v_R - c_R > v_O - c_O$. Furthermore, the widget O entails low production costs for the seller: $c_O < c_R$ and $c_O < c_I$.[18]

[18] The assumption that v_O and c_O are known ex-ante (and thus can be foreseen by both parties) is not critical. We could assume that v_O and c_O are realizations of random variables that become known after the contract is written. As long as for any realization of v_O and c_O we have that $v_R - c_R > v_O - c_O$, $c_O < c_R$ and $c_O < c_I$ the relevant constraint on implementability does not depend on the precise values of v_O and c_O. Even a contract that conditions on both parties' announcements of the values of v_O and c_O would not help to relax the relevant constraint. This is because, for any value of v_O and c_O, trade of O is imposed

The cost vector (κ_I, κ_O) is revealed to the seller before making the investment decisions and cannot be observed by the buyer or a third party. It is the realization of a random variable which can take values in $[0, \infty]^2$ and has a commonly known distribution given by the cdf F and density function f.

We assume that only one widget is needed. Since $v_I - c_I > v_R - c_R > v_O - c_O$, the ex-post efficient trade is the improved widget if available, and the R widget otherwise. The creation and trade of the opportunistic widget is always socially undesirable. We also assume that the seller cannot create both the I and O widgets simultaneously. We argue in Section 6.2 that this assumption is not driving our results, but we keep it to simplify the exposition.

The outcome of the investments is common knowledge between buyer and seller.[19] Yet, a third party can only observe that a new trading opportunity exists, but cannot verify whether it is I or O. We also assume that it is possible to describe the R widget ex-ante, so that ex-post, a third party can verify its identity. However, since the I and O widgets have not been created, they cannot be described in advance, and hence, a third party cannot tell them apart ex-post.[20]

The timing is as follows: at time $t = 0$, the two parties can write a contract which specifies the terms of trade. At time $t = 1$ the seller observes the costs of creating each

neither on the equilibrium path nor off the equilibrium path for the relevant disagreement (see section 5.1 and the Appendix A).

[19] This assumption is not crucial. In Section 6.1 we argue that the same results hold when the outcome of the investments is private information of the seller.

[20] Alternatively, we can also assume that it is not possible to describe the differences between these yet-to-be discovered widgets and R, so that the identity of none of the widgets is verifiable. This could be for several reasons. R may not have been created at the time the mechanism is designed, but it is known it can be produced somehow. Alternatively, R may already exist, but it is not possible to describe it accurately. In order to do so, it would be necessary to know in which ways other widgets can be different. Since the I and O widgets have not been created, it may be impossible to distinguish them from R ex-ante. This adds an additional dimension that is not verifiable: the identity of the R widget. However, it turns out this does not make any difference to the solution of the implementation problem (see footnotes 22 and 27). And hence, we do not consider this case for simplicity.

of the widgets, (κ_I, κ_O), and makes the investment decisions on both the improved and opportunistic widgets. At time $t = 2$, buyer and seller observe the widgets they can trade. Then, an outcome compatible with the contract is imposed on the two parties. Furthermore we assume that buyer and seller renegotiate to the (ex-post) efficient trade if this was not already prescribed by the contract (at this point, the seller may decide to show any widget she hid previously). During the renegotiation, we let the bargaining power of the seller be $\alpha < 1$, and that of the buyer be $1 - \alpha$.[21] In particular, if the contract results in an outcome which gives the seller and the buyer utilities of u_S and u_B respectively, after renegotiation the efficient widget is traded and the seller will receive a payoff of $u_S + \alpha (v_W - c_W - (u_S + u_B))$, and the buyer $u_B + (1 - \alpha)(v_W - c_W - (u_S + u_B))$, where $W = I$ if the improved widget was created and $W = R$ otherwise.

In general, a contract is a mapping from a message space to the set of possible outcomes. We can restrict attention to truthful revelation mechanisms, in which a party's message m describes the (observable) state of the world. There are three possible states: the state where R is the only widget available for trade, and the two states where either an improved widget, or an opportunistic widget is available, in addition to the R widget. With some abuse of notation, we denote these states $\{R, I, O\}$.[22] Since state R is verifiable, we can assume that both parties report $m_B = m_S = R$ when this state arises. A mechanism only needs to elicit information about the two states in which there is a new widget. Then, for each pair of messages (m_B, m_S), the mechanism can specify a transfer from buyer to seller $p(m_B, m_S)$ and a probability of trading each of the widgets $(x_R(m_B, m_S), x_N(m_B, m_S))$, such that $x_R, x_N \geq 0$ and $x_R + x_N \leq 1$, where x_R corresponds to the R widget, and x_N to

[21] When $\alpha = 1$, the seller gets all the rents in a renegotiation. In such a case, the first best can be easily achieved with ex-post negotiations, since no contract is necessary to protect her investments.

[22] If the R widget cannot be distinguished ex-post, the message space has to be expanded to include the elicitation of the identity of each widget, so that $m \in \{R, IR, RI, OR, RO\}$, where XY denotes the state where there are two widgets, the first being X, and the second being Y.

the new widget (if available).[23] Note that the mechanism specifies no trade with positive probability if $x_R + x_N < 1$.

4 Two Benchmarks

This section characterizes the first best and the outcome in the absence of any contract, where the parties simply bargain ex-post over the division of the trade surplus. Both will serve as useful benchmarks.

4.1 First Best

The first-best outcome requires the invention and trade of the efficient widget if the social benefits of I exceed the cost κ_I, i.e. in the first best I is created if and only if:

$$\kappa_I \leq (v_I - c_I) - (v_R - c_R) \,.$$

We assume that creating the improved widget is socially desirable with some positive probability, i.e. $\Pr(\kappa_I \leq (v_I - c_I) - (v_R - c_R)) > 0$. Notice that the investment in creating the opportunistic widget generates no value. Therefore, in the first-best outcome O is never invented.

This outcome can easily be achieved in an environment where parties can commit not to renegotiate. For instance, a mechanism that gives the seller full bargaining power by letting her make a take-it-or-leave-it offer would be able to implement it. Since the seller would capture all the rents generated by the transaction, she would invest efficiently. Similarly,

[23] Implicit in this formulation is the assumption that the mechanism can only prescribe the trade of at most one widget. This does not restrict generality as a mechanism that can prescribe the trade of both R and the newly created widget, cannot do better. This is because enforcing the trade of R is affecting the buyer and the seller's threat points (in the renegotiations) in the same way, independently of what the state of the world is (see Appendix A).

in our model with renegotiations, when $\alpha = 1$, the seller gets all the rents when bargaining with the buyer, and hence, no contract would be necessary to protect her investment.

4.2 Incomplete Contracts

When buyer and seller do not write a contract, they must bargain ex-post for the terms of trade. At that stage, the seller is only able to capture a fraction α of the rents. When either no additional widget is created or the opportunistic widget is created, it is efficient to trade the R widget, and the seller gets $\alpha \cdot (v_R - c_R)$. If the improved widget is created, the seller gets a share $\alpha \cdot (v_I - c_I)$. Hence, without a contract, the seller will not create O, since she would have to pay κ_O to obtain the same rents she gets without any investment. Thus the seller is only willing to invest in creating I if:

$$\kappa_I \leq \alpha \left[(v_I - c_I) - (v_R - c_R) \right].$$

In particular there is underinvestment in I as compared to the socially optimal investment, i.e. the ex-ante probability of inventing I is below the socially optimal probability. When there is no contract governing this relationship, the seller underinvests in the improvement of the widget, however, he sees no reason to waste resources being opportunistic, since there is no contract to benefit from.

5 Optimal Contracting

In this section, we consider the problem of designing the optimal contract. To simplify notation, let $p_R = p(R, R)$, $p_I = p(I, I)$ and $p_O = p(O, O)$ denote the prices specified by the mechanism when buyer and seller agree on the state of the world. When parties can renegotiate any previous agreement, we can restrict attention to truthful revelation mechanisms that implement the efficient trade when both parties truthfully report the state of the world. On the equilibrium path, the seller will get a profit of

$$U_S = \begin{cases} p_I - c_I - \kappa_I & \text{if seller invents } I \\ p_O - c_R - \kappa_O & \text{if seller invents } O \\ p_R - c_R & \text{if seller does not invent a new widget.} \end{cases}$$

Notice that the seller invests in I if and only if:

$$\kappa_I \leq (p_I - c_I) - (p_R - c_R) \quad \text{and} \quad \kappa_I \leq \kappa_O + [(p_I - c_I) - (p_O - c_R)] \, .$$

The first inequality states that the seller prefers to invest in I rather than not to invest at all. The second states that she prefers to invest in I rather than in O. Similarly, she invests in O if and only if:

$$\kappa_O < (p_O - p_R) \quad \text{and} \quad \kappa_O < \kappa_I - [(p_I - c_I) - (p_O - c_R)] \, .$$

Let $\Delta = (v_I - c_I) - (v_R - c_R)$ be the social benefit of investing in I. Similarly, we denote the seller's contractual benefit from investing in the improved widget by $\Delta_I = (p_I - c_I) - (p_R - c_R)$ and the seller's benefit from investing in the opportunistic widget by $\Delta_O = p_O - p_R$. The ex-ante probability of creating I is thus given by $\Pr(\kappa_I \leq \Delta_I - \max(0, \Delta_O - \kappa_O))$, the ex-ante probability of creating O is $\Pr(\kappa_O < \Delta_O - \max(\Delta_I - \kappa_I, 0))$. We thus interpret Δ_I and Δ_O as the incentives to invest in the improved or opportunistic widgets, respectively: the larger Δ_I (Δ_O) the higher the ex-ante probability that the I (O) widget is created.[24]

The welfare W generated by a contract that induces truthtelling about the state of the

[24] Note that an increase in Δ_I does not necessarily lead to a strictly higher probability that I is created, as $\Pr(\kappa_I \leq \Delta_I)$ might be constant over some range $(\Delta_I^*, \Delta_I^{**})$, $\Delta_I^* < \Delta_I^{**}$.

world is given by:

$$W = (v_R - c_R) + \int_{\kappa_I \leq \Delta_I - \max(0, \Delta_O - \kappa_O)} (\Delta - \kappa_I) \cdot dF - \int_{\kappa_O < \Delta_O - \max(\Delta_I - \kappa_I, 0)} \kappa_O \cdot dF. \quad (1)$$

In order to increase the (ex-ante) probability of inventing the improved widget, more incentives to invest in I should be provided. This requires setting a high price p_I, relative to the price p_R, to increase Δ_I. In contrast, in order to deter the inefficient investment in the opportunistic widget, the mechanism should lower the price p_O relative to p_R, so that Δ_O is low. As we will see in the next section, the fact that the outcome of the investment is not verifiable by a third party constrains the set of prices p_R, p_I, p_O that can support truthtelling. In particular, not all combinations of Δ_I and Δ_O are feasible. We say that a contract is optimal if it maximizes welfare among the set of all possible contracts that support truthtelling in an incentive compatible way. The next subsection derives these incentive compatibility constraints, which are used in Subsection 5.2 to characterize the optimal contract.

5.1 Resolving Disagreements

This subsection provides an informal discussion of the constraints truthtelling imposes on the implementation problem. The formal derivations can be found in Appendix A.[25]

Notice that whenever one party deviates unilaterally from truthtelling, there is a disagreement between the buyer's and seller's reports. To assure that in equilibrium both agents report the true identities of available widgets, the mechanism needs to be able to punish any possible (one-sided) deviation. In order to achieve this, the designer has two instruments. She can set transfer prices and/or enforce the exchange of widgets in a way that

[25] General conditions for implementation when agents can renegotiate (and cannot commit not to renegotiate) are derived in Maskin and Moore (1999).

punishes the deviator.[26] There are two possible disagreements: either $(m_B, m_S) = (I, O)$ or $(m_B, m_S) = (O, I)$.[27] In both, buyer and seller disagree on the type of widget that has been created. Consequently, buyer and seller also disagree on the efficient action: in the first, the buyer claims they should trade R, while the seller wants to trade the new widget; in the second, the opposite is true.

The first disagreement, (I, O), can arise for two reasons: either the true state is I, and the seller is lying, or the state is O and the buyer is lying. Notice that in both cases, the liar is making a claim against his own interests: the buyer claiming the new widget being better than it actually is, or the seller claiming it is worse. A simple way of avoiding this disagreement is to increase the equilibrium payoff for the seller in the I state, and for the buyer in the O state. But this amounts to increasing p_I and decreasing p_O, which goes in the direction of what the implementation problem would require to achieve the first best. As a result, this disagreement can be easily resolved, without imposing restrictions on the set of outcomes that can be implemented.

The second disagreement, however, is harder to resolve, and imposes restrictions on the implementation problem. As before, there are only two ways to arrive at this disagreement. Either the buyer lies when the state is I, or the seller lies when the state is O. Now, however, each of the parties is distorting the truth in their own interest: either the buyer is trying to make the new widget look worse than it is, or the seller is exaggerating its quality.

We show in Appendix A that enforcing the exchange of a widget (either R or the new

[26] Note that any payments that the designer imposes on one party will have to go to the other, since ex-post renegotiations would prevent any waste.

[27] If the identity of the R widget cannot be verified ex-post, the message game is complicated by the fact that there may be two widgets to be traded: R plus either I or O. The mechanism then must elicit the identity of each of the widgets. As a result, there are potentially more disagreements. Nevertheless, most disagreements are easily resolved. There is only one disagreement which is binding, corresponding to the announcement $(m_B, m_S) = (OR, IR)$. In this disagreement, buyer and seller agree on the identity of the R widget, and hence, it is irrelevant whether the identity of this widget can be verified (in the worst disagreement, they indeed agree on which is the R widget). Notice that this disagreement is analogous to the second one described in the main text.

one) cannot discourage misreporting. Hence, lying can only be prevented by specifying no trade after such a disagreement and appropriately setting payments $p(O,I)$, p_I and p_O. In particular the buyer's payoff from truthtelling when the true state is I (in which case the contract specifies trade of the improved widget at price p_I) must be (weakly) larger than his payoff if he reports O. In such a case, the contract specifies that he pays $p(O,I)$ and no widget is traded. But the subsequent renegotiation would give him a share $(1-\alpha)$ of total benefits from trading the improved widget. Thus truthtelling requires that:

$$v_I - p_I \geq -p(O,I) + (1-\alpha) \cdot (v_I - c_I).$$

Similarly, to prevent the seller from reporting I when the true state is O, we must have that:

$$p_O - c_R \geq p(O,I) + \alpha \cdot (v_R - c_R).$$

The price $p(O,I)$ is also a limited instrument to induce truthtelling. Increasing $p(O,I)$ relaxes the buyer's constraint, making it more costly for him to lie, but at the expense of making the seller more willing to lie. Since both constraints must be satisfied, the only way to relax them simultaneously is by increasing $v_I - p_I$ or $p_O - c_R$. The first means a decrease in p_I, and hence, the seller's payoff in case she creates the improved widget. Alternatively, the second means an increase in p_O, and hence, the seller's payoff if she invents the opportunistic widget. The intuition is straightforward: in order to induce truthtelling, the mechanism needs to give rents to the buyer to admit when the seller made the right investment (lowering the payoff of the seller), and for the seller to admit when she engaged in rent-seeking (increasing her payoff from doing it). Both of these alternatives go against the direction needed for efficiency.

Adding these two inequalities and rearranging terms, we obtain a constraint in terms of the social and contractual incentives: $\Delta_I \leq \Delta_O + \alpha\Delta$. This constraint says that the contractual benefit the seller obtains from creating the improved widget cannot be larger than her contractual benefit from creating the opportunistic widget plus $\alpha\Delta$, the seller's benefit from creating I in the absence of any contract. Therefore, whenever $\Delta_O = 0$, so the seller has no incentive to create O, the best the contract can achieve is the implementation of the incomplete contract outcome. Furthermore, in order to increase the incentives to invest in the improved widget beyond what the incomplete contract can obtain, we must increase Δ_O above zero, which usually induces some incentives to invest in O (i.e. it induces incentives for rent-seeking).

Any optimal contract minimizes the amount of investment in creating O, for a given Δ_I. Therefore, there is always an optimal contract for which the constraint will be binding.[28] In what follows we focus attention on optimal contracts and, therefore, restrict attention to contracts with:

$$\Delta_I = \Delta_O + \alpha\Delta. \tag{2}$$

In Appendix A, we show that this condition is sufficient for implementability. To simplify notation, we describe a contract by the incentives it provides to invest in the opportunistic widget, Δ_O. It should be clear, however, that there are many ways to choose the set of prices and trades $(p(m_B, m_S), x_1(m_B, m_S), x_2(m_B, m_S))$ that generate the same incentives. And, therefore, Δ_O does not uniquely identify a contract, but a set of contracts that implement the same outcome.

[28] Note that if the distribution of (κ_I, κ_O) has full support, then any optimal contract will necessarily satisfy $\Delta_I = \Delta_O + \alpha\Delta$.

5.2 Opportunism as a Constraint on Contracting

As discussed above, the incentive compatibility constraint (2) imposes a relation between the incentives to create the improved and the opportunistic widgets. Increasing the incentives to invest in the improved widget can only be encouraged if, at the same time, incentives for the opportunistic widget go up as well, potentially resulting in inefficient rent-seeking. In general, the optimal mechanism will trade-off a lower investment in the creation of I with a lower investment in the creation of O, and thus the first best cannot typically be obtained. An exception occurs when the invention of the opportunistic widget is particularly costly. In this case, increasing Δ_O does not induce any inefficient investment, and incentive compatibility does not impose strong constraints on the implementation problem. As a result, we may be able to provide first-best incentives. To state this formally, let $\widetilde{\Delta} := \min \{x | \ \Pr(\kappa_I \leq x) = \Pr(\kappa_I \leq \Delta)\}$ be the lowest level of incentives to invest in I that results in first-best investment in I. The following proposition makes the earlier intuition precise.

Proposition 1 *The first best can be implemented if and only if:*

$$\Pr\left(\kappa_O \geq \min\left(\widetilde{\Delta} - \alpha\Delta, \kappa_I - \alpha\Delta\right)\right) = 1.$$

If there exist $\varepsilon > 0$ *such that for all* $(\kappa_I, \kappa_O) \in [\Delta - \varepsilon, \Delta + \varepsilon] \times [\Delta - \alpha\Delta - \varepsilon, \Delta - \alpha\Delta]$ *we have* $f(\kappa_I, \kappa_O) > 0$ *then the ex-ante probability of inventing the improved widget under the optimal mechanism is lower than in the first best.*

In order to get the first best, we must have $\Delta_I = \widetilde{\Delta}$, so that the contractual benefits of the seller equal the social benefit. However, this implies that $\Delta_O = \widetilde{\Delta} - \alpha\Delta$, but the seller must not invest in creating O. This can only happen when the return from an investment in O never exceeds the cost κ_O or when investing in I is more profitable than investing in O. In particular, the first best can be achieved if either the cost of invention of the opportunistic widget always exceeds its benefits ($\kappa_O \geq \Delta_O = (1-\alpha)\,\Delta$ with probability 1) or if the gains from inventing I always exceed the gains from creating O ($\Delta_O - \kappa_O \leq \Delta_I - \kappa_I$ with probability 1). Nevertheless, in most cases, the first best cannot be achieved.

The next proposition shows that in many environments a simple option contract can implement the second-best outcome.

Proposition 2 *Suppose that $\alpha \cdot (v_I - v_R) \leq (1-\alpha) \cdot (c_R - c_I)$. Then, the second best can be implemented with the following contract: the seller sells at a price p_R if no new widget is created, and at a price p_N otherwise; in the latter case, the buyer has the option to choose either the new (shown) widget or the already-known widget R.*

Note that $\alpha \cdot (v_I - v_R) \leq (1-\alpha) \cdot (c_R - c_I)$ is always fulfilled for selfish investments, i.e. if we have that $v_I \leq v_R$ (which implies $c_I \leq c_R$). Then the buyer will not pick the improved widget when available. Consequently, the seller obtains $p_N - c_R$, plus a share of the increase in total welfare $\alpha\Delta$ in the renegotiation stage. Since the buyer would never choose to buy O, the most the seller can get from creating it is $p_N - c_R$. Therefore, the above contract satisfies $\Delta_I = \Delta_O + \alpha\Delta$, and hence, the second-best outcome can be implemented by choosing p_R and p_N appropriately. Incidentally, this contract is optimal because it provides incentives for creating I, while minimizing the rents that the seller gets from inventing the opportunistic widget. Instead, if the seller chooses what to supply,[29] she would offer O for trade at a price p_N when available. And she would further get additional rents of $\alpha\left[(v_R - c_R) - (v_O - c_O)\right]$ from renegotiating to the efficient trade of R. The second-best contract eliminates these additional benefits from creating O, thereby minimizing incentives for its creation.

[29] This is one of the contracts that we considered in Section 2.

If investments are cooperative (i.e. if $v_I > v_R$), an option contract will make the buyer choose the improved widget (rather than R) as long as his bargaining power is sufficiently small. But this means that the seller's additional payoff from inventing I is not aligned with the effect of such an innovation on total welfare Δ. Consequently, a contract that results in different prices, depending on whether the I or O widget was invented, can outperform a simple option contract.

This proposition also makes clear the contracting trade-off. In general, the optimal contract gives incentives to invest in both, O and I, and thus results in socially undesirable opportunism. In particular, when the conditions of the proposition are satisfied, a single price p_O is charged, irrespective of the nature of the widget created. Hence, it is clear that positive incentives for efficient investments can only be created at the expense of inefficient opportunistic behavior. In the following we explore conditions that diminish the value of contracting.

Proposition 3 *Let Δ_O^* be the optimal contract when the distribution of costs has density f. Consider a function $\phi(\kappa_I, \kappa_O)$, with $f(\kappa_I, \kappa_O) + \phi(\kappa_I, \kappa_O) \geq 0$ and which satisfies one of the following two conditions:*

1. *there exists $\widehat{\kappa}_O(\kappa_I) \geq \kappa_I - \alpha\Delta$ such that $\phi(\kappa_I, \kappa_O) \leq 0$ for all $\kappa_O > \widehat{\kappa}_O(\kappa_I)$, and $\phi(\kappa_I, \kappa_O) \geq 0$ for all $\kappa_O \leq \widehat{\kappa}_O(\kappa_I)$; furthermore, $\int_0^{\overline{\kappa}_O} \phi(\kappa_I, \kappa_O) \cdot d\kappa_O = 0$ for all κ_I*
2. *there exists $\widehat{\kappa}_I(\kappa_O) \leq \kappa_O + \alpha\Delta$ such that $\phi(\kappa_I, \kappa_O) \geq 0$ for all $\kappa_I > \widehat{\kappa}_I(\kappa_O)$, and $\phi(\kappa_I, \kappa_O) \leq 0$ for all $\kappa_I \leq \widehat{\kappa}_I(\kappa_O)$; furthermore, $\int_0^{\overline{\kappa}_I} \phi(\kappa_I, \kappa_O) \cdot d\kappa_I = 0$ for all κ_O*

Then, the optimal contract when the costs have density $f(\kappa_I, \kappa_O) + \phi(\kappa_I, \kappa_O)$, $\widehat{\Delta}_O^*$, satisfies $\widehat{\Delta}_O^* \leq \Delta_O^*$.

The previous result shows that if low costs for creating O become more likely, the optimal contract will provide fewer incentives. This is because for the social planner a given level of incentives Δ_O is more costly if κ_O is more likely to be low. Then the probability that the seller behaves opportunistically by creating O instead of I is higher. Similarly, if high costs for creating I become more likely, providing incentives becomes less profitable. A given level of Δ_O will induce a smaller efficient investment, and hence the optimal contract will provide lower incentives.

This result has a simple interpretation. When quality is difficult to describe, making it easier for the seller to deceive the buyer, the contract should optimally lower the price paid for performance. Conversely, when performance becomes more costly for the seller, it becomes more likely that she will want to behave opportunistically instead, and therefore, the contract should also optimally reduce the payment for compliance.

In the following, we address the question of whether the trade-off between inducing more incentives to invent I and reducing the incentives to invest in O can diminish the value of contracting to zero. The trading partners would then prefer to have an incomplete contract, and rely on efficient negotiations after investment has taken place.

The incomplete contract is optimal whenever $\Delta_O = 0$ is the maximizer of (1). Intuitively, when $\Delta_I = \alpha\Delta$, incentives to innovate in the improved widget are below the socially optimal level. Thus, the incomplete contract can only be optimal if any increase of Δ_I beyond $\alpha\Delta$ comes at such a high cost of adjusting Δ_O that this increase does not improve total welfare. The next result gives a sufficient condition for this to be true when the distributions of κ_I and κ_O are independent. Let $f(\kappa_I, \kappa_O) = f_I(\kappa_I) \cdot f_O(\kappa_O)$ and denote by r_I and r_O the hazard rates of f_I and f_O, respectively. Then, the following result holds:

Proposition 4 *Suppose that the costs κ_I and κ_O are independent, and their hazard rates r_I and r_O satisfy $[(1-\alpha)\Delta - k] \cdot r_I(k + \alpha\Delta) \leq k \cdot r_O(k)$ for all $k \in [0, (1-\alpha)\Delta]$. Then, the incomplete contract is optimal.*

A marginal increase in Δ_O increases the likelihood of creating the improved widget by $[1 - F_O(\kappa_I - \alpha\Delta)] \cdot f_I(\kappa_I)$, generating a benefit of $(\Delta - \kappa_I)$. At the same time, this also increases the probability of creating O by $[1 - F_I(\kappa_O + \alpha\Delta)] \cdot f_O(\kappa_O)$, resulting in a cost of κ_O. For the incomplete contract to be optimal, the costs must outweigh the benefits. And the condition in the proposition guarantees this to be the case.

Notice that the marginal cost of increasing incentives beyond the incomplete contract is zero, whereas the marginal benefit $(\Delta - \kappa_I)$ is strictly positive. As a result, the probability of having a cost κ_I around $\alpha\Delta$ must be arbitrarily small, and it is only allowed to rise gradually, as the cost κ_O increases, and the benefit $\Delta - \kappa_I$ decreases.

6 Extensions

6.1 Seller's Disclosure of Information to the Buyer

Throughout this paper we have assumed that both buyer and seller observe the investment undertaken by the latter. This simplifies the exposition of the results. And since symmetric observability by the two parties is always assumed in this literature, it facilitates the comparison of our result with previous work. Nevertheless, it is useful to point out that the results do not hinge on this assumption. In this section, we show that the results remain unaltered under asymmetric observability. In particular, we assume, as would seem natural, that the outcome of the investments is private information of the seller. Nevertheless, once the seller shows a new widget to the buyer, he immediately observes whether it is I or O.

The timing of events remains the same as before, with the exception that at $t = 2$, only the seller observes the widgets they can trade, and decides which widgets to show as available for trade. In particular the seller can decide not to show the buyer a widget that has been created. Thus, the message spaces for buyer and seller are different. While the buyer can still report $m_B \in \{R, I, O\}$, the seller can announce $m_S \in \{R, RI, RO, I, O\}$, where RI and RO refer to the states where a new widget (I in the former, O in the latter case) has been created but not shown to the buyer. I and O refer to states where a new widget has been created and shown. We will show here that we can still implement all outcomes that could be achieved in the case where created widgets are observable by both, buyer and seller. We do so in two steps. We first show that the seller cannot benefit from hiding a widget and then admitting in the implementation of the mechanism that she did so. And then we show that the seller cannot benefit either by hiding a widget until the renegotiation stage.

Whenever we have that the seller reports state RI or RO, the contract can require her to show the new widget to the buyer, and ask again the buyer and the seller about the state of the world. If the seller fails to show a new widget because she lied and has not invented one, she can be punished with a sufficiently large payment to the buyer.[30] Thus, by reporting RI or RO, she cannot improve upon revealing the information to the buyer, and then reporting either I or O.

Finally, it remains to show that the seller will not create a widget and hide to increase her position in the renegotiations. First note that the opportunistic widget is always shown to the buyer if the seller has created it. If she hides it initially, she can show it at the renegotiation stage, but then, this widget has no value. Therefore, if the seller intends to hide it, she would prefer not to create it in the first place. Furthermore, the seller always shows the improved widget to the buyer if $\alpha\Delta \leq \Delta_I$. Creating I but hiding it from the buyer will give the seller an additional payoff of $\alpha\Delta$ as compared to the state where only R exists. But creating I and showing it to the buyer will result in an additional payoff of Δ_I.

[30] By a similar argument we can assume that both, buyer and seller agree on the number of widgets shown. If they disagreed, the liar can easily be detected by asking the party who reported a new widget to show its existence, and punished, by making him/her pay the other party.

The condition $\alpha\Delta \leq \Delta_I$ does not restrict the implementation problem, since an optimal contract gives at least the same incentives to invest in I as the incomplete contract.

This argument shows that the seller never has an incentive to hide from the seller a widget that has been created. Clearly, we will still have the binding constraint (2), as we need truthful reporting of states I and O, if the seller reveals all the information to the buyer. As a result, the model where the seller's investments are private information is analogous to the model with symmetric information between buyer and seller. All the results in the previous section would carry through unchanged.

6.2 Contracting When There Are Multiple Widgets

Throughout this paper, we have assumed that the seller can only create one new widget. This is a convenient assumption that simplifies our analysis. And we want to consider now the generality of our conclusions when this is relaxed.

As discussed in the main text, the optimal mechanism must satisfy $\Delta_O = \Delta_I - \alpha\Delta$. This constraint, in turn, discourages the seller from trying to invent both O and I at the same time, and hide one before playing the mechanisms. Suppose the seller created both widgets. Then she could hide O and show only I to the buyer. They would, therefore, agree to trade I at a price p_I, as the mechanism states. In this case, O would be useless, and the seller would rather avoid the cost of inventing. Instead, the seller could hide I and show only O. They would then agree to trade R at a price p_O. And later, the seller could show I to the buyer and ask for a renegotiation, capturing the rents $\alpha\Delta$. Doing this, the seller obtains a payoff of $p_O - c_R + \alpha\Delta - \kappa_I - \kappa_O$. But this is dominated by the invention of I alone, which would yield a payoff of $p_I - c_I - \kappa_I = p_O - c_R + \alpha\Delta - \kappa_I$, where the equality follows from the truthtelling constraint.

A final possibility is that the seller shows both I and O to the buyer before playing the mechanism. In such a case, the mechanism should also specify what happens in this state of the world. Nevertheless, since the seller can hide O, she can guarantee herself the payoff from the I state, and hence could never be punished for creating both widgets. Still, the mechanism could offer more to the seller, to encourage the creation of both I and O. To see the usefulness of such a strategy, consider the initial example. We showed that whenever $\kappa_O < \kappa_I$, no contract can induce the creation of the improved widget, since the seller would always prefer to create O, instead. Nevertheless, if the contract specified a high payoff to the seller for inventing both, it could achieve this objective. Notice, however, that the main message of the paper still applies: in order to give incentives for efficient investments, the contract cannot avoid giving incentives to behave opportunistically. Furthermore, the incomplete contract may still be optimal, since as long as $\kappa_O > \Delta - \kappa_I$, creating both widgets is still less desirable than having no investment.

There is yet another reason to be sceptical about the use of contracts that reward the creation of both I and O. Just like we argued at the beginning that contracts that reward the creation of I may suffer from investments in O, rewarding the creation of both I and O may lead, instead, to the creation of multiple opportunistic widgets.[31] Therefore, when two new widgets are available, we may still have to elicit whether there is an improved widget among them, resulting in further truthtelling constraints. To avoid having to make the same argument multiple times, it is then natural to consider a model where multiple widget creation is either not possible, or not encouraged by the contract.

[31] It seems reasonable to assume that whenever a loophole in the contract has been discovered, the seller can exploit it in multiple ways. This can be modelled by allowing the seller to produce numerous small variations of O which could be used whenever a contract requires the seller to show a certain number of widgets.

7 Opportunism and ownership structure

The contracting model we develop in the paper can be extended in several directions. As an illustration, we offer an application to the theory of the firm in the simplest formulation possible. The purpose is to show that having a theory of the firm grounded on a formal contracting model brings new insights to the vertical integration decision.

We extend our model by introducing an upstream and a downstream producer, in addition to the buyer (whom we can think of as a final customer). The upstream producer, U, produces an intermediate widget W_U that is purchased by the downstream producer, D, who in turn uses this as an input to produce some final widget $W_D(W_U)$. This is then sold to the final customer B. As in our standard model, the upstream and downstream producers write a contract specifying the terms of their trade. After the upstream and downstream producers have traded, the downstream producer contracts with the final customer, again in the same way as in our standard model.[32]

Each producer can invest in either improving the widget it supplies, or in creating an opportunistic widget that reduces the value of the trade (relative to the regular widget) for that particular step of the supply chain. There are three possible versions of the intermediate widget, i.e. $W_U \in \{R_U, I_U, O_U\}$. As in the standard model, they are labelled "improved," "regular," and "opportunistic." U can create either I_U or O_U at the respective costs of $\kappa_{U,I}$ and $\kappa_{U,O}$. The downstream producer can then turn the intermediate widget W_U into an improved, a regular, or an opportunistic final widget, i.e. $W_D(W_U) \in \{R_D(W_U), I_D(W_U), O_D(W_U)\}$ (or briefly $W_D \in \{R_D, I_D, O_D\}$ when the dependency is clear). Again, the creation of an improved or opportunistic final widget comes

[32] This timing makes our framework directly applicable to each contracting stage. Moreover, it is equivalent to a model with the following timing: first, D contracts with the final customer over the provision of a final widget; then, D writes a contract with U subcontracting the provision of an intermediate widget; after this, both U and D make their investment decisions; finally, the widgets are produced and exchanged.

at a cost of $\kappa_{D,I}$ or $\kappa_{D,O}$, which we take to be independent of W_U for simplicity. We assume that all three parties are perfectly informed about everything that happens at each step of the production process, but third parties cannot verify the nature of the new widgets.

Denote U's production cost for W_U by $c_U(W_U)$. Producer D's cost for transforming W_U into $W_D(W_U)$ is $c_D(W_D(W_U))$. B's valuation for the final good is $v_B(W_U, W_D)$. In order to cleanly separate the incentives provided by the contract between U and D from those provided by the contract between D and B, we assume that production costs and valuations are independent and separable. To be more precise, we assume that $c_D(W_D(W_U))$ is the same for all W_U (we will write $c_D(W_D)$) and $v_B(W_U, W_D) = v_{B,U}(W_U) + v_{B,D}(W_D(W_U))$ with $v_{B,D}(W_D(W_U))$ constant in W_U (we will write $v_{B,D}(W_D)$).

In order to produce the widgets, two assets, $A1$ and $A2$, are needed. The upstream production requires the use of $A1$ and U's investment is specific to this asset. Downstream production requires asset $A2$, and D's investment is specific to this asset. We consider the following ownership structures: either assets are separately owned by the producers (non-integration), or both assets are owned by one of the producers (upstream or downstream integration).[33]

Let $\underline{z}_P(A_P, W_P)$ be the outside option of producer $P \in \{U, D\}$, when this producer owns assets $A_P \in \{\varnothing, \{A1\}, \{A2\}, \{A1, A2\}\}$, and has created widget $W_P \in \{\varnothing, I, R\}$.[34] This assumes that a producer cannot gain from the other producer's innovation, even when it owns the asset of that production stage. The human capital developed to create a widget therefore remains with the particular producer.[35] The outside option of B is normalized

[33] We do not consider here the possibility of the final consumer owning assets. Since this party does not invest, it would be inefficient for it to own any of the assets.

[34] Since the outside option consists of selling in the market, the producers would not get any return from trying to sell an opportunistic widget. The best they can hope for is to sell the best widget they may produce, either the regular or the improved one, if available.

[35] It is straighforward to extend the model to allow for more general outside options of the form $\underline{z}_P(A_P, W_U, W_D) = \underline{u}_P(A_P, W_P) + \underline{y}_P(A_P, W_{-P})$.

to zero.

Finally, we will denote D's expected payoff from transacting with the final buyer when U supplies widget W_U by $v_D(W_U)$.[36]

With this notation the surplus from trading between D and B is $S_D(W_U, W_D) = [v_B(W_U, W_D) - c_D(W_D)] - \underline{z}_D(A_D, W_D)$. We define $\Delta^D = S_D(W_U, I_D) - S_D(W_U, R_D) = [v_B(I_D) - c_D(I_D)] - [v_B(R_D) - c_D(R_D)] - [\underline{z}_D(A_D, I_D) + \underline{z}_D(A_D, R_D)]$, and Δ^D does not depend on W_U. Similarly, the surplus from trading between U and D is $S_U(W_U) = [v_D(W_U) - c_U(W_U)] - [\underline{z}_U(A_D, W_U) + \underline{z}_D(A_D, \varnothing)]$. We define $\Delta^U = S_U(I_U) - S_U(R_U) = [v_D(I_U) - c_U(I_U)] - [v_D(R_U) - c_U(R_U)] - [\underline{z}_U(A_U, I_U) - \underline{z}_U(A_U, R_U)]$ which is independent of W_D.

Denote by α_D the bargaining power of D with respect to B, and by α_U the bargaining power of U with respect to B. The results for our baseline model apply directly to each of the two production stages. If we denote $\Delta\underline{z}_P(A_P) = \underline{z}_P(A_P, I_P) - \underline{z}_P(A_P, R_P)$, the constraints on contracting corresponding to (2) are given by

$$\Delta_O^P + \alpha_P \cdot \Delta^P + \Delta\underline{z}_P(A_P) \geq \Delta_I^P,$$

where Δ_O^P and Δ_I^P are P's contractual incentives to invest in the opportunistic and improved widgets, respectively.[37] Producer P therefore invests in I_P if and only if:

$$\kappa_{P,I} \leq \Delta_I^P = \Delta\underline{z}_P(A_P) + \alpha_P\Delta^P + \Delta_O^P \text{ and } \kappa_{P,I} \leq \kappa_{P,O} + \left(\Delta_I^P - \Delta_O^P\right) = \kappa_{P,O} + \Delta\underline{z}_P(A_P) + \alpha_P\Delta^P.$$

[36] Notice that v_D also depends on D's assets, A_D. This is so because v_D is a function of D's outside option, which depends on A_D. However, Δ^U will be independent of A_D.

[37] Notice that the contracting outcomes depend on the asset allocation. However, in the second contracting stage, the optimal incentives to invest in I_D do not depend on the outcome of the first contracting stage (i.e. on W_U). The impact of the separability and independence assumptions is clear from this formula: we can eliminate any dependence of the outcome of the second contracting stage on the outcome of the contracting between U and D.

P invests in O if and only if:

$$\kappa_{P,O} < \Delta_O^P \text{ and } \kappa_{P,O} < \kappa_{P,I} - \left(\Delta_I^P - \Delta_O^P\right) = \kappa_{P,I} - \Delta \underline{z}_P\left(A_P\right) - \alpha_P \Delta^P.$$

The conditions are essentially the same as before. Now the incentives under incomplete contracts are $\Delta \underline{z}_P\left(A_P\right) + \alpha_P \Delta^P$. After investing, a producer now gets both a share of the increase in surplus, $\alpha_P \Delta^P$, plus the increase in his outside option, $\Delta \underline{z}_P\left(A_P\right)$.

Holding the contractual incentives Δ_O^P constant, the incentives to invest in I_P are increasing in $\Delta \underline{z}_P\left(A_P\right)$, while the incentives to invest in O_P are decreasing in $\Delta \underline{z}_P\left(A_P\right)$. Therefore, transferring ownership of an asset to producer P increases the probability that this party will invest in improving the value of the transaction, and decreases the probability of opportunistic behavior. Conversely, taking the ownership of an asset away from producer P decreases its incentives to improve the value of the transaction and increases the likelihood that it will behave opportunistically. Hence, the optimal ownership structure must take into account not only which of the parties' investments is more important for the relationship, but also which party is in a better position to behave opportunistically. If one party finds it difficult to behave opportunistically, it is not very costly to provide it with incentives for efficient investment using a contract. Therefore, there is little need for using asset ownership to provide that party with assurance that the investments will be protected. It may therefore be optimal to transfer ownership to the other party, even if that party's investment is less important.

When transferring assets, the optimal contract at each step of the supply chain—and therefore the incentives to invest and to behave opportunistically—will also change. But it will still be the case that when a producer owns more assets, the value that is generated in its step of the supply chain increases at the expense of the value that is produced in the other step of the supply chain.

This model provides a theory of the firm where the assumption of incomplete contracts emerges from the possibility of behaving opportunistically. It shows that vertical integration is not a solution to the opportunism problem (as Williamson claims): while integration reduces the opportunism of the owner, it increases the incentives to behave opportunistically for the other producer. Moreover, the model encompasses the property rights theory of the firm when the optimal contract is the incomplete contract. When contracting solves the hold-up problem, asset ownership becomes irrelevant. And for all intermediate cases, the optimal ownership structure trades off the desire to induce efficient investments (which calls for giving the assets to the party whose investments are more important), with the need to curb opportunism (which calls for giving the assets to the party that is more likely to behave opportunistically).

8 Conclusion

This paper introduces a cost of contracting that originates from the possibility that a contracting party may behave opportunistically and search for and exploit a loophole in the contractual formulations. The possibility of such opportunistic behavior is anticipated and can be observed by the parties, but it cannot be verified. Then typically no contract, not even one that is contingent upon parties' reports on whether opportunism occurred, can provide first-best incentives for relationship-specific investments when it is assumed that parties renegotiate any inefficient contractual outcome. To be more precise, it is shown that whenever a contract provides incentives to foster investments to increase the value of the relationship, these same incentives also encourage opportunistic behavior which devalues the relationship. The optimal contract has to take these opposite effects into consideration; in general, it is optimal to provide below first-best incentives. If opportunistic behavior is relatively inexpensive (as compared to the welfare enhancing investment) the value of contracting may become low, or even zero.

The model is not only useful for understanding the barriers to contracting. It can also be used to motivate the assumption of incomplete contracts which is common in the theories of the firm. We demonstrate that assuming non-verifiability of the state of the world can be enough to justify the assumption of incomplete contracts even if contracts can potentially be complex. To obtain this result, we only have to assume that post-contractual opportunistic behavior is possible, and that inefficient outcomes are renegotiated.

Our model, given its simplicity, can also serve as a framework for addressing further important contracting questions. As an illustration we extend the model by including asset ownership in order to address the problem of optimal ownership structure. We expect the model also to be useful to understand how opportunism affects the advantages and disadvantages of long-term as opposed to short-term contracts. This could offer new insights to explain the optimal length of contracts. These and other considerations are left for future research.

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Appendix A

In this appendix we derive the implementability constraint (2). Prices $p(m_B, m_S)$ and probabilities of trade $(x_R(m_B, m_S), x_N(m_B, m_S))$ have to be specified such that truthtelling occurs in a Nash equilibrium. Necessary and sufficient conditions for this are given in Theorem 0 in Segal (1999).

Assume first that $m_B = I$ and $m_S = O$. Applying Theorem 0 in Segal (1999), implementability requires that there exists $p(I,O)$ and $(x_1(I,O), x_2(I,O))$ such that the following two constraints are fulfilled for the seller and the buyer respectively

$$\begin{aligned} p_I - c_I &\geq p(I,O) - x_R(I,O)\, c_R - x_N(I,O)\, c_I \\ &\quad +\alpha\left[(v_I - c_I) - x_R(I,O)(v_R - c_R) - x_N(I,O)(v_I - c_I)\right], \\ v_R - p_O &\geq -p(I,O) + x_R(I,O)\, v_R + x_N(I,O)\, v_O \\ &\quad +(1-\alpha)\left[(v_R - c_R) - x_R(I,O)(v_R - c_R) - x_N(I,O)(v_O - c_O)\right]. \end{aligned}$$

Adding these constraints gives:

$$p_I - p_O \geq x_N(I,O)\left((1-\alpha)(c_O - c_I) + \alpha(v_O - v_I)\right) + (1-\alpha)(c_I - c_R) + \alpha(v_I - v_R).$$

As $c_O < c_I$ and $v_O < v_I$, the constraint is least binding for $x_N(I,O) = 1$ and we have that the two constraints can be fulfilled if:

$$p_I - p_O \geq (1-\alpha)(c_O - c_R) + \alpha(v_O - v_R)$$

or

$$p_O - c_R \leq p_I - c_O - \alpha\left[(v_O - c_O) - (v_R - c_R)\right].$$

Consider now the case where $m_B = O$ and $m_S = I$. Applying Theorem 0 in Segal (1999), implementability requires that there exists $p(O,I)$ and $(x_R(O,I), x_N(O,I))$ such that the following two constraints are fulfilled for the seller and the buyer respectively:

$$\begin{aligned} p_O - c_R &\geq p(O,I) - x_R(O,I)\, c_R - x_N(O,I)\, c_O \\ &\quad + \alpha\left[(v_R - c_R) - x_R(O,I)(v_R - c_R) - x_N(O,I)(v_O - c_O)\right], \\ v_I - p_I &\geq -p(O,I) + x_R(O,I)\, v_R + x_N(O,I)\, v_I \\ &\quad + (1-\alpha)\left[(v_I - c_I) - x_R(O,I)(v_R - c_R) - x_N(O,I)(v_I - c_I)\right]. \end{aligned}$$

Adding these constraints gives:

$$p_O - p_I \geq x_N(I,O)\left((1-\alpha)(c_I - c_O) + \alpha(v_I - v_O)\right) + (1-\alpha)(c_R - c_I) + \alpha(v_R - v_I).$$

As $c_O < c_I$ and $v_O < v_I$ the constraint is least binding for $x_2(I,O) = 0$ and we have that:

$$p_O - p_I \geq (1-\alpha)(c_R - c_I) + \alpha(v_R - v_I)$$

or

$$p_O - c_R \geq p_I - c_I - \alpha\left[(v_I - c_I) - (v_R - c_R)\right].$$

Furthermore, the calculations show that if we have that for some (p_O, p_I) the condition:

$$p_I - c_O - \alpha\left[(v_O - c_O) - (v_R - c_R)\right] \geq p_O - c_R \geq p_I - c_I - \alpha\left[(v_I - c_I) - (v_R - c_R)\right] \quad (3)$$

is fulfilled, then we can find a contract $(p(m_B, m_S),\ x_1(m_B, m_S), x_2(m_B, m_S))$ for which $p(I,I) = p_I$ and $p(O,O) = p_O$ that is implementable. In this sense, (3) is sufficient and necessary for implementability.

Appendix B

Proof of Proposition 1. Suppose that $\Pr\left(\kappa_O \geq \min\left(\widetilde{\Delta} - \alpha\Delta, \kappa_I - \alpha\Delta\right)\right) = 1$, and set $\Delta_I = \widetilde{\Delta}$, and $\Delta_O = \widetilde{\Delta} - \alpha\Delta$. Clearly, Δ_I and Δ_O satisfy the truthtelling constraint. Moreover, as $\Pr\left(\kappa_O < \min\left(\widetilde{\Delta} - \alpha\Delta, \kappa_I - \alpha\Delta\right)\right) = 0$, we cannot have that $\kappa_O < \Delta_O$ and $\kappa_O < \kappa_I + \Delta_O - \Delta_I$ simultaneously, and hence O is never invented. Furthermore, the I widget is invented whenever $\kappa_I \leq \Delta$. To see this, notice that $\kappa_I \leq \Delta$ implies that $\kappa_I \leq \widetilde{\Delta}$, since $\Pr\left(\kappa_I \in \left[\widetilde{\Delta}, \Delta\right]\right) = 0$. But this means that $\kappa_I \leq \Delta_I$, and hence the seller is willing to invent it. Also, $\kappa_O \geq \min\left(\widetilde{\Delta} - \alpha\Delta, \kappa_I - \alpha\Delta\right) = \kappa_I - \alpha\Delta = \kappa_I + \Delta_O - \Delta_I$, and hence the seller prefers to invent I, rather than O. Therefore, I is indeed created for any $\kappa_I \leq \Delta$.

To show the other direction, suppose now that there exists a mechanism that implements the first best. We can characterize it by Δ_O, since it must satisfy the truthtelling constraint, and hence, we can set $\Delta_I \leq \Delta_O + \alpha\Delta$. Moreover, the mechanism should not provide incentives to invest in innovating O. This implies that investing in innovation of O is unprofitable or less profitable than investing in I, i.e. $\Pr\left(\kappa_O \geq \min\left(\Delta_O, \kappa_I + \Delta_O - \Delta_I\right)\right) = 1$. Furthermore, it should induce an innovation in I whenever $\kappa_I \leq \Delta$. Since we have that $\Pr\left(\kappa_I \in \left[\widetilde{\Delta} - \varepsilon, \widetilde{\Delta}\right]\right) > 0$ for any $\varepsilon > 0$, we must have $\Delta_I \geq \widetilde{\Delta}$, or $\Delta_O \geq \widetilde{\Delta} - \alpha\Delta$. Therefore, $\Pr\left(\kappa_O \geq \min\left(\widetilde{\Delta} - \alpha\Delta, \kappa_I - \alpha\Delta\right)\right) \geq \Pr\left(\kappa_O \geq \min\left(\Delta_O, \kappa_I + \Delta_O - \Delta_I\right)\right) = 1$.

Assume now that $f\left(\kappa_I, \kappa_O\right) > 0$ for all $\left(\kappa_I, \kappa_O\right) \in [\Delta - \varepsilon, \Delta + \varepsilon] \times [\Delta - \alpha\Delta - \varepsilon, \Delta - \alpha\Delta]$. Clearly, a contract cannot be optimal if it induces a higher probability of inventing I than in the first best. Welfare, given a contract $\Delta_O \leq (1 - \alpha)\Delta$, is:

$$\begin{aligned} W\left(\Delta_O\right) &= \int_0^{\alpha\Delta + \Delta_O} \int_{\max(0, \kappa_I - \alpha\Delta)}^{\infty} \left(\Delta - \kappa_I\right) \cdot f\left(\kappa_I, \kappa_O\right) \cdot d\kappa_O \cdot d\kappa_I \\ &\quad - \int_0^{\Delta_O} \int_{\alpha\Delta + \kappa_O}^{\infty} \kappa_O \cdot f\left(\kappa_I, \kappa_O\right) \cdot d\kappa_I \cdot d\kappa_O \end{aligned}$$

and therefore:

$$\frac{\partial W}{\partial \Delta_O} = \int_{\Delta_O}^{\infty} (\Delta - \Delta_O - \alpha\Delta) \cdot f(\Delta_O + \alpha\Delta, \kappa_O) \cdot d\kappa_O - \int_{\Delta_O+\alpha\Delta}^{\infty} \Delta_O \cdot f(\kappa_I, \Delta_O) \cdot d\kappa_I$$

and

$$\left.\frac{\partial W}{\partial \Delta_O}\right|_{\Delta_O = \Delta - \alpha\Delta} = -\int_{\Delta}^{\infty} (1-\alpha) \cdot (\Delta - \alpha\Delta) \cdot f(\kappa_I, \Delta - \alpha\Delta) \cdot d\kappa_I.$$

and we have that in the optimal contract $\Delta_O < (1-\alpha)\Delta$. This implies that $\Delta_I < \Delta$. ■

Proof of Proposition 2.

We need to show that for any possible value of Δ_O, we can construct a contract of this form such that $\Delta_I = \Delta_O + \alpha\Delta$. Assume first that there was no innovation. Then they must trade the R widget at a price of p_R. If the seller created a widget, she will always show it, as explained in Section 5.1. Suppose the seller creates O and shows it. The buyer will choose R since $v_R - p_N \geq v_O - p_N + (1-\alpha) \cdot [(v_R - c_R) - (v_O - c_O)]$ is always satisfied. When the seller creates I, the buyer will also choose R whenever $v_I - p_N \leq v_R - p_N + (1-\alpha)[(v_I - c_I) - (v_R - c_R)]$, which is satisfied if and only if $\alpha \cdot (v_I - v_R) \leq (1-\alpha) \cdot (c_R - c_I)$. Hence, when the seller creates O her payoff is $p_N - c_R$ and when she creates I her payoff is $p_N - c_R + \alpha\Delta$, since the buyer chooses R in either case. Thus, in an equivalent truthful revelation mechanism we have that $p_O = p_N$ (recall that $p_O - c_R$ is the seller's payoff in the revelation mechanism when O is created) and that $p_I = p_N - c_R + \alpha\Delta + c_I$ (recall that $p_I - c_I$ is the seller's payoff in the revelation mechanism when I is created). In particular, we have that $\Delta_I = \Delta_O + \alpha\Delta$. This shows that for any second-best contract given by prices (p_R, p_I, p_O) setting $p_N = p_O$ implements the second-best outcome as well. ■

Proof of Proposition 3. Let $\widehat{f}(\kappa_I, \kappa_O) = f(\kappa_I, \kappa_O) + \mu \cdot \phi(\kappa_I, \kappa_O)$. Then, it suffices to show that welfare is submodular in (Δ_O, μ) under either of the conditions of the proposition. Differentiating the welfare function we obtain:

$$\frac{\partial W}{\partial \Delta_O} = [(1-\alpha)\Delta - \Delta_O] \cdot \int_{\Delta_O}^{\infty} \widehat{f}(\Delta_O + \alpha\Delta, \kappa_O) \cdot d\kappa_O - \Delta_O \cdot \int_{\Delta_O + \alpha\Delta}^{\infty} \widehat{f}(\kappa_I, \Delta_O) \cdot d\kappa_I$$

If we further differentiate with respect to μ, we obtain:

$$\frac{\partial^2 W}{\partial \mu \partial \Delta_O} = [(1-\alpha)\Delta - \Delta_O] \cdot \int_{\Delta_O}^{\infty} \phi(\Delta_O + \alpha\Delta, \kappa_O) \cdot d\kappa_O - \Delta_O \cdot \int_{\Delta_O + \alpha\Delta}^{\infty} \phi(\kappa_I, \Delta_O) \cdot d\kappa_I$$

Under condition 1, $\int_{\Delta_O}^{\infty} \phi(\Delta_O + \alpha\Delta, \kappa_O) \leq 0$ since $\phi(\Delta_O + \alpha\Delta, \kappa_O) > 0$ for $\kappa_O < \Delta_O$ and integrates to zero in the full range. Furthermore, $\phi(\kappa_I, \Delta_O) \geq 0$ for all $\kappa_I \geq \Delta_O + \alpha\Delta$. Hence, $\frac{\partial^2 W}{\partial \mu \partial \Delta_O} \leq 0$, and welfare is submodular in (Δ_O, μ). A similar argument yields the same result under condition 2. ■

Proof of Proposition 4.

Denote by $W(\Delta_O)$ the welfare that results from Δ_O (and $\Delta_I = \Delta_O + \alpha\Delta$). For the incomplete contract to be optimal, it must be the case that $W(\Delta_O) \leq W(0)$ for all $\Delta_O > 0$. When costs are independent, we can write:

$$\begin{aligned}
& W(\Delta_O) - W(0) \\
= & \int_{\alpha\Delta}^{\Delta_O + \alpha\Delta} \int_{\kappa_I - \alpha\Delta}^{\infty} (\Delta - \kappa_I) \cdot f(\kappa_I, \kappa_O) \cdot d\kappa_O \cdot d\kappa_I - \\
& - \int_0^{\Delta_O} \int_{\kappa_O + \alpha\Delta}^{\infty} \kappa_O \cdot f(\kappa_I, \kappa_O) \cdot d\kappa_I \cdot d\kappa_O \\
= & \int_{\alpha\Delta}^{\Delta_O + \alpha\Delta} (\Delta - \kappa_I) \cdot [1 - F_O(\kappa_I - \alpha\Delta)] \cdot f_I(\kappa_I) \cdot d\kappa_I - \\
& - \int_0^{\Delta_O} \kappa_O \cdot [1 - F_I(\kappa_O + \alpha\Delta)] \cdot f_O(\kappa_O) \cdot d\kappa_O \\
= & \int_0^{\Delta_O} \{((1-\alpha)\Delta - \kappa) \cdot [1 - F_O(\kappa)] \cdot f_I(\kappa + \alpha\Delta) - \kappa \cdot [1 - F_I(\kappa + \alpha\Delta)] \cdot f_O(\kappa)\} \cdot d\kappa,
\end{aligned}$$

where the last step follows from the change of variables $\kappa = \kappa_I - \alpha\Delta$ and $\kappa = \kappa_O$. The assumption that $[(1-\alpha)\Delta - k] \cdot r_I(k + \alpha\Delta) \leq k \cdot r_O(k)$ implies that the integrand is non-positive. As a result, the last integral cannot be positive for any $\Delta_O \in [0, (1-\alpha)\Delta]$, and hence, the incomplete contract is optimal. ■