The Role of Decision Rights in Co-development Initiatives

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Problem definition: How should decision rights be allocated between firms occupying different positions in the value chain to maximize the value of a co-development project?

Academic/Practical Relevance: We contribute to the OM literature on the benefits and challenges of co-development initiatives by looking at the design of optimal governance structures that specify the allocation of rights to make certain decisions. Our problem is motivated by real-world challenges observed in co-development project initiation discussions between technology companies. We utilize a game-theoretic model to study the allocation of the ex-ante right to set the contract terms and the ex-post right to choose which contract to implement, once the market potential is realized.

Results: First, we find that delegating more control to a party, does not necessarily imply that the party will be incentivized to exert greater effort. Specifically, we show that allocating both rights to the seller as opposed to only the ex-ante right, actually reduces his effort. Second, when the buyer has low bargaining power, the ex-post decision right should be delegated to the seller, i.e., the party with lower exposure to the effort-contingent outcome. Otherwise, the ex-post decision right should be delegated to the buyer but the ex-ante right should be held by the seller. Finally, we show that simple contracts with decision rights outperform a spot contract when the ex-post bargaining power of one of the parties is substantially higher.

Managerial Implications: Our results offer insights for how managers should structure the optimal governance structure for co-development projects. We also identify when and how companies should delegate rights to their partners to maximize the value of the project. We show that the optimal governance structure depends crucially on the position in the value chain of the party with the higher bargaining power.

Key words: co-development, collaboration, contracting, decision rights, renegotiation.

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1. Introduction

Interfirm collaborative agreements are one of the predominant mechanisms that firms use to gain a competitive advantage. This is particularly true in industries characterized by high levels of uncertainty and substantial development costs (Hagedoorn 2002). This paper focuses on such co-development agreements in which firms invest resources to co-create a new product or service. Co-development agreements are commonly practiced in high tech industries such as the telecommunication and microelectronic equipment, semiconductor industry as well as complex IT products and services. They are fundamentally different than arms-length licensing agreements of an existing technology as both parties work together to co-create a new technology or product (Bhaskaran and Krishnan 2009, Ryall and Sampson 2009). They are also different than strategic alliances in that the firms do not create a separate organizational unit to launch a project nor do they extend their collaboration across their entire product portfolio (see Gerwin and Ferris 2004 for a classification of the various types of alliances).

Co-development initiatives are typical in the semiconductor industry, particularly for the design and development of innovative products. Consider the joint development project for the next generation of NAND flash memory products by Sandisk and Toshiba. Sandisk's strategy is to create new markets for NAND flash memory through constantly improving the performance of its products. For instance, technology advances can reduce the cost per bit by increasing the density of the memory chips on the wafer. Such performance improvements on the memory have significant impact on the demand for Sandisk's products that use NAND flash memory (e.g., USB drives, cameras, media players, smartphones) (Sandisk Corp. 2011, p. 3). While the NAND flash memory is manufactured by Toshiba (Sandisk Corp. 2011, p. 4), developing such improvements requires Sandisk and Toshiba to undertake joint research and development activities. Similarly, Taiwan Semiconductor Manufacturing Company (TSMC) and MediaTek joined forces to design state-of-the-art microchips that build on the technology of TSMC to develop "the best and most competitive Internet of Things (IoT) product solutions" for the customers of MediaTek (TSMC 2016).

Co-development projects are also common in the information and communication technology (ICT) industry. We engaged in several project initiation discussions between a large telecommunication equipment provider (seller) and its different potential partners, typically information technology services companies (buyers), which were interested in working with the seller to develop bespoke IT systems for their customers. For instance, a co-development project with one buyer (hereafter named as Buyer A) aimed to develop an innovative design for a data center management system. Such a system would offer real-time data management services leading to more efficient energy use and reduced disruption times. Specifically, the seller would focus on the hardware components (e.g., low voltage sensors) and Buyer A would focus on developing the software to integrate those components in the platform. The end-product would be a hardware equipment (that would be manufactured by the seller) that would enable a complete and transparent view of the data center. This would allow Buyer A to offer a higher-quality service to her clients who were becoming increasingly concerned about the energy efficiency of their data centers. Thus, the technology developments in the integrated platform would have a significant impact on the demand for Buyer A's product.

The above examples are typical of co-development agreements where a firm positioned upstream in the value chain (hereafter referred to as the seller) works with a firm positioned downstream in the value chain (hereafter referred to as the buyer). Both parties make investments to develop an innovative technology, which influences the demand for the buyer's product. Such agreements allow firms to pursue the development of innovative initiatives through collaboration which results in a more efficient sharing of the substantial development costs. Yet, and precisely because of the innovative nature of such projects, incentivizing the participating firms to invest efficiently can be challenging. First, given the highly specialized expertise required for the development of these products, it is hard to verify the effort exerted by each party. Moreover, given that the result of these development efforts is an intermediate output that will constitute only part of the end-product/service, it is extremely difficult to make future rewards contingent on the final outcome in a way that they can be enforceable by a court. For example, in the information technology platform described above, the new product will be sold by Buyer A bundled together in a more wide-ranging service offering (e.g., consulting services by Buyer A). This absence of outcome-dependent contracts gives rise to the well-known holdup problem (Grossman and Hart 1986), and inefficient levels of investments.

The seminal framework of Grossman and Hart (1986) suggests that a mechanism to overcome the under-investment problem is to transfer property/decision rights of the key project assets to the party whose effort is most critical for the success of the project. This mitigates any rent appropriation concerns due to opportunistic behavior once the uncertainty has been resolved, and therefore, encourages upfront investments. Accordingly, there is widespread use of such contractual provisions, i.e., decision rights, across a range of industries such as oil and gas (Masten and Crocker 1985, Goldberg and Erickson 1987), pharmaceuticals (Lerner and Merges 1998), high-tech and IT services (Ryall and Sampson 2009, Susarla 2012).

Such contractual provisions that give one party control over specific decisions of the project are also considered in co-development initiatives. In the example of the IT services co-development initiative, the seller expressed a strong interest in designing the new network device, but stated that the project would only be attractive to him if a "sufficient" number of units were to be deployed for the new service. In particular, the seller requested a substantial quantity commitment by Buyer A with the option for the seller to deliver any quantity up to that level. Such a commitment effectively transfers control over the quantity decision to the seller. At the same time, Buyer A did not want to give up control over this decision. In the end, despite the strong synergies between the two companies, the project was abandoned, precisely because they never reached an agreement on which party should hold the quantity decision right. Interestingly, in a co-development initiative with a different buyer (hereafter named as Buyer B), the project was successfully initiated under a governance structure where the seller held the quantity decision right.

Such agreements that give a party the right to control a specific decision are also common in the semiconductor industry. For example, in the Sandisk-Toshiba collaboration, Sandisk was contractually obligated to purchase up to 50% of output produced by Toshiba for this initiative (Sandisk Corp. 2011, p. 4). Such a commitment transfers the control over the quantity decision to Toshiba, the party responsible for manufacturing the products. Having the seller retain the control over quantity decisions is also typical in microchip manufacturing, and particularly among the largest semiconductor manufacturers, such as TSMC (Clarke 2006). As the above examples suggest, which party has the right to make certain key decisions such as the quantity is a critical issue that arises in co-development initiatives. Another such critical decision involves who sets the contract terms. Given that the total surplus created may depend on which party (buyer or seller) sets the contract terms, the party who has the initial right to make these decisions may benefit from delegating this right to the other party.

Motivated by the above examples, our work seeks to understand how decision rights should be allocated between firms occupying different positions in the value chain to maximize the value of the project. Existing research focuses on settings where the collaborating parties have clearly defined roles (e.g., when one party is primarily responsible for the research activities and the other for the marketing activities or for financing the project). In that case, the Grossman and Hart (1986) framework provides definitive hypotheses about the optimal allocation of decision rights. That is, the party whose effort is most critical should hold the decision right for that particular stage (e.g., see Lerner and Merges 1998 for applications in the pharmaceutical industry). In contrast, co-development implies that the contribution of both parties can be crucial during the development stage.[1] Moreover, another challenge with co-development initiatives is that they frequently require a "pure co-operative" investment, which as defined by Che and Hausch (1999), is an investment where the effort of one party generates a direct benefit only for their partner. For example, an upstream seller, who has to exert effort to improve the demand potential for his buyer's product (as in our motivating examples). This is fundamentally different to "selfish" investments, where a seller invests in reducing his production cost or a buyer invests in increasing her demand potential (see the discussion in Che and Hausch 1999). Within such a co-development setting, our primary

[1] This is also stressed in Ryall and Sampson (2009), who argue that given the lack of theory to guide the development of appropriate hypotheses in co-development settings, they choose a rather exploratory approach in their study of joint technology development projects.

research question is: Who should be allocated the ex-ante right to set the contract terms, and who should be allocated the ex-post decision right to choose from the proposed contracts?

We develop a model to study co-development initiatives where a buyer and a seller exert efforts to improve the market potential of the project. That is, the seller makes a pure co-operative investment to improve the value of the project. We focus on innovative projects for which future payments cannot be made contingent on future outcomes, such as the realized market potential of the project. Instead, the parties consider a menu of non-contingent contracts, each of which specify a quantity and an associated transfer payment. A key characteristic of our model is the governance structure, which specifies the allocation of different rights between the two parties. In line with our motivating examples and industry interactions, we focus on the following two rights: The contract terms are set upfront by the party who holds the right to do so. We refer to this right as the ex-ante right because the contract terms are set before the market potential is realized. Once the market potential is realized, the decision of which contract to implement is made by the party who holds the ex-post decision right. We examine four governance structures that differ based on the allocation of these two rights to identify which governance structure should be preferred by the parties.

Our results offer several insights for firms that engage in co-development initiatives. First, we find that delegating more control to a party, does not necessarily imply that the party will be incentivized to exert greater effort. Specifically, we show that allocating both rights to the seller as opposed to only the ex-ante right, actually reduces his effort. Second, while the seller exerts no effort when the buyer has both rights, the buyer exerts effort even when the seller has both rights. This result highlights how the position of a party in the value chain plays a key role in its incentive to invest in the co-development initiative.

Moreover, our analysis offers insights on how firms should choose a governance structure for a co-development initiative. In industries characterized by powerful sellers, such as the semiconductor industry, where sellers such as TSMC and Toshiba are powerful because of their specialization and scale (McKinsey 2011, p.25), it is important that the seller holds the ex-post decision right. In contrast, in settings where the buyer might have high ex-post bargaining power, such as our example from the ICT industry between the large telecommunication equipment provider and Buyer A (who maintained long-term relationships with key end-customers), the buyer should hold the ex-post decision right, but the seller should hold the ex-ante right to set the contract terms. Lastly, we find that renegotiation, which is usually thought of as an impediment to incentivizing the collaborating parties (e.g., hold-up problem), can actually be a powerful way of aligning the interests of the firms, and therefore, maximizing the value from a co-development initiative.

2. Literature Review

The benefits and challenges of co-development have been the subject of a number of recent papers in operations management. Corbett and DeCroix (2001) study a setting where a seller and buyer both exert efforts to reduce the consumption of an indirect material and the production cost. They show that shared-savings contracts improve the total profitability, but may not always lead to lower environmental impact. Their framework is extended in Corbett et al. (2005) to examine the optimality of linear contracts in the presence of double moral hazard. Gilbert and Cvsa (2003) highlight the holdup problem in a supply chain setting where a firm exerts effort on innovations that reduces the partner's variable cost (or stimulate demand). They examine whether the seller should commit to a price ex-ante in order to encourage innovation or wait and set the price after the demand has been realized. Bhaskaran and Krishnan (2009) compare the effectiveness of different approaches between two firms such as sharing revenues, development costs or efforts in settings where both the efforts and outcomes are observable and contractible. For settings where efforts are unobservable and monitoring is costly, Roels et al. (2010) compare fixed-price, time and material, and performance-based contracts. More recently, Bhattacharya et al. (2013) show how gain-sharing contracts outperform cost-plus contracts in an IT setting of joint product development between a client and a customer support center. Bhattacharya et al. (2014) study the efficiency of milestone-based options contracts in a bilateral research and development (R&D) partnership between a risk-averse provider that conducts early-stage research and a risk-neutral client that performs late-stage development activities. They show that milestone-based options contracts pareto dominate buyout options contracts when the provider has some bargaining power in renegotiation. A common characteristic of the above papers is that the outcome of the co-development efforts, is fully observable and verifiable, and as such, contracts contingent on this outcome can be written upfront. However, as discussed earlier, the open-ended nature of many co-development agreements prohibits the writing of such outcome-contingent contracts.

Instead, firms often rely on "simple" contracts, i.e., contracts in which future payments are not contingent on the outcome. The importance and wide applicability of such simple contracts is highlighted in a stream of operations management (OM) papers that study their efficacy in different settings. Van Mieghem (1999) analyzes the performance of non-contingent contracts on capacity investment levels in the context of subcontracting. Plambeck and Taylor (2006) derive the optimal structure of informal agreements (i.e., relational contracts) that make payments contingent on a non-contractible outcome in a setting where the two parties repeat the same transaction in subsequent periods. Plambeck and Taylor (2007a) show that simple (i.e., fixed-quantity) contracts can induce optimal investments in innovation and capacity, if the firms can properly design the renegotiation process. Kim and Netessine (2013) show that price, quantity, or price-quantity commitments fail to induce collaborative efforts aiming at reducing the seller's production cost. As such, they suggest an alternative mechanism which they coin expected margin commitment in which the seller is guaranteed to earn a fixed margin above the expected unit cost. Li (2013) also examines the role of price commitments in inducing seller effort by a manufacturer when the latter can also adjust his supply base (i.e., the number of sellers). She shows that supply base design and pricing mechanism are strategic complements, and as such, decisions pertaining to them need to be coordinated. Rahmani et al. (2017) consider a dynamic collaborative process and show that simple contracts can perform surprisingly well when the project completion is determined by its current state or an exogenous deadline. Xiao and Xu (2012) show that in royalty-based contracts, contingent payments are critical as they act as substitutes or complements to the value added by the possibility of renegotiation. However, none of the above papers examines the role of decision rights. Our paper contributes to this stream of research by explicitly examining how the allocation of such rights affects the efficacy of non-contingent contracts to induce co-operative investments.

As mentioned before, a stream of research in economics studies the role of property/decision rights (Grossman and Hart 1986, Hart and Moore 1988). Prior work in economics also analyzes non-contingent contracts, especially ones that appropriately design the renegotiation stage (Chung 1991, Aghion et al. 1994, Nöldeke and Schmidt 1995). Renegotiation design refers to the "design of rules that govern the process of renegotiation" (Aghion et al. 1994, p. 257), and effectively determine the ex-post bargaining power of the two parties. Yet, these papers, along with most of the subsequent ones on incomplete contracts (see Tirole 1999 for a thorough review) focus on the so-called "selfish" investments where the seller invests in reducing his production cost and/or the buyer invests in increasing the value he gains from the product. Importantly, Che and Hausch (1999) show that the findings of previous work on the value of simple contracts (without any allocation of decision rights) under "selfish" investments are not transferable to settings of "co-operative" investments. We contribute to this literature by studying non-contingent contracts with allocation of decision rights for co-operative investments.

The OM literature on the role of decision rights has primarily been focused on the effectiveness of Vendor Managed Inventory (VMI) programs (Cachon and Fisher 1997) and more broadly on inventory and procurement ownership decisions (Netessine and Rudi 2006, Randall et al. 2006, Kayis et al. 2013). In the context of knowledge-intensive services, where information transfer and processing are costly, Xue and Field (2008) study whether it should be the client or the service provider the party who decides on how the work between the two parties should be divided. They show that the decision right should be held by the most productive party, i.e., the party who has the lower cost for transferring and processing information. In the context of pharmaceutical R&D,

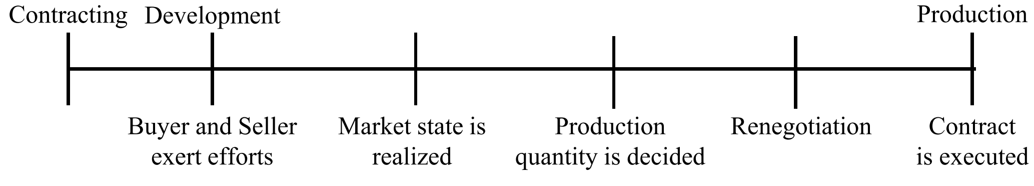
Savva and Scholtes (2014) show that the inclusion of opt-out options that give the partners the right to exit a joint project, can significantly improve the efficiency of licensing contracts. In a similar context, Crama et al. (2016) study the structure of optimal licensing contracts between an innovator and a marketer, who invest sequentially in research and marketing, respectively. They examine the conditions under which the innovator would transfer the launch decision right to the marketer as well as the effects of a buy-out or a take-back option.

Our paper makes several unique contributions to the existing literature: First, we study how the allocation of ex-ante and ex-post decision rights affects the joint output created under simultaneous and co-operative investments. In contrast to the existing literature that assumes that one of the parties has the ex-ante right, we investigate whether and when the ex-ante right should be delegated to the other party. We also investigate two different types of ex-post decision rights, namely quantity and termination rights. Second, we allow for renegotiation of the contract terms and show that the ex-post bargaining power of the two parties needs to be jointly considered with the allocation of decision rights. Third, we also examine the value of contracting (i.e., compare simple contracts with decision rights versus spot contracts) in this context.

3. Model

We consider a risk-neutral buyer (denoted by B) who collaborates with an upstream risk-neutral seller (denoted by S) to undertake a joint development initiative. This initiative aims to create a product to capture a new market opportunity in a highly uncertain environment. The initiative specifies a governance structure that outlines the allocation of the rights to make specific decisions during the course of the project, and a menu of non-contingent contracts.[2] Subsequently, the seller and buyer exert development efforts that stochastically improve the market potential of the project. Once the development stage is completed, the market potential is realized, and the terms of the ex-ante contract are executed (potentially after renegotiation). The sequence of events is summarized in Figure 1 and a table of notation is provided in §OE of the Online Supplement.

Figure 1 Sequence of events.



[2] In Section 6, we consider the case where the parties do not sign an ex-ante contract and instead simply rely on ex-post negotiation for trade (also referred to as the spot contract).

3.1 Market potential and co-development efforts

The market potential depends on the efforts of the buyer and seller, which are exerted simultaneously. Let e_B and e_S denote the effort of the buyer and the seller, respectively. These efforts are nonverifiable, and therefore, non-contractible. The cost of effort x for either party is given by $C(x) = cx^2$, where $c > 0$. Accordingly, we assume that the effort cost is the same for both parties, which implies that in our model, any differences in their decisions is driven solely by their position in the value chain.[3] In a co-development initiative, certain tasks may be more expensive for one party to undertake compared to the other. Therefore, both parties exerting efforts can lead to lower costs than if the same effort had to be exerted only by one of the parties (see Bhaskaran and Krishnan 2009 and references therein). Such economies of scale in development are captured by the convex increasing property of the cost function.[4]

The co-development efforts stochastically influence the market potential M for the product as follows:

$$M \doteq \begin{cases} H \text{ with probability } p(e_B, e_S), \\ L \text{ with probability } 1 - p(e_B, e_S), \end{cases}$$

where $H > L > 0$. We assume a linear inverse demand function, i.e., the per-unit selling price is given by $M - Q$, when Q products are put on the market (see Padmanabhan and Png 1997, Plambeck and Taylor 2005, 2007b for a similar model). Note that since the parties' efforts influence the probability of achieving high market potential, a low market potential may be realized even after exerting high efforts. As such, if one party could observe the effort of the other, a low market potential outcome ($M = L$) could never constitute sufficient evidence for the court to impose a penalty (i.e., the effort would remain non-verifiable). We assume that $p(e_B, e_S) \doteq e_B + e_S$ in order to model how the parties' efforts influence the probability of market realization (see Xiao and Xu 2012 for a similar specification).[5] Note that our model represents a setting where both parties' efforts generate a direct benefit only for the buyer, i.e., the seller's effort is a pure co-operative investment, whereas the buyer's effort is a selfish investment (cf., Che and Hausch 1999).

[3] We consider an extension in §OA in the Online Supplement, where the cost of effort is different for the parties and show that most of our key results and insights continue to hold. Moreover, this extension offers some additional insights about when to opt for development instead of co-development. For example, we find that a party may choose to simply rely on development when the buyer has a significant effort cost advantage over the seller.

[4] In settings where such economies of scale do not exist, parties will find it less attractive to pursue co-development initiatives.

[5] We can consider a more general specification of the form $p(e_B, e_S) = \gamma(e_B + e_S) + (1-\gamma)e_B e_S$ with $\gamma \in (0, 1]$, where $\gamma = 1$ represents the specification used in our main analysis. It yields similar structural and qualitative insights as our main analysis. See §OB in the Online Supplement for more details.

3.2 Contracting

The market potential is observable by both parties but not verifiable. In our co-development setting, the market potential is typically closely linked to the technical milestones achieved by the joint efforts of the parties. For example, both parties are aware that if a certain performance threshold is achieved, a higher price can be commanded in the market. This implies that the realization of M is observable by both parties. However, for such innovative co-development projects, it is difficult to write formal contracts that are contingent on the market realization (Loch et al. 2006, Susarla 2012). As such, the market potential is not verifiable by a third party, and future payments cannot be made contingent on it. However, payments can be made contingent on the production quantity, Q, which is verifiable.

Specifically, we consider a setting where one party (the buyer or the seller) offers a take-it-or-leave-it menu of contracts to the other party, who has to choose whether to accept or reject it. The party making the offer is usually the one that it is ex-ante more powerful. However, the total surplus created may depend on which party makes these offers. Accordingly, the party that initially holds the right to make take-it-or-leave-it offers may prefer to delegate this right to the other party (as will be shown later in the paper). Accordingly, a governance structure ij with $i,j \in \{B,S\}$ specifies the allocation of two different rights:

- Party i holds the ex-ante right to set the contract terms and offer a menu of non-contingent contracts to the other party. Specifically, each of these contracts specifies a transfer payment t from the buyer to the seller for delivering a quantity Q.[6] Recall that the realized demand state can be high or low in our model. Therefore, without loss of generality, by the revelation principle, we can consider a menu of such schemes denoted by (t_L, Q_L) and (t_H, Q_H) for the low- and the high-quantity contracts, respectively.[7] Accordingly, let the terms of the menu of contracts be denoted by $\gamma \doteq \{t_L, Q_L, t_H, Q_H\}$.
- Party j holds the *ex-post decision right*, which entitles him/her to choose a particular contract from the menu after the demand state is realized. Let the contract chosen by party j be denoted by M_j where $M_j \in \{L, H\}$.

3.3 Production and Renegotiation

After the market potential M is realized and observed by both parties, party j who holds the ex-post decision right chooses a contract M_j, which determines the default allocation (t_{M_j}, Q_{M_j}). The parties' payoffs from the default allocation are given by $\pi_B^\gamma(M_j|M) \doteq (M - Q_{M_j})Q_{M_j} - t_{M_j}$

[6] We also consider an extension in §7.2 where the parties sign a revenue-sharing contract.

[7] Note that given the one-to-one mapping between the quantity and per-unit selling price in our model, choosing the quantity Q is equivalent to deciding the per-unit selling price for the product, which is given by $M - Q$.

and $\pi_S^\gamma(M_j|M) \doteq t_{M_j} - kQ_{M_j}$, where $0 < k < L$ denotes the unit production cost faced by the seller to manufacture and deliver the product to the buyer.[8] Instead of trading an inefficient quantity, the parties can renegotiate to the efficient quantity. In line with prior work on renegotiation (Edlin and Reichelstein 1996), we adopt the Generalized Nash Bargaining model for the renegotiation outcome where the bargaining power of the buyer is denoted by α, and the bargaining power of the seller by $1-\alpha$. Note that even though ex-ante one of the parties makes take-it-or-leave-it offers, the relationship-specific investments of the two parties, give rise to ex-post bargaining (i.e., the *Fundamental Transformation*, see Williamson 1979).

Accordingly, the parties' payoffs after renegotiation can be written as

$$\Pi_B^\gamma(M_j|M) \doteq \pi_B^\gamma(M_j|M) + \alpha\big(\pi_e(Q_e(M)|M) - \pi_e(Q_{M_j}|M)\big)$$
$$\Pi_S^\gamma(M_j|M) \doteq \pi_S^\gamma(M_j|M) + (1-\alpha)\big(\pi_e(Q_e(M)|M) - \pi_e(Q_{M_j}|M)\big),$$

where $\pi_e(Q|M) \doteq (M - Q - k)M$ is the total surplus given a quantity decision Q and realized demand state M, and $Q_e(M) = \arg\max_{0\le Q\le M} \pi_e(Q|M)$ is the efficient quantity that maximizes the total surplus.

3.4 Problem formulation

Under a governance structure ij with $i,j \in \{B,S\}$, that allocates the ex-ante right to party i and the ex-post decision right to party j, party i's problem of setting the terms for the menu of contracts can be considered as choosing a direct mechanism $\gamma = \{t_L, Q_L, t_H, Q_H\}$. Party i may be able to choose an incentive-feasible mechanism, i.e., one that induces party j to choose the (t_L, Q_L) contract when the demand state is low and the (t_H, Q_H) contract when the demand state is high. Accordingly, a mechanism γ is incentive feasible $(M_j = M)$ only if $\Pi_j^\gamma(M|M) \ge \Pi_j^\gamma(M'|M)$ holds for $M, M' \in \{L, H\}$. Let the set of incentive-feasible mechanisms when party j has the ex-post decision right be denoted by $\Gamma_F(j)$. Note that the incentive-feasibility conditions are only required when the same party does not hold both the rights $(i \ne j)$. Without loss of generality, we assume that the reservation utility of both parties is normalized to zero.

Under a given incentive-feasible mechanism γ and governance structure ij, the parties' problems to choose their efforts are given by

$$\max_{e_B\ge 0} U_B^\gamma(e_B, e_S) \doteq p(e_B, e_S)\Pi_B^\gamma(H|H) + (1 - p(e_B, e_S))\Pi_B^\gamma(L|L) - C(e_B)$$
$$\max_{e_S\ge 0} U_S^\gamma(e_B, e_S) \doteq p(e_B, e_S)\Pi_S^\gamma(H|H) + (1 - p(e_B, e_S))\Pi_S^\gamma(L|L) - C(e_S).$$

[8] This assumption implies that is efficient to offer the product even when $M = L$. In §7.1, we consider an extension with $L < k < H$, where it is efficient to offer the product only when $M = H$. When $M = L$, it is efficient to instead terminate the initiative and not offer the product.

Let $e_B^\gamma \doteq \arg\max_{e_B \geq 0} U_B^\gamma(e_B, e_S)$ and $e_S^\gamma \doteq \arg\max_{e_S \geq 0} U_S^\gamma(e_B, e_S)$ denote the optimal effort levels. Accordingly, party i's problem to choose an incentive-feasible mechanism γ under a given governance structure ij can be written as

$$\max_{\gamma \in \Gamma_F(j)} U_i^\gamma(e_B^\gamma, e_S^\gamma) = p(e_B^\gamma, e_S^\gamma)\Pi_i^\gamma(H|H) + (1 - p(e_B^\gamma, e_S^\gamma))\Pi_i^\gamma(L|L) - C(e_i),$$

subject to incentive-compatibility constraints given by $e_B^\gamma = \arg\max_{e_B \geq 0} U_B^\gamma(e_B, e_S)$ and $e_S^\gamma = \arg\max_{e_S \geq 0} U_S^\gamma(e_B, e_S)$, and an ex-ante participation constraint[9] given by

$$U_{-i}^\gamma(e_B^\gamma, e_S^\gamma) = p(e_B^\gamma, e_B^\gamma)\Pi_{-i}^\gamma(H|H) + (1 - p(e_B^\gamma, e_B^\gamma))\Pi_{-i}^\gamma(L|L) - C(e_{-i}) \geq 0.$$

Note that this formulation implies that party i offers a contract that maximizes her expected utility subject to party j meeting his reservation utility. Let $\gamma_{ij} \doteq \{t_L^{ij}, Q_L^{ij}, t_H^{ij}, Q_H^{ij}\}$ denote the optimal mechanism chosen by party i under a given governance structure ij, and let the resulting equilibrium effort levels be denoted by e_B^{ij} and e_S^{ij}.

4. Analysis

In this section, we compare the efficacy of different governance structures by determining the equilibrium effort levels under each one of them. In each case, we solve the model using backward induction to obtain the subgame perfect equilibrium. We begin by solving for the first-best case where the efforts are chosen to maximize the total surplus. Then, we examine each of the four governance structures described earlier. For brevity and expositional clarity, we relegate the proofs and the expressions for equilibrium decisions to the Appendix.

4.1 First-best Case.

Under the first-best case, for a given realization of demand potential M, the efficient quantity $Q_e(M)$ is chosen to maximize the total surplus $\pi_e(Q|M)$. It can be shown that $Q_e(M) = \frac{M-k}{2}$ (see Appendix §A1 for details). The problem to determine co-development efforts is then given by

$$\max_{e_B, e_S \geq 0} U^F(e_B, e_S) \doteq p(e_B, e_S)\pi_e(Q_e(H)|H) + (1 - p(e_B, e_s))\pi_e(Q_e(L)|L) - C(e_B) - C(e_S),$$

where $U^F(e_B, e_S)$ is jointly concave in e_B and e_S (see Appendix §A1). Let e_B^F and e_S^F denote the equilibrium first-best effort levels and let $U^F \doteq U^F(e_B^F, e_S^F)$. Note that $p(e_B^F, e_S^F) < 1$ holds if and only if $c > \frac{(H-L)(H-2k+L)}{4}$. Therefore, for the rest of the analysis, we assume that this condition holds, which will also ensure that $p(e_B, e_S)$ is less than 1 under any governance structure.

[9] The inclusion of an ex-ante participation constraint implicitly assumes that the parties cannot unilaterally renege from the contract ex post (Chen et al. 2016), which is reasonable in our context. Our model can be adapted for the situation where the parties can renege by including interim participation constraints. We find that such a modification only influences the cases where one party does not hold both the rights (BS and SB). For these cases, while the transfer payments are different, the equilibrium efforts and total surplus remain unchanged. Therefore, all our key results continue to hold (for brevity, details available on request).

4.2 Buyer has the ex-post decision right ($j = B$).

We begin by considering governance structures where the buyer holds the ex-post decision right. The next result shows that without loss of generality, we can restrict our attention to renegotiation-proof mechanisms.

LEMMA 1. *When the ex-post decision right is held by the buyer ($j = B$), given any incentive-feasible mechanism γ, there exists a payoff-equivalent renegotiation-proof mechanism $\gamma^{'} = \{t^{'}_L, Q_e(L), t^{'}_H, Q_e(H)\}$ that is also incentive feasible.*

Accordingly, when $j = B$, we can focus on renegotiation-proof mechanisms, where $Q_H^{iB} = Q_e(H)$ and $Q_L^{iB} = Q_e(L)$. The party holding the ex-ante right sets the incentive-feasible mechanism $\gamma \in \Gamma_F(B)$ anticipating its effect on the efforts, e_B and e_S. We proceed by considering the governance structure where the buyer holds both rights ($i = B$). Under this structure, the buyer proposes a menu of contracts to the seller before they exert co-development efforts, and also holds the right to choose from the contracts ex post.

PROPOSITION 1. *When the buyer holds both rights, the buyer exerts effort equal to the first-best level ($e_B^{BB} = e_B^F$), while the seller does not exert any effort ($e_S^{BB} = 0$), with $t_H^{BB} = kQ_e(H)$ and $t_L^{BB} = kQ_e(L)$.*

When the buyer has both rights, she sets the contract terms anticipating their effect on the seller's incentive to exert effort. The higher the payment t_H is, the more incentivized the seller would be to exert effort. At the same time, however, a high payment t_H lowers the value that the buyer can appropriate from the high demand realization. According to Proposition 1, when the buyer holds both rights, the latter effect dominates the former, and that is why, the buyer sets the payments (t_L^{BB}, t_H^{BB}) so low that the seller is indifferent between the high and low demand state. Put differently, the buyer only reimburses the seller for his production cost ($U_S^{BB} = 0$), irrespective of the demand realization, and as such, the seller exerts no effort in the project.

The above result is in line with Kim and Netessine (2013) who show that price commitments (simple contracts) lead to zero effort from at least one of the parties, and Che and Hausch (1999) who show that for pure co-operative investments, simple contracts fail to induce efforts by the party not benefiting directly from the investment.

We next consider the governance structure, where the ex-ante right is delegated to the seller ($i = S$). Under this structure, the seller sets the contract terms, but the buyer holds the right to choose from them ex post. Proposition 2 compares the equilibrium effort levels with the case where both rights are held by the buyer.

Proposition 2. *When only the ex-ante right is delegated to the seller, the seller exerts more effort than when the buyer has both rights ($e_S^{SB} > e_S^{BB}$), while the buyer exerts less effort ($0 < e_B^{SB} < e_B^{BB}$). Moreover, $t_H^{SB} > kQ_e(H)$ and $t_L^{SB} > kQ_e(L)$.*

Recall from Proposition 1, that when the buyer holds both rights, the seller does not exert any effort. When the seller holds the ex-ante right, he maximizes his payoff by increasing the payments t_H and t_L. However, these are constrained by the incentive-feasibility conditions for the buyer, who holds the ex-post decision right.

The seller sets the payment t_H such that the incentive-feasibility constraint for the high-demand state is binding and the payment t_L such that the buyer's ex-ante participation constraint is binding. In other words, the buyer enjoys a positive payoff under the high-demand state, but merely breaks even under the low-demand state. Accordingly, the buyer has an incentive to exert effort to reach the high-demand state. However, note that the buyer now has to pay higher transfer payments to procure the product, and therefore benefits less from a high-demand state than when she holds both rights. That is why, the buyer exerts lower effort compared to the case described in Proposition 1. As the seller appropriates the remaining value from a high-demand realization, he now has an incentive to exert effort. Therefore, both parties exert efforts under this governance structure.

4.3 Seller has the ex-post decision right ($j = S$).

We next consider governance structures where the seller holds the ex-post decision right. We first analyze whether an incentive-feasible renegotiation-proof mechanism can be designed.

Lemma 2. *When the ex-post decision right is held by the seller ($j = S$), regardless who holds the ex-ante right, a renegotiation-proof contract cannot be incentive feasible.*

When the seller has the ex-post decision right, the incentive feasibility conditions are given by $\Pi_S^\gamma(H|H) \geq \Pi_S^\gamma(L|H)$ and $\Pi_S^\gamma(L|L) \geq \Pi_S^\gamma(H|L)$, which simplify to $t_H - kQ_e(H) \geq t_L - kQ_e(L)$ and $t_H - kQ_e(H) \leq t_L - kQ_e(L)$. It can be readily seen that there are no t_H and t_L values for which the seller would strictly prefer the $(t_H, Q_e(H))$ contract when $M = H$, and the $(t_L, Q_e(L))$ contract when $M = L$. Intuitively, the seller's payoff does not depend on the realization of demand potential M, and therefore, it is not possible to design a contract that induces an efficient decision under each realization of state M (cf., Tirole 1999, p. 755). This result illustrates that the position in the value chain of the party who holds the ex-post decision right crucially influences whether a renegotiation-proof contract is incentive feasible, or alternatively, whether the parties' payoffs are the outcome of renegotiation.

Given that the mechanism cannot be renegotiation proof, the seller will choose the contract that offers a higher payoff. As the seller's payoff does not depend on the state, he will choose the same contract under both high and low demand realizations. In particular, there are two possibilities based on whether the seller prefers the high- or low-quantity contract[10]:

1. If $\Pi_S^\gamma(L|L) > \Pi_S^\gamma(H|H)$, then the seller always chooses the $(t_L, Q_e(L))$ contract and renegotiation takes place when $M = H$.

2. If $\Pi_S^\gamma(L|L) < \Pi_S^\gamma(H|H)$, then the seller always chooses the $(t_H, Q_e(H))$ contract and renegotiation takes place when $M = L$.

The next lemma investigates which of the above possibilities occurs in equilibrium.

LEMMA 3. *When the ex-post decision right is held by the seller, regardless who holds the ex-ante right, in equilibrium, the contract terms are set such that the seller always chooses the contract which is efficient in the low state. Therefore, renegotiation takes place only when $M = H$.*

Renegotiation allows a party to appropriate additional value, proportional to her/his bargaining power, once the market potential is realized. Given that a renegotiation-proof contract is not feasible (see Lemma 2), the party who sets the contract terms prefers to have the renegotiation taking place under the high-demand rather than the low-demand realization. By doing so, s/he can use renegotiation as an additional lever to induce her/his partner to exert effort towards the high-demand state. Conversely, if renegotiation occurred at the low-demand state, it would disincentivize the collaborating party to invest towards the high-demand state.

We can now analyze the equilibrium efforts under the governance structures where the seller holds the ex-post decision right.

PROPOSITION 3. *When the seller holds the ex-post decision right, the equilibrium efforts are the same regardless of who holds the ex-ante right, i.e., $e_B^{BS} = e_B^{SS} > 0$ and $e_S^{BS} = e_S^{SS} > 0$.*

The above result shows that when the seller holds the ex-post right, the allocation of the ex-ante right does not affect the equilibrium effort levels. This counter-intuitive result is driven by the fact that the parties' incentive to exert effort does not depend on the contract terms when the seller holds the ex-post decision right. The reason for this is as follows: The seller never chooses the $(t_H, Q_e(H))$ contract (see Lemma 3), so its terms are irrelevant for the parties' incentive to exert effort. Moreover, the $(t_L, Q_e(L))$ contract is always chosen by the seller. In the case of low-demand realization, the contract is executed without renegotiation, while in the case of high-demand realization it forms the disagreement outcomes for the renegotiation. In either case, the *status-quo* payoffs are the same, and therefore, the parties' incentive to exert effort does not depend on the contract terms. Instead, the additional value that each party can appropriate from the high-demand realization is entirely determined by its respective bargaining power during the renegotiation stage.

[10] There can be a third possibility, where $\Pi_S^\gamma(H|H) = \Pi_S^\gamma(L|L)$ and renegotiation takes place in both states. However, it can be shown that it is always dominated (for brevity, details available on request).

Corollary 1. *When the buyer holds both rights, the seller exerts no effort* ($e_S^{BB} = 0$)*. When the seller holds both rights, the buyer exerts a strictly positive effort* ($e_B^{SS} > 0$)*.*

The above result notes a sharp contrast between the governance structures where the same party holds both rights. Yet, when the buyer holds both rights, the seller exerts no effort towards the project, while the buyer exerts a strictly positive effort even if the seller holds both rights. The reason behind this result is as follows: When the buyer holds both rights, she offers a renegotiation-proof contract, which is structured such that the seller is indifferent between the high and the low demand states. In contrast, when the seller holds both rights, the buyer is able to renegotiate under the high demand state, and extract additional value. That is why, the buyer remains incentivized to exert effort, even though the seller maintains both rights. This result highlights that the position in the value chain of the party who holds both rights, plays a key role in determining the co-development efforts.

Corollary 2. *The seller exerts lower effort when he has both rights than when he only has the ex-ante right, i.e.,* $e_S^{SS} < e_S^{SB}$*.*

Conventional wisdom suggests that delegating additional rights can be an effective mechanism to incentivize a party to exert effort. Accordingly, one may expect that when the seller holds both rights as opposed to only one of the rights, he would exert higher effort towards the project. However, the above result shows that this is not true. The seller exerts lower effort when he has both rights, than the case where he only holds the ex-ante right. Therefore, if the seller already holds the ex-ante right, allocating the ex-post decision right to him will lower his effort.

To see why this happens, recall that when the seller holds only the ex-ante right, he can offer a renegotiation-proof contract that allows him to appropriate the entire value of the joint initiative, while still incentivizing the buyer to exert effort. Transferring the ex-post decision right to the seller implies that a renegotiation-proof contract is no longer feasible. Instead, the bargaining power of each party determines the value they will appropriate from the total renegotiation surplus, and therefore, their incentives to exert effort (see Proposition 3). In fact, if the seller could extract the entire renegotiation surplus, then his incentive to exert effort in both cases will be the same, i.e., $e_S^{SS} = e_S^{SB}$ at $\alpha = 0$. However, as the bargaining power of the buyer increases, the seller extracts less value from the renegotiation surplus, and thus exerts lower effort.

4.4 Buyer's and Seller's Payoffs

Given the equilibrium efforts derived in the previous sections, we now examine the buyer's and the seller's payoff under the different governance structures. Subsequently, in Section 5, we build on this discussion to compare the total surplus under different governance structures.

PROPOSITION 4. *The buyer's payoff is maximized when she retains the ex-ante right but delegates the ex-post decision right to the seller (BS case).*

One would expect that the buyer would prefer more control over the project, that is, to retain both rights. Yet, according to Proposition 4 the buyer is better off with less control over the project, and can increase her payoff by delegating the ex-post decision right to the seller. Recall that in the case where the buyer retains both rights (BB case), the seller does not exert any effort. By delegating the ex-post decision right to the seller (BS case), the buyer allows for renegotiation, which in turn, provides an incentive to the seller to exert effort towards the high-demand state. Those joint efforts by the buyer and the seller lead to a higher probability of achieving a high market potential. This is why the buyer's payoff is maximized when she delegates the ex-post decision right, but holds the ex-ante right.

PROPOSITION 5. *There exists a threshold $\widehat{A}_1(H,L,k) \doteq \frac{H+2k-3L}{H-L}$, such that for $\alpha < \widehat{A}_1(\cdot)$, the seller's payoff is maximized when he retains both rights (SS case). Otherwise, the seller's payoff is maximized when he retains the ex-ante right but delegates the ex-post decision right to the buyer (SB case).*

Proposition 5 illustrates the counter-intuitive finding that the seller is not always better off by retaining both rights. In fact, it is particularly when the seller has low bargaining power ($\alpha > \widehat{A}_1(\cdot)$), that he should transfer the ex-post decision right to the buyer. This can be explained as follows. When the seller retains both rights (SS case), the prospect of renegotiation under the high-demand state incentivizes both firms to exert effort. The seller, who also holds the ex-ante right, can appropriate the value of those joint efforts, by setting appropriately the contract terms. Yet, as the bargaining power of the buyer increases, and the buyer appropriates a higher share of the renegotiation surplus, the prospect of renegotiation becomes less attractive for the seller. Instead, the seller is better off delegating the ex-post right to the buyer, and only retaining the ex-ante right. By doing so, the seller can offer a renegotiation-proof contract, which restricts the value that the buyer can appropriate from the initiative, despite her high bargaining power.

5. Comparison of Governance Structures

In this section, we compare the different governance structures. In order to do so, we use the total generated surplus as the metric, in line with the extant literature (Hart et al. 1997, Che and Hausch 1999, Corbett and DeCroix 2001, Roels et al. 2010).

Moreover, given our modeling framework, the governance structure that maximizes the total surplus will also be the one most likely to emerge in practice. The reason for this is as follows: Under our setting, one party (the buyer or the seller) can make take-it-or-leave-it offers to the other party. This is usually the party which is ex-ante more powerful. Under such a framework, there can be two possibilities: First, this party's payoff is also maximized under the governance structure that maximizes the total surplus. In which case, the party will clearly choose this governance structure. Second, this party's payoff is maximized under a different governance structure than the one that maximizes the total surplus. In which case, the party will want to increase its payoff by moving to the structure that maximizes the total surplus. This can be done by designing a transfer payment between the parties such that the other party is indifferent between the two governance structures. This will enable implementing the governance structure that maximizes total surplus, allowing the party to reap the entire excess surplus from this governance structure. Please see §OF in the Online Supplement for a more detailed discussion and a proof showing that such a transfer payment can be designed in our setting. In sum, the governance structure that maximizes the total surplus will be the one adopted.

Before comparing the total surplus under the different governance structures, it is worth noting the following preliminary results: First, all of the governance structures lead to lower total surplus than the first-best case. Second, recall that when the ex-post decision right is held by the seller, the equilibrium effort levels are the same irrespective of who holds the ex-ante right (see Proposition 3), and consequently, the total surplus is also the same, i.e., $U^{BS} = U^{SS}$. Third, recall that the only governance structure where one of the parties does not exert effort towards the project is when the buyer holds both the decision rights. As such, the case where the buyer holds both the decision rights leads to lowest total surplus, and is dominated. The next result characterizes the governance structure that maximizes the total surplus.

PROPOSITION 6. *If $\alpha < \widehat{A}_1(H, L, k)$ the total surplus is maximized when the ex-post decision right is delegated to the seller and the ex-ante right is delegated to either party (BS/SS cases). Otherwise, it is maximized when the ex-post decision right is delegated to the buyer, but the ex-ante right is delegated to the seller (SB case). $\widehat{A}_1(H, L, k)$ increases in H and k, but decreases in L.*

In order to maximize the total surplus, the governance structure should always delegate right(s) to the seller. If the buyer has high bargaining power ($\alpha \geq \widehat{A}_1(\cdot)$), then the buyer should hold the ex-post decision right, but the ex-ante right should be delegated to the seller. Otherwise, the seller should hold the ex-post decision right, and either party can hold the ex-ante right. The key driver behind this result is that in a co-development setting the total surplus is maximized when both parties remain incentivized to exert effort. Recall that in our setting, the downstream firm (the buyer) is primarily affected by the demand realization, while the upstream firm (the seller), has lower exposure to it. When the buyer has high bargaining power, incentivizing the seller requires transferring the ex-ante right to the seller, while at the same time preventing renegotiation by leaving the ex-post right to the buyer. In contrast, when the seller has high bargaining power, allowing for renegotiation is sufficient to ensure that both parties remain incentivized, and in turn, that the total surplus is maximized.

The above result provides several key guidelines for how to choose a governance structure for a co-development initiative: First, delegating the ex-post decision right to the seller becomes more attractive as the co-development efforts have the potential to make a substantial difference to the demand realization (i.e., $H - L$ is larger). This can be seen from the threshold $\widehat{A}_1(\cdot)$, which is increasing in H and decreasing in L. Second, maximizing the total surplus may require a governance structure that allows for renegotiation rather than one that ensures a renegotiation-proof mechanism. Renegotiation can be enabled by transferring the ex-post decision right to the seller. Third, our results show that the governance structure that maximizes the total surplus for a co-development initiative crucially depends on the position in the value chain of the party with the higher bargaining power.

Our results also offer managerial insights for our motivating examples of the different co-development initiatives between the upstream telecommunication equipment provider (seller) and its downstream partners (buyers). Consider the case of the joint initiative between the seller and Buyer B. Given that the project's value was primarily driven by the seller's proprietary know-how and technological infrastructure, the seller had a stronger ex-post bargaining position (low α). Accordingly, the initiative was realized under a governance structure where the seller retained the ex-post decision right, but the ex-ante right was delegated to Buyer B. This is in line with our results, which suggest a BS governance structure when the seller has stronger ex-post bargaining position (low α). Compare this to the case between the seller and Buyer A. Unfortunately, the seller insisted on retaining the ex-post decision right (in a way similar to his initiative with Buyer B), a proposal that was rejected by Buyer A, and eventually, the discussions came to an end despite the promising nature of the project. A key difference in this case was that in contrast to Buyer B, Buyer A had a stronger ex-post bargaining position (high α). This was because a critical element of the value of the project was the deep insights into the end-customers' business models that Buyer A had acquired through long-standing relationships with them. Our results suggest that the seller should have delegated the ex-post decision right to Buyer A, but kept the ex-ante right for himself, i.e., utilize a SB governance structure. The above examples also highlight the need for firms to adapt the governance structure and be willing to delegate decisions rights depending on the characteristics of the co-development project, rather than attempting to implement a one-size-fits-all approach.

Another example of successful implementation of a co-development project is the Toshiba-Sandisk joint development of NAND memories. In this case, Toshiba (seller) has significant ex-post bargaining power (low α) because it is the inventor of the NAND technology (Toshiba 2016) and Sandisk (buyer) purchases its vast majority of NAND memories from Toshiba (Sandisk Corp. 2011, p. 3). Sandisk retained the ex-ante right, but transferred the ex-post decision right to Toshiba. This corresponds to a BS governance structure, which is consistent with our results. In a contrasting example, TSMC is a powerful seller that maintains strong ex-post bargaining position (low α) given the importance that its customers place on the technological superiority of its chips (Hou 2017). It is also known for commanding a strong price premium (Eassa 2017). TSMC typically retains the ex-post decision right by deciding how much capacity to allocate to each of its buyers (Clarke 2006). This corresponds to a SS governance structure, which is consistent with our results that if the seller is powerful and maintains strong ex-post bargaining position, both rights should be held by the seller.

6. Value of Contracting

Our analysis so far, has focused on different governance structures that specify a menu of non-contingent transfer payments and the allocation of rights in a co-development project. We have shown that such governance structures can play a key role in shaping the incentives of each party to exert effort towards improving the value of the project. However, in some cases, the two parties may forgo signing an ex-ante contract and instead rely completely on ex-post negotiation for dividing the value generated from the project. In practice, the two parties can sign a Memorandum of Understanding (MoU) which describes the scope and an intended course of action for the project, but without any legal commitment from either party. For example, Pirelli, Rosneft and Rostec signed an MoU for a joint research and development agreement for innovative materials for tyres manufacturing (Pirelli 2013). The benefits of forgoing any ex-ante contract have also been highlighted in the extant literature (Van Mieghem 1999, Che and Hausch 1999) which typically refers to it as a *spot* contract.

Under a spot contract, the parties just split the ex-post total profits based on their respective bargaining power. Therefore, their problem under a spot contract is to choose their efforts:

$$\max_{e_B \geq 0} U_B^{spot}(e_B, e_S) \doteq \mathbb{E}_M \alpha \pi_e(Q_e(M), M) - C(e_B)$$
$$\max_{e_S \geq 0} U_S^{spot}(e_B, e_S) \doteq \mathbb{E}_M (1-\alpha) \pi_e(Q_e(M), M) - C(e_S)$$

Let e_S^{spot} and e_B^{spot} denote the equilibrium efforts under the spot contract. The following proposition reveals an interesting result regarding the role of a spot contract on the parties' effort levels.

PROPOSITION 7. *If* $\alpha < \widehat{A}_2(H,L,k) \doteq \frac{2(L-k)}{H+L-2k}$*, then the seller (buyer) always exerts a higher (lower) effort under a spot contract, i.e.,* $e_S^{spot} > e_S^{SB} > e_S^{BS} = e_S^{SS}$ $(e_B^{spot} < e_B^{SB} < e_B^{BS} = e_B^{SS} < e_B^{BB})$.

Proposition 7 states that unless the buyer has significant bargaining power, a spot contract leads to higher effort by the seller, but a lower effort by the buyer. In other words, the spot contract may be the most effective mechanism to induce effort by the party that has lower exposure to the demand realization. By relying entirely on renegotiation, the seller becomes more dependent on the demand realization, and therefore, more incentivized to invest effort to improve it. The exact opposite takes place for the buyer whose payoff now is less dependent on the high-demand realization, particularly when her bargaining power is low.

The seminal work of Che and Hausch (1999) illustrate that for pure co-operative investments such as the one considered in our model, parties may be better off not using simple (or non-contingent) contracts and simply relying on ex-post negotiation. The next result identifies when including decision rights in non-contingent contracts improves their value as compared to a spot contract, which is also illustrated in Figure 2.

PROPOSITION 8. *A contract that retains the ex-ante right with the buyer (seller) leads to a higher payoff for the buyer (seller) compared to the spot contract. However, the spot contract maximizes the total surplus if* $\widehat{A}_3(H, L, k) < \alpha < \widehat{A}_4(H, L, k)$.

The above proposition shows that a spot contract is appropriate only when the two parties are relatively similar with respect to their bargaining power. Note that the key advantage of a spot contract is that the value that each party appropriates is proportional to the total surplus, and therefore, both parties have an incentive to maximize it. Yet, the actual value that each party appropriates is also determined by its bargaining power, and as such, incentives remain well-balanced only when the bargaining powers of the parties are also evenly balanced. Therefore, the spot contract leads to higher total surplus only for intermediate values of α. In contrast, for co-development initiatives where one of the parties is disproportionately more powerful, such as those between a large buyer working with a small seller or vice versa, non-contingent contracts with a judicious allocation of decision rights outperform spot contracts. Specifically, as discussed in Proposition 6, when the buyer has high bargaining power, the seller should hold only the ex-ante right. Otherwise, the seller should hold the ex-post decision right.

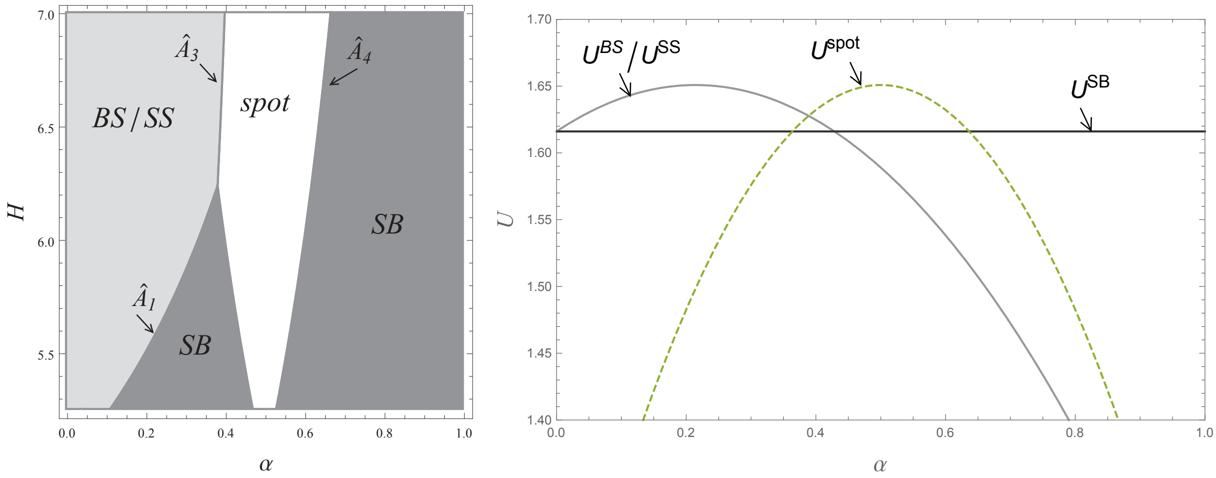
7. Extensions and Discussion of Assumptions

We now consider two extensions that capture additional considerations and relax some of the assumptions used in our main analysis.

7.1 Potential for Termination of the Initiative

We now analyze a setting with $L < k < H$, where it is efficient to only offer the product when $M = H$. When $M = L$, it is efficient to terminate the initiative and not offer the product, i.e.,

Figure 2 When does a contract lead to higher total surplus than the spot contract?



(a) (b)

Note. In both panels, $k = 2$, $L = 3$ and $c = 6.2$. In panel b, $H = 6.5$, $U^{BB} = 1.18$ and $U^F = 2.12$.

$Q_e(L) = 0$ and $t_L = 0$. For brevity, a complete characterization of the results for this extension and other details are relegated to §OC in the Online Supplement. In what follows, we focus on describing the implications for our key results.

Our results for the BB case continue to hold, i.e., the seller does not exert any effort but the buyer exerts effort equal to the first-best level (see Proposition 1). Our results for the SB case also continue to hold, except that the buyer does not exert any effort (see Proposition 2). Proposition 3, which states that the efforts are the same under the BS and SS cases continues to hold for $\alpha < \widehat{A}_5(H, L, k)$ (see §OC in the Online Supplement for details). When $\alpha \geq \widehat{A}_5(H, L, k)$, the seller does not exert any effort under the SS governance structure. Accordingly, the BS case leads to (weakly) higher total surplus than the SS case. The total surplus is maximized under the governance structure where the buyer holds the ex-ante right but the seller holds the ex-post decision right (BS case). Accordingly, this result is a special case of our analogous result in Proposition 6. The reason why the SB case does not maximize the total surplus is that under this extension, the buyer does not exert any effort under the SB case, requiring the seller to exert a higher effort on his own.

In sum, as in our results for the main analysis, when there is potential for termination of the initiative, the ex-post decision right should be delegated to the upstream party- the seller, who has lower exposure to the demand realization.

7.2 Revenue-sharing Contract

In the main paper, we assumed that the contractual structure utilized by the parties was a transfer payment t from the buyer to the seller for delivering a quantity Q. We now examine a situation where the parties instead consider a revenue-sharing contract. Under such a contractual structure, once the market potential is realized, the efficient quantity is chosen, and the parties split the resulting revenues according to a pre-determined sharing rule. Let $\eta \in [0,1]$ denote the share of the revenue given to the buyer. Under such a revenue sharing contract, the only decision that the parties have to make is the revenue share η. Either the buyer or the seller can hold the right to decide η. Let η^{Rz} denote the optimal revenue share chosen by party $z \in \{B, S\}$ when s/he holds the decision right, and let the resulting equilibrium effort levels and total surplus evaluated at $\eta = \eta^{Rz}$ be denoted by e_B^{Rz}, e_S^{Rz}, and U^{Rz}, respectively.

For brevity, the details of this analysis are relegated to §OD in the Online Supplement. In what follows, we focus on describing the main insights from this extension. We find that when the seller sets the revenue share, he extracts the entire revenues from the buyer, i.e., $\eta^{RS} = 0$. Under this setting, the buyer does not exert any effort ($e_B^{RS} = 0$ and $e_S^{RS} > 0$). However, when the buyer sets the revenue share, she has to compensate the seller for the incurred production costs, and thus always chooses to share some of the revenues with him, i.e., $0 < \eta^{RB} < 1$. Under this setting, both parties exert effort ($e_B^{RB}, e_S^{RB} > 0$). We can also show that the total surplus is strictly higher when the revenue share is set by the buyer (as compared to when it is set by the seller).

Note that it is analytically intractable to compare the total surplus under the revenue-sharing contract with that under the contractual structures studied in our main analysis. However, we can numerically verify that as long as $H - L$ is not small, the total surplus under the revenue-sharing contract is strictly lower, i.e., $U^{RB} < \max\{U^{BS}, U^{SB}\}$ (see §OD in the Online Supplement for details). That is, under this setting, a revenue-sharing contract is dominated by the quantity and transfer payment contract considered in our main analysis, and thus, our results throughout the paper continue to hold for this setting. If instead $H - L$ is small, then the parties prefer using a revenue-sharing contract, where the buyer should set the revenue share. These results imply that in the more interesting case for our co-development context, where the parties are developing a new technology (i.e., $H - L$ is large), a revenue-sharing contract is not attractive for the parties.

8. Conclusions

Motivated by our interactions with a telecommunication equipment provider (seller) that initiated co-development initiatives with different IT services companies (buyers), we developed a model that captures two key elements of the contractual process. First, for such innovative projects, contingency-based contracts are hard to write, and as such, firms rely on non-contingent commitments. Second, instead of specifying decisions, contracts often specify the party responsible for making that decision. Such contractual clauses that specify the allocation of decision rights have been observed across a number of industries (Lerner and Merges 1998, Ryall and Sampson 2009, Susarla 2012), yet we lack a theoretical framework that studies the design of different governance structures and their effectiveness for co-development projects.

Our results help explain the choice of governance structures for successful implementation of co-development initiatives in practice. They also provide three principles to design the governance structure of such co-development initiatives. First, we show that there might be a non-monotonic relationship between control and incentives to exert effort. Specifically, we show that a seller who can both propose contracts and also choose between them ex post, will exert less effort, than when he only has the right to propose contracts. Second, we show that maximizing the value of the initiative might require allocating both decision rights to the party with the higher bargaining power. While this might seem counter to an equitable collaboration, it will lead the parties to exert higher efforts. Lastly, we show that renegotiation, which is typically considered an impediment to investment efforts, can actually be used to incentivize efforts and improve efficiency, if decision rights are also appropriately allocated.

Finally, prior empirical literature has studied the allocation of decision rights in IT outsourcing contracts, where only one party (i.e., the vendor) exerts efforts (Susarla 2012). However, there is a need for empirical research for co-development initiatives where the efforts of both parties can be crucial. Our results could be utilized to formulate hypotheses about how decision rights are allocated in co-development initiatives and tested using datasets similar to the ones discussed in Susarla (2012) and references therein. Specifically, our analysis yields the following hypotheses: i) Projects for which the buyer has high bargaining power, should be associated with governance structures in which the buyer maintains the ex-post control/decision rights, and rather favorable payment terms for the seller; ii) Projects for which the seller has high bargaining power, should be associated with governance structures in which the seller maintains the ex-post control/decision rights; iii) The seller is more likely to maintain the ex-post control/decision right for projects where the development efforts have the potential to make a substantial difference in the demand outcome.

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Appendix

A1. Proofs.

For all the proofs, let i and j denote the party that has the ex-ante and ex-post right, respectively, where $i, j \in \{B, S\}$.

We first provide the analysis for the first-best case. In the production stage, the problem is to choose the quantity Q to maximize the total surplus $\pi_e(Q|M) = (M - k - Q)Q$, which is strictly concave in Q. Solving the first-order condition, the efficient quantity is given by $Q_e(M) = \frac{M-k}{2}$. The problem to determine the co-development efforts is given by $\max_{e_B, e_S} U^F(e_B, e_S) =$

$p(b,s)\pi_e(Q_e(H)|H)+(1-p(b,s))\pi_e(Q_e(L)|L)-C(e_B)-C(e_S)$, where the Hessian of $U^F(e_B,e_S)$ is negative definite. Therefore, $U^F(e_B,e_S)$ is jointly concave in e_B and e_S. Solving the first-order condition, we get $e_B^F=e_S^F=\frac{(H-L)(H+L-2k)}{8c}$. Let $U^F\doteq U^F(e_B^F,e_S^F)=\frac{\left(H(H-2k)-L(L-2k)\right)^2+8c(L-k)^2}{32c}$. Note that $p(e_B^F,e_S^F)=\frac{(H-L)(H+L-2k)}{4c}<1$ if and only if $c>\frac{(H-L)(H+L-2k)}{4}$.

Proof of Lemma 1. Let $j=B$. Consider a given incentive feasible mechanism $\gamma\doteq\{t_L,Q_L,t_H,Q_H\}$. We need to show that there always exists a payoff-equivalent renegotiation-proof mechanism $\gamma'\doteq\{t_L',Q_e(L),t_H',Q_e(H)\}$ that is also incentive feasible.

In order for the renegotiation-proof mechanism γ' to be payoff-equivalent to the given mechanism γ, let $(L-Q_e(L))Q_e(L)-t_L'=\Pi_B^\gamma(L|L)$ and $(H-Q_e(H))Q_e(H)-t_H'=\Pi_B^\gamma(H|H)$. This simplifies to $t_L'=t_L+(1-\alpha)\big((L-Q_e(L))Q_e(L)-(L-Q_L)Q_L\big)+\alpha k\big(Q_e(L)-Q_L\big)$ and $t_H'=t_H+(1-\alpha)\big((H-Q_e(H))Q_e(H)-(H-Q_H)Q_H\big)+\alpha k\big(Q_e(H)-Q_H\big)$. Accordingly, we have that

$$\begin{aligned}t_H'-t_L'=t_H-t_L&+(1-\alpha)\big((H-Q_e(H))Q_e(H)-(L-Q_e(L))Q_e(L)\big)+\alpha k\big(Q_e(H)-Q_e(L)\big)\\&-(1-\alpha)\big((H-Q_H)Q_H-(L-Q_L)Q_L\big)-\alpha k\big(Q_H-Q_L\big).\end{aligned}\quad(1)$$

Given that the mechanism γ is incentive feasible, we have that $\Pi_B^\gamma(H|H)\geq\Pi_B^\gamma(L|H)$ and $\Pi_B^\gamma(L|L)\geq\Pi_B^\gamma(H|L)$, which simplify to $t_H-t_L\leq(1-\alpha)\big((H-Q_H)Q_H-(H-Q_L)Q_L\big)+\alpha k\big(Q_H-Q_L\big)$ and $t_H-t_L\geq(1-\alpha)\big((L-Q_H)Q_H-(L-Q_L)Q_L\big)+\alpha k(Q_H-Q_L)$. These equations together with equation 1 imply that

$$\begin{aligned}t_H'-t_L'&\leq(1-\alpha)\big((H-Q_e(H))Q_e(H)-(H-Q_e(L))Q_e(L)\big)+\alpha k\big(Q_e(H)-Q_e(L)\big)\\&\leq(H-Q_e(H))Q_e(H)-(H-Q_e(L))Q_e(L).\\t_H'-t_L'&\geq(1-\alpha)\big((L-Q_e(H))Q_e(H)-(L-Q_e(L))Q_e(L)\big)+\alpha k\big(Q_e(H)-Q_e(L)\big)\\&\geq(L-Q_e(H))Q_e(H)-(L-Q_e(L))Q_e(L).\end{aligned}$$

The above conditions can be rewritten as $(H-Q_e(H))Q_e(H)-t_H'\geq(H-Q_e(L))Q_e(L)-t_L'$ and $(L-Q_e(L))Q_e(L)-t_L'\geq(L-Q_e(H))Q_e(H)-t_H'$, which implies that the renegotiation-proof mechanism γ' is incentive feasible. □

Proof of Propositions 1-2. We first focus on the cases where the buyer has the ex-post decision right ($j=B$). From Lemma 1, we can restrict our attention to renegotiation-proof mechanisms, which we denote by $\gamma\doteq\{t_L,Q_e(L),t_H,Q_e(H)\}$. The conditions for this mechanism to be incentive feasible, we need $(H-Q_e(H))Q_e(H)-t_H\geq(H-Q_e(L))Q_e(L)-t_L$ and $(L-Q_e(L))Q_e(L)-t_L\geq(L-Q_e(H))Q_e(H)-t_H$ to hold, which simplify to $x_{1B}(t_L)\leq t_H\leq x_{2B}(t_L)$, where $x_{1B}(t_L)\doteq t_L-\frac{(H-L)(H-2k-L)}{4}$ and $x_{2B}(t_L)\doteq t_L+\frac{(H-L)(H+2k-L)}{4}$, where $x_{1B}(t_L)<x_{2B}(t_L)$.

We next analyze the problem to determine the equilibrium effort levels in the co-development stage. $U_B^\gamma(e_B,e_S)$ is strictly concave in e_B and $U_S^\gamma(e_B,e_S)$ is strictly concave in e_S. Solving the first-order conditions simultaneously, we get $e_B(t_H,t_L) = \frac{H^2-L^2-4(t_H-t_L)}{8c}$ and $e_S(t_H,t_L) = \frac{2(t_H-t_L)-k(H-L)}{4c}$. Under the assumption $x_{1B}(t_L) \le t_H \le x_{2B}(t_L)$, the equilibrium efforts for these cases are given as follows:

$$\left(e_B^\gamma(t_H,t_L), e_S^\gamma(t_H,t_L)\right) \doteq \begin{cases} \left(\frac{H^2-L^2-4(t_H-t_L)}{8c}, 0\right) & \text{if } t_H \le y_B(t_L) \doteq t_L + \frac{k(H-L)}{2}, \\ \left(\frac{H^2-L^2-4(t_H-t_L)}{8c}, \frac{2(t_H-t_L)-k(H-L)}{4c}\right) & \text{if } y_B(t_L) < t_H, \end{cases} \tag{2}$$

where $x_{1B}(t_L) < y_{1B}(t_L) < x_{2B}(t_L)$.

Consider the case where the buyer has the ex-ante right ($i=B$), i.e., the buyer sets the contract terms. The buyer's problem under this case is given by $\max_{t_H,t_L} U_B^\gamma(e_B^\gamma, e_S^\gamma)$ such that $x_{1B}(t_L) \le t_H \le x_{2B}(t_L)$ and $U_S^\gamma(e_B^\gamma, e_S^\gamma) \ge 0$. We first analyze the case where $t_H \le y_B(t_L)$, which implies that $e_S^\gamma(t_H,t_L) = 0$. As $U_B^\gamma(e_B^\gamma, e_S^\gamma)$ is strictly decreasing in t_H and $U_S^\gamma(e_B^\gamma, e_S^\gamma)$ is strictly increasing in t_H, the buyer will prefer to set $U_S^\gamma(e_B^\gamma, e_S^\gamma)$ to 0, which happens at $t_H = t_1(t_L)$ (expression not provided for brevity). The required condition for this case $x_{1B}(t_L) < t_H \le y_B(t_L)$ evaluated at $t_H(t_L) = t_1(t_L)$ is given by $\frac{k(L-k)}{2} < t_L < t_2$. As $U_B^\gamma(e_B^\gamma, e_S^\gamma)$ evaluated at $t_H = t_1(t_L)$ is strictly decreasing in t_L, we have that the local maximizer for this case is $t_L = t_L^a \doteq \frac{k(L-k)}{2}$ and $t_H = t_H^a \doteq t_1\left(\frac{k(L-k)}{2}\right) = \frac{k(H-k)}{2}$. We next analyze the case where $t_H > y_B(t_L)$, which implies that $e_S^\gamma(t_H,t_L) > 0$. As $U_B^\gamma(e_B^\gamma, e_S^\gamma)$ is strictly decreasing in t_H and $U_S^\gamma(e_B^\gamma, e_S^\gamma)$ is strictly increasing in t_H, the buyer will prefer to set $U_S^\gamma(e_B^\gamma, e_S^\gamma)$ to 0, which happens at $t_H = t_3(t_L)$ (expression not provided for brevity). The required condition for this case $y_B(t_L) < t_H < x_{2B}(t_L)$ evaluated at $t_H(t_L) = t_3(t_L)$ is given by $t_4 < t_L < \frac{k(L-k)}{2}$. $U_B^\gamma(e_B^\gamma, e_S^\gamma)$ evaluated at $t_H(t_L) = t_3(t_L)$ is concave in t_L and maximized at $t_L = t_5$, where $t_4 < t_5 < \frac{k(L-k)}{2}$. Therefore, the local maximizer for this case is $t_L = t_L^b \doteq t_5$ and $t_H = t_H^b \doteq t_3(t_5)$ (expressions not provided for brevity). Comparing $U_B^\gamma(e_B^\gamma, e_S^\gamma)$ evaluated at (t_H^a, t_L^a) and at (t_H^b, t_L^b), we find that the difference between them is given by $\frac{3(H-L)^2(H-2k+L)^2}{128c} > 0$, which is always positive. Therefore, the global maximizer is given by $t_H^{BB} = \frac{k(H-k)}{2}$ and $t_L^{BB} = \frac{k(L-k)}{2}$.

Substituting these values, we get $U_B^{BB} \doteq U_B^{\gamma BB}(e_B^{BB}, e_S^{BB}) = \frac{16c(L-k)^2+(H-L)^2(H-2k+L)^2}{64c}$, $U_S^{BB} \doteq U_S^{\gamma BB}(e_B^{BB}, e_S^{BB}) = 0$, $e_B^{BB} = e_B^F = \frac{(H-L)(H-2k+L)}{8c} > 0$, and $e_S^{BB} = 0$. Moreover, we have that $\Pi_B^{\gamma BB}(H|H) = \frac{(H-k)^2}{4} > 0$, $\Pi_B^{\gamma BB}(L|L) = \frac{(L-k)^2}{4} > 0$, $\Pi_B^{\gamma BB}(H|H) - \Pi_B^{\gamma BB}(L|H), \Pi_B^{\gamma BB}(L|L) - \Pi_B^{\gamma BB}(H|L) = \frac{(H-L)^2}{4} > 0$, $t_H^{BB} = kQ_e(H)$, and $t_L^{BB} = kQ_e(L)$. This proves Proposition 1.

Consider the case where the seller has the ex-ante right ($i = S$). The seller's problem is given by $\max_{t_H,t_L} U_S^\gamma(e_B^\gamma, e_S^\gamma)$ such that $x_{1B}(t_L) \le t_H \le x_{2B}(t_L)$, and $U_B^\gamma(e_B^\gamma, e_S^\gamma) \ge 0$. As $U_S^\gamma(e_B^\gamma, e_S^\gamma)$ is strictly increasing in t_H, $U_B^\gamma(e_B^\gamma, e_S^\gamma)$ is strictly decreasing in t_H and positive for all $t_H \le x_{2B}(t_L)$, $t_H(t_L) = x_{2B}(t_L)$. As $U_S^\gamma(e_B^\gamma, e_S^\gamma)$ is strictly increasing in t_L, the seller will prefer to set $U_B^\gamma(e_B^\gamma, e_S^\gamma)$ to 0, which happens at $t_L^{SB} = t_{10} \doteq \frac{(H-L)^2(H-2k+L)^2}{64c} + 4(L^2 - k^2)$ and $t_H^{SB} = x_{2B}(t_L^{SB'}) = \frac{(H-L)^2(L-k)^2+4c(2Hk-k^2-2kL+L^2)}{16c}$. We have $U_B^{SB} \doteq U_B(e_B^{SB}, e_S^{SB}) = 0$, $U_S^{SB} \doteq U_S(e_B^{SB}, e_S^{SB}) = \frac{(H-k)(L-k)(H-L)^2}{16c} + \frac{H^4-4H^3k+16c(L-k)^2-6H^2L(L-2k)-L^3(3L-4k)+4HL^2(2L-3k)}{64c}$,

$e_B^{SB} = \frac{(H-L)(L-k)}{4c} > 0$, and $e_S^{SB} = \frac{(H-L)^2}{8c} > 0$. Moreover, we have $\Pi_B^{\gamma_{SB}}(H|H) = \frac{(H-L)(L-k)}{2} > 0$, $\Pi_B^{\gamma_{SB}}(L|L) = 0$ and $\Pi_B^{\gamma_{SB}}(H|H) = \Pi_B^{\gamma_{SB}}(L|H)$, $\Pi_B^{\gamma_{SB}}(L|L) - \Pi_B^{\gamma_{SB}}(H|L) = \frac{(H-L)^2}{2} > 0$. Note that $e_S^{BB} = 0 < e_S^{SB}$ and $e_B^{SB} - e_B^{BB} = \frac{-(H-L)^2}{8c} < 0$, proving Proposition 2. □

Proof of Lemmas 2-3, Proposition 3 and Corollaries 1-2. We now consider the cases where the seller has the ex-post decision right ($j = S$). The conditions for a renegotiation-proof mechanism to be incentive feasible are given by $\Pi_S^{\gamma}(H|H) \geq \Pi_S^{\gamma}(L|H)$ and $\Pi_S^{\gamma}(L|L) \geq \Pi_S^{\gamma}(H|L)$, which simplify to $t_H - Q_e(H) \geq t_L - Q_e(L)$ and $t_L - Q_e(L) \geq t_H - Q_e(H)$. These conditions cannot simultaneously hold, proving Lemma 2.

There are two possible cases for how the mechanism may be structured:

Case a. $t_L - Q_e(L) > t_H - Q_e(H)$ or $\Pi_S^{\gamma}(L|L) > \Pi_S^{\gamma}(H|H)$. Under this case, the seller will always chooses the low-quantity contract and renegotiation takes place when $M = H$. In order to analyze the problem to determine the equilibrium effort levels in the co-development stage, $U_B^{\gamma}(e_B, e_S)$ is strictly concave in e_B and $U_S^{\gamma}(e_B, e_S)$ is strictly concave in e_S. Solving the first-order conditions simultaneously, we get $e_B^a = \frac{(H-L)(H\alpha+L(2-\alpha)-2k)}{8c} > 0$ and $e_S^a = \frac{(H-L)^2(1-\alpha)}{8c} > 0$.

In order to analyze the problem in the contracting stage, first consider the case where the buyer has the ex-ante right ($i = B$). The buyer's problem is given by $\max_{t_L, t_H} U_B(e_B^a, e_S^a)$ such that $t_L - Q_e(L) > t_H - Q_e(H)$ and $U_S(e_B^a, e_S^a) \geq 0$. As $U_B(e_B^a, e_S^a)$ is strictly decreasing in t_H and $U_S(e_B^a, e_S^a)$ is strictly increasing in t_L, the buyer will prefer to set $U_S(e_B^a, e_S^a)$ to 0, which happens at $t_L = t_6 \doteq \frac{k(L-k)}{2} - \frac{(H-L)^3(1-\alpha)(H-4k+3L+\alpha(H-L))}{64c}$. Next consider the case where the seller also has the ex-ante right ($i = S$). The seller's problem is given by $\max_{t_L, t_H} U_S(e_B^a, e_S^a)$ such that $t_L - Q_e(L) > t_H - Q_e(H)$, and $U_B(e_B^a, e_S^a) \geq 0$. As $U_B(e_B^a, e_S^a)$ is strictly decreasing in t_H and $U_S(e_B^a, e_S^a)$ is strictly increasing in t_L, the seller will prefer to set $U_B(e_B^a, e_S^a)$ to 0, which happens at $t_L = t_7 \doteq \frac{(H-L)^4\alpha(2-\alpha)+4(L-k)((H-k)(H-L)^2+4c(L+k))}{64c}$.

Case b. $t_L - Q_e(L) < t_H - Q_e(H)$ or $\Pi_S^{\gamma}(L|L) < \Pi_S^{\gamma}(H|H)$. Under this case, the seller will always choose the high-quantity contract and renegotiation takes place when $M = L$. In order to analyze the problem to determine the equilibrium effort levels in the co-development stage, note that $U_B^{\gamma}(e_B, e_S)$ is strictly concave in e_B and $U_S^{\gamma}(e_B, e_S)$ is strictly concave in e_S. Solving the first-order conditions simultaneously, we get $e_B^b = \frac{(H-L)(H(2-\alpha)+L\alpha-2k)}{8c} > 0$ and $e_S^b = 0$.

In order to analyze the problem in the contracting stage, first consider the case where the buyer has the ex-ante right ($i = B$). In order to analyze the problem in the contracting stage, the buyer's problem is given by $\max_{t_L, t_H} U_B(e_B^b, e_S^b)$ such that $t_L - Q_e(L) < t_H - Q_e(H)$ and $U_S(e_B^b, e_S^b) \geq 0$. As $U_B(e_B^b, e_S^b)$ is strictly decreasing in t_H and $U_S(e_B^b, e_S^b)$ is strictly increasing in t_H, the buyer will prefer to set $U_S(e_B^b, e_S^b)$ to 0, which happens at $t_H = t_8$ (expression not provided for brevity). Similarly, consider the case where the seller also has the ex-ante right ($i = S$). The seller's problem is given by $\max_{t_L,t_H} U_S(e_B^b, e_S^b)$ such that $t_L - Q_e(L) < t_H - Q_e(H)$ and $U_B(e_B^b, e_S^b) \geq 0$. As $U_B(e_B^b, e_S^b)$ is strictly decreasing in t_H and $U_S(e_B^b, e_S^b)$ is strictly increasing in t_H, the seller will prefer to set $U_B(e_B^b, e_S^b)$ to 0, which happens at $t_H = t_9$ (expression not provided for brevity).

To prove Lemma 3, we need to compare the payoff of the party with the ex-ante right between Cases 1 and 2 above.

For $i = B$, the difference between $U_B(e_B^a, e_S^a)$ evaluated at $t_L = t_6$ and $U_B(e_B^b, e_S^b)$ evaluated at $t_H = t_8$ is given by $\frac{(H-L)^3(1-\alpha)(H-4k+3L+\alpha(H-L))}{64c}$, which is positive under our assumption that $c > \frac{(H-L)(H+L-2k)}{4}$. Similarly, for $i = S$, the difference between $U_S(e_B^a, e_S^a)$ evaluated at $t_L = t_7$ and $U_S(e_B^b, e_S^b)$ evaluated at $t_H = t_9$ is given by $\frac{(H-L)^3(1-\alpha)(H-4k+3L+\alpha(H-L))}{64c} > 0$. This implies that regardless of who has the ex-ante right, they prefer to set the contract terms such that $\Pi_S^\gamma(L|L) > \Pi_S^\gamma(H|H)$. Therefore, the seller always chooses the low quantity contract in equilibrium and renegotiation takes place only when $M = H$.

To prove Proposition 3, we have from the Proof of Lemma 3 that for $i = B$, $e_B^{BS} = \frac{(H-L)(H\alpha+L(2-\alpha)-2k)}{8c} > 0$, $e_S^{BS} = \frac{(H-L)^2(1-\alpha)}{8c} > 0$, $U_S^{BS} = 0$ and $U_B^{BS} > 0$ (expressions not provided for brevity). Note that $e_S^{SB} - e_S^{BS} = \frac{(H-L)^2\alpha}{8c} > 0$. For $i = S$, we have $t_L^{SS} = t_7$, $e_B^{SS} = \frac{(H-L)(H\alpha+L(2-\alpha)-2k)}{8c} > 0$, $e_S^{SS} = \frac{(H-L)^2(1-\alpha)}{8c} > 0$, $U_S^{SS} > 0$ (expression not provided for brevity) and $U_B^{SS} = 0$. It is straightforward to see that $e_B^{BS} = e_B^{SS}$ and $e_S^{BS} = e_S^{SS}$. The proofs of Corollaries 1-2 follows directly from a comparison of the equilibrium effort levels. □

Proof of Propositions 4-6. The buyer's payoff under different governance structures is give by $U_B^{SB} = U_B^{SS} = 0$, $U_B^{BB} = \frac{16c(L-k)^2+(H-L)^2(H-2k+L)^2}{64c}$ and $U_B^{BS} = \frac{1}{4}\Big((L-k)^2 + \frac{(H-L)^2\left((H-2k)^2+2\alpha(H-L)(H+2k-3L)-2\alpha^2(H-L)^2-4Hk+6HL-3L^2\right)}{16c}\Big)$. We have that $U_B^{BS} - U_B^{BB} = \frac{(H-L)^3(1-\alpha)(\alpha(H-L)+2(L-k))}{32c} > 0$ because $0 < k < L < H$ and $0 < \alpha < 1$. Therefore, $U_B^{BS} > U_B^{BB} > U_B^{SB} = U_B^{SB} = 0$, proving Proposition 4.

The seller's payoff under different governance structures is given by $U_S^{BS} = U_S^{BB} = 0$, $U_S^{SB} = \frac{(H-k)(L-k)(H-L)^2}{16c} + \frac{H^4-4H^3k+16c(L-k)^2+6H^2L(2k-L)+L^3(4k-3L)+4HL^2(2L-3k)}{64c}$ and $U_S^{SS} = \frac{1}{4}\Big((L-k)^2 + \frac{(H-L)^2\left((H-2k)^2+2\alpha(H-L)(H+2k-3L)-2\alpha^2(H-L)^2-4Hk+6HL-3L^2\right)}{16c}\Big)$. We have that $U_S^{SS} - U_S^{SB} = \frac{\alpha(H-L)^3(H+2k-3L-\alpha(H-L))}{32c}$, which is positive if and only if $\alpha < \widehat{A}_1(H,L,k) \doteq \frac{H-3L+2k}{H-L}$. Therefore, $U_S^{SS} > U_S^{SB} > U_S^{BS} = U_S^{BB} = 0$ for $\alpha < \widehat{A}_1(\cdot)$. Otherwise, $U_S^{SB} > U_S^{SS} > U_S^{BS} = U_S^{BB} = 0$. $d\widehat{A}_1(\cdot)/dH = \frac{2(L-k)}{(H-L)^2} > 0$, $d\widehat{A}_1(\cdot)/dL = \frac{-2(H-k)}{(H-L)^2} < 0$ and $d\widehat{A}_1(\cdot)/dk = 2 > 0$, proving Proposition 5.

For the rest of the proofs, let $U^{ij} = U_B^{ij} + U_S^{ij}$. Given that $U^{BB} = U_B^{BB}$, $U^{BS} = U_B^{BS}$, and $U_B^{BS} > U_B^{BB}$ (from Proposition 4), which implies that $U^{BS} > U^{BB}$. Moreover, $U^{SS} = U_S^{SS}$, $U^{BS} = U_B^{BS}$ and $U_S^{SS} = U_B^{BS}$, which implies that $U^{BS} = U^{SS}$. Therefore, to identify the governance structure that maximizes the total surplus, we need to compare U^{SB} and $U^{BS} = U^{SS}$. In order to do so, recall from the proof of Proposition 5 that $U_S^{SS} > U_S^{SB}$ for $\alpha < \widehat{A}_1(\cdot)$. Given that $U^{SB} = U_S^{SB}$ and $U^{SS} = U_S^{SS}$, we have that $U^{SS} = U^{BS} > U^{SB} > U^{BB}$ for $\alpha < \widehat{A}_1(\cdot)$. Otherwise, $U^{SB} > U^{SS} = U^{BS} > U^{BB}$. This proves Proposition 6. □

Proof of Propositions 7-8. We begin by solving for the efforts under the spot case. $U_S^{spot}(e_B, e_S)$ is strictly concave in e_S and $U_B^{spot}(e_B, e_S)$ is strictly concave in e_B. Solving the first-order conditions simultaneously, we get $e_B^{spot} = \frac{\alpha(H-L)(H+L-2k)}{8c}$ and $e_S^{spot} = \frac{(1-\alpha)(H-L)(H+L-2k)}{8c}$.

Recall from Propositions 1-3, we have that $e_S^{BB} = 0 < e_S^{BS} = e_S^{SS} < e_S^{SB}$, $e_B^{SB} < e_B^{BS} = e_B^{SS}$ and $e_B^{SB} < e_B^{BB}$. As $e_S^{spot} - e_S^{BS} = \frac{(H-L)(L-k)(1-\alpha)}{4} > 0$, we have $e_S^{BB} = 0 < e_S^{BS} = e_S^{SS} < e_S^{spot}$. As $e_B^{BS} - e_B^{BB} = \frac{-(1-\alpha)(H-L)}{8c} < 0$ and $e_B^{BS} - e_B^{spot} = \frac{(H-L)(L-k)(1-\alpha)}{4c} > 0$, we have $e_B^{SB} < e_B^{BS} = e_B^{SS} < e_B^{BB}$ and $e_B^{spot} < e_B^{BS} = e_B^{SS} < e_B^{BB}$. In addition, $e_S^{spot} - e_S^{SB} = e_B^{SB} - e_B^{spot} = \frac{-(H-L)(H\alpha-L(2-\alpha)+2k(1-\alpha)}{8c}$, which is negative if and only if $\alpha > \widehat{A}_2(H, L, k) = \frac{2(L-k)}{H+L-2k}$. This proves Proposition 7.

In order to prove Proposition 8, we need to first prove a couple of preliminaries. U^{SB} and U^{BB} are independent of α. U^{BS} and U^{SS} are concave in α because $d^2U^{BS}/d\alpha^2 = d^2U^{SS}/d\alpha^2 = \frac{-(H-L)^4}{16c} < 0$. Therefore, there exists a unique value of α that maximizes U^{BS} and U^{SS}, and is given by $\alpha^{BS} = \alpha^{SS} = \frac{H+2k-3L}{2(H-L)}$. U^{spot} is concave in α as $d^2U^{spot}/d\alpha^2 = \frac{-(H-L)^2(H-2k+L)^2}{16c} < 0$. Therefore, there exists a unique value of α that maximizes the total surplus under the spot case, given by $\alpha^{spot} = \frac{1}{2}$. $\alpha^{spot} - \alpha^{BS} = \frac{L-k}{H-L} > 0$, which implies that $\alpha^{BS} = \alpha^{SS} < \alpha^{spot}$.

To prove the first part of Proposition 8, note that $U_B^{BB} - U_B^{spot}$ is decreasing in α and zero at $\alpha = 1$, which implies that $U_B^{BB} > U_B^{spot}$. Given that $U_B^{BS} > U_B^{BB}$, we have that $U_B^{BS} > U_B^{BB} > U_B^{spot}$. We also have that $U_S^{SB} - U_S^{spot} = \frac{4(H-L)^3(L-k)+16c\alpha(L-k)^2+\alpha^2(H-L)^2(H-2k+L)^2}{64c} > 0$ and $U_S^{SS} - U_S^{spot}$ is increasing in H and positive at $H = L$, which implies that $U_S^{SS} > U_S^{spot}$.

To prove the second part of Proposition 8, recall from above that U^{SB} is independent of α and U^{spot} is concave in α and maximized at $\alpha = \alpha^{spot} = 1/2$. Moreover, at $\alpha = 0$ and $\alpha = 1$, we have that $U^{SB} - U^{spot} = \frac{(H-L)^3(L-k)}{16c} > 0$ and $U^{SB} - U^{spot}$ is decreasing in α for $\alpha \in [0, 1/2]$ and increasing otherwise. Therefore, there exists thresholds $\alpha = a_1$ and $\alpha = a_2$ such that $U^{SB} > U^{spot}$ if $\alpha < a_1$ and $\alpha > a_2$, where $a_1 \doteq \min\left(\frac{H-L}{H-2k+L}, \frac{2(L-k)}{H-2k+L}\right)$ and $a_2 \doteq \max\left(\frac{H-L}{H-2k+L}, \frac{2(L-k)}{H-2k+L}\right)$. In addition, recall that U^{BS} and U^{spot} are both concave in α and $\alpha^{BS} < \alpha^{spot} = 1/2$. We have $U^{BS} - U^{spot} = \frac{(L-k)(H-L)^3}{16c} > 0$ at $\alpha = 0$ and $U^{BS} - U^{spot} = \frac{-(L-k)^2(H-L)^2}{32c} < 0$ at $\alpha = \alpha_{spot}$. Therefore, there exists a threshold $\alpha = a_3 \doteq \frac{H-L}{2(H-k)}$, such that $U^{BS} = U^{SS} > U^{spot}$ only if $\alpha < a_3$.

Recall that $U^{BS} = U^{SS} > U^{SB}$ if and only if $\alpha < \widehat{A}_1(H, L, k)$, where $\widehat{A}_1(H, L, k) < 1$ and $\widehat{A}_1(H, L, k) > 0$ only if $H > 3L - 2k$. If $H > 2L - k + \sqrt{5}(L - k)$, then $0 < a_1 < a_3 < \widehat{A}_1(\cdot) < a_2$. This implies that the total surplus is maximized under the BS case when $\alpha < a_3$, spot case when $a_3 \leq \alpha \leq a_2$, and SB/SS cases when $\alpha > a_2$. If $-2k + 3L \leq H \leq 2L - k + \sqrt{5}(L - k)$, we have $0 < \widehat{A}_1(\cdot) < a_3 < a_1 < a_2$. This implies that the total surplus is maximized under the BS case when $\alpha < \widehat{A}_1(\cdot)$, under the SB case when $\widehat{A}_1 \leq \alpha < a_1$ and $\alpha > a_2$, and under the spot case if $a_1 \leq \alpha \leq a_2$. Finally, if $H < -2k + 3L$, then $\widehat{A}_1(\cdot) < 0 < a_3 < a_1 < a_2$. This implies that the total surplus is maximized under the SB case when $\alpha < \alpha_1$ and $\alpha > a_2$, and otherwise it is maximized under the spot case.

Summarizing the above: The total surplus is maximized under the spot case if $\widehat{A}_3(H,L,k) \leq \alpha \leq \widehat{A}_4(H,L,k)$, where $\widehat{A}_4(H,L,k) \doteq a_2$ and $\widehat{A}_3(H,L,k) = a_3$ for $H > 2L - k + \sqrt{5}(L-k)$ and $\widehat{A}_3(H,L,k) = a_1$ for $H \leq 2L - k + \sqrt{5}(L-k)$. Otherwise, the total surplus is maximized under the BS case if $\alpha < \widehat{A}_1(H,L,k)$ and under the SB/SS cases otherwise. This proves Proposition 8. □

Online Supplement for The Role of Decision Rights in Co-development Initiatives

OA. Different costs of effort.

In the main model, we assumed that both parties have the same cost of effort. We now consider an extension where these costs can differ. In particular, we now assume that the cost of effort is given by $c_B x^2$ for the buyer and $c_S x^2$ for the seller, where $c_B, c_S > 0$. In what follows, we focus on investigating the robustness of our results under this extension. For brevity, the proofs and details of this extension are available in a Technical Appendix (available on request). We can show that most of our key results and insights continue to hold.

We next focus on discussing the implications of different costs of effort for our results. Let $\beta(H, L, k) \doteq \max\left(\frac{H-L}{H-4k+3L}, \frac{H+2k-3L}{H-L}\right)$, where $0 < \beta(\cdot) < 1$.

- Let $\beta(H, L, k) < \frac{c_B}{c_S} \leq 1$. We find that our analysis for all four of the governance structures is structurally similar to our main analysis. The only change is that the cost factor c in the expressions for the equilibrium decisions and payoffs is replaced by c_B and c_S as appropriate. Accordingly, all our structural results and insights continue to hold when $\beta(\cdot) < \frac{c_B}{c_S} \leq 1$.

- Let $\frac{c_B}{c_S} > 1$. The seller's cost of effort is lower than the buyer's cost under this setting. The analysis for the BS, SB and SS governance structures continues to remain structurally similar to our main analysis. The only change is that the cost factor c in the expressions for the equilibrium decisions and payoffs is replaced by c_B and c_S as appropriate. However, the seller may exert effort for the BB case (i.e., $e_S^{BB} > 0$). This *may* lead the total surplus to be maximized under the BB governance structure (i.e., $U^{BB} > U^{BS}, U^{SS}, U^{SB}$ may occur).

- Let $\frac{c_B}{c_S} \leq \beta(H, L, k)$. We find that our analysis for all the governance structures except SB is structurally similar to our main analysis. The only change is that the cost factor c is replaced by c_B and c_S as appropriate in the expressions for the equilibrium decisions and payoffs. However, the difference in our results for the SB case is that the buyer exerts zero effort (i.e., $e_B^{SB} = 0$). This *may* lead the total surplus to be maximized under the BB governance structure (i.e., $U^{BB} > U^{BS}, U^{SS}, U^{SB}$ may occur).

OB. General specification for $p(b, s)$.

In the main paper, we assumed that $p(b, s) = e_B + e_S$. We can generalize our model to assume $p(e_B, e_S) = \gamma(e_B + e_S) + (1 - \gamma)e_B e_S$, where $\gamma \in (0, 1]$.[1] Note that at $\gamma = 1$, it simplifies to the specification used in our main analysis. The generalization for $p(e_B, e_S)$ with $\gamma \neq 1$ renders our model analytically intractable, even for the relatively simpler case where the buyer holds both the rights. However, we can numerically verify whether our results hold for this general specification. To that end, we conducted a numerical analysis by generating all possible combinations (30,240 in total) for the following parameter values: five equally-spaced levels for $\alpha \in [0.1, 0.9]$, nine equally-spaced levels for $\gamma \in [0.1, 1]$, $c = 6$, four equally-spaced levels for $H \in [6, 6.4, 6.8, 7.2]$ and thirteen equally-spaced levels for $L, k \in [2.4, 7.2]$. We only retain the 11,960 combinations where the conditions $k < L < H$ and $p(e_B^F, e_S^F) \leq 1$ hold. For each of the combinations of parameter values, we use numerical optimization to obtain the equilibrium efforts, parties' payoffs, and total surplus.

Based on this extensive numerical analysis, we find that our key results continue to structurally and qualitatively hold. In particular, we find that the results regarding comparisons of equilibrium efforts in Propositions 2-3 and 7, and Corollaries 1-2 remain unchanged. Similarly, our result in Proposition 6 continues to qualitatively hold in that the total surplus is maximized under the BS/SS cases for low values of α, and under the SB case otherwise. The only difference in our results is that under the BB case (see Proposition 1), the seller may exert effort for the BB case (i.e., $e_S^{BB} > 0$) and $U_B^{BB} > U_B^{BS}$) can happen for for moderate values of γ. However, our general insight that the seller's effort is lowest under the BB governance structure continues to hold.

OC. Potential for Termination of the Initiative.

For this extension, consider the setting with $L < k < H$, which implies that it is efficient to terminate the initiative when $M = L$. That is, $Q_e(L) = 0$ and $t_L = 0$. For brevity, the details and proofs for this extension are available in a Technical Appendix (available on request).

We begin by considering the cases where the buyer has the ex-post decision right ($j = B$). Lemma 1 from the paper continues to hold, i.e., we can restrict our attention to renegotiation-proof mechanisms. As can be seen from Propositions C1 and C2 below, Propositions 1 and 2 from the paper continue to hold, except that $e_B^{SB} = 0$.

Proposition C1. *When the buyer holds both rights, the buyer exerts effort equal to the first-best level ($e_B^{BB} = e_B^F$), while the seller does not exert any effort ($e_S^{BB} = 0$).*

Proposition C2. *When only the ex-ante right is delegated to the seller, the seller exerts more effort than when the buyer has both rights ($e_S^{SB} > e_S^{BB}$), while the buyer exerts less effort ($0 = e_B^{SB} < e_B^{BB}$).*

We next consider the cases where the seller has the ex-post decision right ($j = S$). Lemma 2 from the paper continues to hold, i.e., a renegotiation-proof mechanism cannot be incentive feasible.

[1] Note that when $\gamma = 0$, the efforts are perfect complements (i.e., $p(e_B, e_S) = e_B e_S$). Under this extreme case, neither party will exert effort because they anticipate lower effort by the other party, in line with the results typically obtained in similar models with a non-contingent context (see Lee and Li 2018, p. 14 for an example).

As can be seen from Lemma C3a below, Lemma 3 from the paper continues to hold for the BS case. Note that under a spot contract, the parties will also rely on ex-post negotiation to offer the product when $M = H$, but when $M = L$, they will choose to terminate the initiative under this extension. Accordingly, the outcomes under the BS case become equivalent to the spot contract.

Lemma C3a. *For the BS case, the contract terms are set such that the seller always chooses the contract which is efficient in the low state, i.e., to terminate the initiative. Therefore, renegotiation takes place only when $M = H$.*

According to the Lemma C3b below, Lemma 3 holds for the SS case only if $\alpha < \widehat{A}_5(H, L)$.

Lemma C3b. *For the SS case, if $\alpha < \widehat{A}_5(H, L)$, then the contract terms are set such that the seller always chooses the contract which is efficient in the low state, i.e., to terminate the initiative, and renegotiation takes place only when $M = H$. Otherwise, the contract terms are set such that the seller always chooses the contract efficient in the high state, i.e., when $M = L$, renegotiation takes place to terminate the initiative.*

Proposition C3a shows that Proposition 3 continues to hold for $\alpha < \widehat{A}_5(H, L)$. Moreover, Proposition C3b below shows that the total surplus is (weakly) higher under the BS case as compared to the SS case. In addition, the BS case is equivalent to the spot case when there is potential for termination of the initiative.

Proposition C3a. *When the seller holds the ex-post decision right, the equilibrium efforts are the same under the BS and SS cases if $\alpha < \widehat{A}_5(H, L)$. Otherwise, we have that $e_B^{BS} < e_B^{SS}$ and $0 = e_S^{SS} < e_S^{BS}$.*

Proposition C3b. *The total surplus is weakly higher under the BS case as compared to the SS case (i.e., $U^{BS} \geq U^{SS}$). Moreover, the BS case leads to the same outcome as the spot case, i.e., $e_B^{BS} = e_B^{spot}$, $e_S^{BS} = e_S^{spot}$, and $U^{BS} = U^{spot}$.*

Corollaries 1 and 2 from the main paper continue to hold because $e_S^{BB} = 0$, $e_S^{SS} > 0$, $e_S^{SS} < e_S^{SB}$. Proposition C4 below shows that the total surplus is maximized under the BS governance structure.

Proposition C4. *The buyer's payoff is maximized when she retains both the rights (BB case). The seller's payoff is maximized when she retains the ex-ante right, but the ex-post decision right is held by the buyer (SB case). The total surplus is maximized when he retains the ex-ante right but delegates the ex-post decision right to the seller buyer (BS case).*

OD. Revenue sharing contractual structure.

In what follows, we will provide details for the results of this extension. For brevity, the proofs for Lemmas D1 and D2 are available in a Technical Appendix (available on request).

Let $\eta \in [0, 1]$ denote the share of the revenue given to the buyer. Under such a revenue sharing contract, the only decision that the parties have to make is the revenue share η. Either the buyer or the seller can hold the right to decide η. Let the party with this right be denoted by $z \in \{B, S\}$. We use the superscript R to denote the decisions and expressions related to the revenue-sharing contract. The parties' ex-post payoffs can be written as $\Pi_B^R(M|\eta) \doteq \eta(M - Q_e(M))Q_e(M)$ and $\Pi_S^R(M|\eta) \doteq (1-\eta)(M - Q_e(M))Q_e(M) - kQ_e(M)$, where $Q_e(M) = \arg\max_{0 \leq Q \leq M} \pi_e(Q|M)$ is the efficient quantity that maximizes the total surplus. Note that the seller incurs the production cost k to manufacture and deliver the product to the buyer. For a given revenue share η, the parties' problems to choose their efforts are given by

$$\max_{e_B \geq 0} U_B^R(e_B, e_S|\eta) \doteq p(e_B, e_S)\Pi_B^R(H|\eta) + (1 - p(e_B, e_S))\Pi_B^R(L|\eta) - C(e_B)$$
$$\max_{e_S \geq 0} U_S^R(e_B, e_S|\eta) \doteq p(e_B, e_S)\Pi_S^R(H|\eta) + (1 - p(e_B, e_S))\Pi_S^R(L|\eta) - C(e_S).$$

Let $e_B^R \doteq \arg\max_{e_B \geq 0} U_B^R(e_B, e_S|\eta)$ and $e_S^R \doteq \arg\max_{e_S \geq 0} U_S^R(e_B, e_S|\eta)$ denote the optimal effort levels. Accordingly, party z's problem to choose the revenue share can be written as $\max U_z^R(e_B^R, e_S^R|\eta)$ subject to $\eta \in [0, 1]$ and an ex-ante participation constraint for the other party, i.e., $U_{-z}^R(e_B^R, e_S^R|\eta) \geq 0$. Let η^{Rz} denote the optimal revenue share chosen by party z when s/he holds the decision right, and let the resulting equilibrium effort levels and total surplus evaluated at $\eta = \eta^{Rz}$ be denoted by e_B^{Rz}, e_S^{Rz}, and U^{Rz}, respectively.

Lemma D1 shows our preliminary result that when the seller sets the revenue share, he will choose to extract the entire revenue. However, when the buyer sets the revenue share, she will allocate a strictly positive share to the seller.

Lemma D1. *When the seller sets the revenue share, $\eta^{RS} = 0$, $e_B^{RS} = 0$ but $e_S^{RS} > 0$. However, when the buyer sets the revenue share, we have $0 < \eta^{RB} < 1$, and $e_B^{RB}, e_S^{RB} > 0$.*

The intuition for the above result is quite straightforward. The party who sets the revenue share chooses η such that the ex-ante participation constraint for the other party is binding ($U_{-z}^R(e_B^R, e_S^R|\eta) = 0$). Recall that the seller has to incur the production cost to deliver the products, and the buyer only enjoys a share of the realized revenues. Therefore, when the seller sets η, he extracts the entire revenues from the buyer. When the buyer sets η, she has to compensate the seller for the incurred production costs, and thus always chooses to share some of the revenues with him.

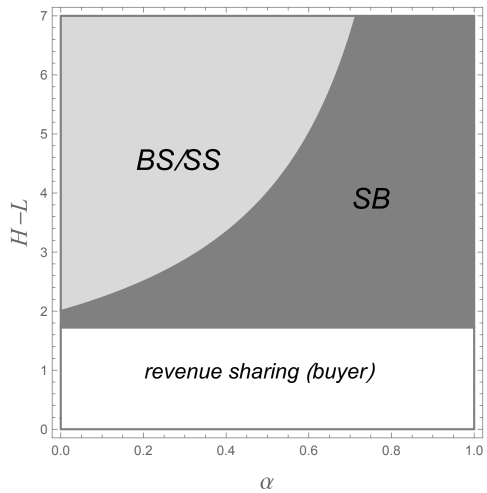
The next lemma compares the total surplus under a revenue sharing contract to identify which party should set the revenue share.

Lemma D2. *The total surplus when the revenue share is set by the buyer is strictly higher than when it is set by the seller.*

The above result implies that to investigate whether a revenue-sharing contract may be preferred to the contractual structure in our main analysis, we only need to consider a revenue-sharing contract where η is chosen by the buyer. In order to examine this, we need to compare U^{RB} with the total surplus U^{BS} and U^{SB} from our main analysis (see Proposition 6 in the paper).

Comparing U^{RB} with U^{SB} and U^{BS} is analytically intractable. However, we can numerically verify that the result for this comparison follows a very clear structure, which is also illustrated in Figure 1: As long as $H - L$ is not small, the total surplus under this revenue-sharing contract (U^{RB}) is strictly lower than that under the contractual structure ($\max\{U^{BS}, U^{SB}\}$). That is, in the more interesting case for our co-development context, where the parties are developing a novel technology, a revenue sharing contract is always dominated by the contractual structure considered

Figure 1: When does a revenue-sharing contract lead to higher total surplus than the contracts considered in our main analysis? In the figure, $k = 2$, $L = 3$ and $c = 6.2$. As long as $H - L$ is not too small, the revenue sharing contract is dominated by the contracts considered in our main analysis.



in our main analysis.

OE. Table of Notation.

e_B	Buyer's effort
e_S	Seller's effort
$C(x) = cx^2$ where $c > 0$	Cost of effort x
$M \in \{H, L\}$ where $H > L$	Market potential
$p(e_B, e_S)$	Probability of achieving high market potential
$Q_e(M)$	Efficient quantity decision for market potential M
t_M	Transfer payment from buyer to seller when contract M is executed
Q_M	Quantity decision when contract M is executed
k	Unit production cost incurred by the seller
α $(1 - \alpha)$	Bargaining power of the buyer (seller)

OF. Details for why the total-surplus maximizing governance structure will be adopted.

Seller is ex-ante powerful. In this case, the seller is the party that initially holds the right to make the take-it-or-leave-it offers. The seller's payoff is maximized under the SS governance structure for $\alpha < \widehat{A}_1(\cdot)$ and under the SB governance structure otherwise (see Proposition **??**). Note from Proposition **??** that the total surplus is also maximized under the SS governance structure for $\alpha < \widehat{A}_1(\cdot)$ and under the SB governance structure otherwise. This implies that the governance structure that maximizes the seller's payoff also maximizes the total surplus for all values of α.

That is, if the seller is ex-ante powerful, the governance structure that emerges in practice will be the one that maximizes the total surplus.

Buyer is ex-ante powerful. In this case, the buyer is the party that initially holds the right to make the take-it-or-leave-it offers. The buyer's payoff is maximized under the BS governance structure for all α (see Proposition **??**). The BS governance structure also maximizes the total surplus for $\alpha < \widehat{A}_1(\cdot)$ (see Proposition **??**). This implies that if $\alpha < \widehat{A}_1(\cdot)$, the governance structure that emerges in practice will be the one that maximizes the total surplus. If $\alpha \geq \widehat{A}_1(\cdot)$, then the total surplus is maximized under the SB governance structure. In this case, it can be shown that the buyer can design a transfer-payment scheme such that the resulting payoffs for *both* the parties are strictly higher by moving to the total-surplus maximizing (SB) governance structure (see proof below).

Proof: Let this transfer payment from the seller to the buyer be denoted by X. Such a transfer payment would lead the payoff from the SB governance structure to be $U_B^{SB} + X$ for the buyer and $U_S^{SB} - X$ for the seller. For the buyer to prefer delegating the ex-ante right to the seller to utilize the SB governance structure, we need $U_B^{SB} + X > U_B^{BS}$ and $U_S^{SB} - X > U_S^{BS}$ to simultaneously hold. Given that $U_B^{BS} = U^{BS}$, $U_B^{SB} = 0$, $U_S^{SB} = U^{SB}$, and $U_S^{BS} = 0$, these conditions simplify to $X > U^{BS}$ and $X < U^{SB}$. This condition can also be written as $U^{BS} < X < U^{SB}$, where $U^{BS} < U^{SB}$ holds because $\alpha \geq \widehat{A}_1(\cdot)$. This implies that there exists a transfer payment $X > 0$ from the seller to the buyer which makes the SB governance structure pareto improving for both parties.

References

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