Organizational design of R&D activities

Stefan Ambec and Michel Poitevin*

Département de sciences économiques

C.R.D.E. and CIRANO

Université de Montréal

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Abstract

This paper addresses the question of whether R&D should be carried out by an independent research unit or be produced in-house by the firm marketing the innovation. We define two contractual structures. In an independent structure, the firm that markets the innovation buys it from an independent research unit which is financed externally. In an integrated structure, the firm that markets the innovation also carries out and finances research leading to the innovation. We compare the two structures under the assumption that the research unit has some private information about the real cost of developing the new product. The sole presence of asymmetric information is not sufficient to differentiate the two structures. It is only when players can renegotiate and collude that a difference emerges. When the marginal cost of developing the innovation is negatively correlated with its marginal profit, the integrated structure dominates. The independent structure dominates in the opposite case.

1 Introduction

Research and development activities take place in various organizational forms depending on who finances, creates, develops, produces and sells the innovation. A widely observed organizational form is in-house R&D. Innovation is created within the firm who then uses the new product or the

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new technology. Researchers-inventors are subject to an employment contract. The innovation is financed, managed and owned by the user firm.

Another organizational structure is "external R&D". Research and development activities are conducted by an independent firm whose objective is to create a new product or a new technology and then develop it with the user firm through a contractual agreement. Innovation is managed and owned by the independent research unit firm and financed by its financial partner, for example, a venture capitalist.

Both organizational structures are observed in many industries. Moreover, the same firm may employ both organizational forms. For example, consider the pharmaceutical industry. The innovation user is the drug firm while an independent research unit is a biotechnology firm. A drug firm like Merck is investing mainly in in-house R&D although some of its major rivals are outsourcing most of their research activities. Only 5% or so of Merck's research spending ends up outside the firm's laboratories. For other top drug companies however, the proportion of research done independently could reach 80%. Recently, American pharmaceutical companies moved from in-house R&D to independent R&D by increasing their research joint venture agreements. These research joint ventures are contractual agreements for developing, producing and selling a new medicine discovered by a biotech firm (Lerner and Merges, 1998). In 1994, 117 ventures between drug and biotechnology firms were signed, 70% more than the previous year[1].

This empirical evidence highlights an important question. Why are the two organizational forms observed? If one organization is more efficient than the other one, the inefficient organizational structure should not be observed in equilibrium. The objective of this paper is to provide some economic intuition based on contractual imperfections about the organizational choice of R&D activities.

The economic environment for the research and development activities and the eventual marketing of the innovation is characterized by two main features: uncertainty and informational asymmetries. When working on an innovation, a firm does not know for sure the result of its R&D activities. Research methodologies employed to discover an innovation (what Dosi (1988) calls "technology trajectories") can be specified ex ante but their outcome can hardly be perfectly predicted. For example, in the case of pharmaceutical industries, one favorite research methodology employed is "combinatorial chemistry" which consists in using arbitrary chemical reactions to gener-

[1] "The Economist", May 13th 1995, pp. 66-67, and May 24th 1997, pp. 59-60.

ate millions of randomly shaped molecules. One of the new discovered molecules might just lead to the next drug. The discovery of a new drug depends on the success of the research process, and its properties (its safety, efficiency, cost effectiveness of treatment) are never known ex ante. Research and development are random activities and, therefore, constitute a risky investment.

Second, the marketing of an innovation is characterized by an asymmetric distribution of information. The value of an innovation depends on its properties such as the new technology's efficiency, the new product's quality or production. While this information is difficult to obtain before the innovation is developed, produced and sold, the research unit may have more information about the cost of bringing the innovation to the market, that is, when the innovation is transferred from its creator to its user. For example, in the pharmaceutical industry, coordination between researcher and factory designers is not easy. Clearly, bringing a new medicine to the market is not trivial and needs cooperation between agents which may not have the same information. A report states that mistakes in the development process increase costs by 40%[2]. Asymmetric information motivates the complexity of research joint venture agreements. Uncertainty and asymmetric information are two basic features of our model. But before describing our model, we review some of the relevant literature.

In the management literature, it is argued that in-house R&D may reduce problems associated with asymmetric information, and that better coordination between innovators, production and marketing departments is achieved within an organization. With its own research unit, a firm has the scientific expertise to evaluate new technologies and new products (Armour and Teece, 1979; Lampel, Miller and Floricel, 1996). This approach assumes that the objective of all units within the firm is to maximize the organization global profit. This may not be true if the units behave non cooperatively or opportunistically. A "selfish" research unit may not behave in accordance with the integrated organization's own interest. For example, a research unit may prefer not to reveal the true value (possibly low) of its discovery if its reward from the innovation does not provide it with such incentives. Hence, integrating the research unit within the user firm does not necessary solve the asymmetric information problem. The solution should be endogenous to the incentives provided by the organizational form, not by the adoption per se of an organizational form.

An incomplete contract approach to R&D management is developed in Aghion and Tirole (1993) in, what they call, a first attempt to open the "black box of innovation". They suppose that R&D

[2] "The Economist", November 9th, 1996.

is a random activity. Its success depends on an initial investment provided by the innovation user C and an effort supplied by the research unit RU. Since the innovation cannot be described ex ante, the contract can only specify the allocation of property rights when R&D is produced in-house. In that case, when R&D is produced in-house, the property right is allocated ex ante to C. When R&D is carried out by an independent research unit, RU owns the innovation and bargains ex post with C over licensing fees. The optimal organizational form of innovation activities depends on the marginal efficiency of RU's effort compared with the marginal efficiency of C's investment, on the ex ante bargaining power of the two parties and on C's financial constraint.

Recent papers pointed out that bureaucratic organizations perform poorly in innovating. In Dearden, Ickes and Samuelson (1990), a centralized structure has low incentives to adopt new technologies because of the ratchet effect. In Quian and Xu (1998), a soft budget constraint and an ex ante heavy evaluation process explain centralized organizations' failure in innovating. A bureaucracy makes mistakes by rejecting promising projects and delaying innovations. In-house R&D produces high cost and ex ante well-specified innovations, but is unable to subsidize less costly projects with higher uncertainty.

The present paper provides a complete contract approach to the organizational design of R&D activities. A contract can be written ex ante contingently on the innovation performance, namely, the development cost, production cost and market value of the innovation. We define two contractual structures. In an integrated structure, the innovation is produced in-house by the firm who then uses or markets it. This firm sets up its own research unit by financing a laboratory and hiring scientists. The contract signed between the firm and the members of the research unit is an employment contract. The manager of the firm has authority over the head of the research unit. He takes the main decisions about the development, production and marketing process of the innovation after considering the advice of its research unit. In an independent structure, the research unit is an independent firm. It is financed by a bank or a venture capitalist. The firm then sells the innovation to another firm by signing a joint-venture agreement or a technological alliance. The research unit installs the new process in a factory, or tests the new product for specific purposes. The user firm then operates the new technology, or produces and markets the new product. Transfers are then paid as prescribed by the financial and joint-venture contracts. The research unit pays back the bank and receives its share of the joint-venture's profit.

The two structures are equivalent when the agents can commit not to renegotiate and not to collude. In the integrated structure, the user firm insures partially the research unit against the uncertainty of the research process. The employment contract gives the research unit incentive to report the true value of the innovation to the manager of the firm. In the independent structure, partial insurance is provided by the financial partner. The research reveals the true value of the innovation by installing the new process or testing the new product. Hence, even under asymmetric information, we show that the two structures yield the same pay-off to the research unit and to the user firm.

The two structures perform differently when agents cannot commit not to renegotiate and not to collude. In the integrated structure, after the research unit reports the innovation quality but before the head of the firm decides the size of the development project, agents have incentive to renegotiate the employment contract. This renegotiation reduces the ex ante efficiency of the integrated structure. In the independent structure, the research unit contracts successively with the bank and the user firm. It may be tempted to secretly agree with the user firm, at the second contracting stage, not to behave as prescribed by the financial contract. That is, to misreport the size of the development project to the bank in order to pay the lower return. The collusion between the research unit and the user firm reduces the ex ante efficiency of the independent structure.

The relative efficiency of the two structures depends on the properties of the innovation. When an innovation costly to develop is also a less drastic technology or a product less valued by consumers, that is, when the marginal cost of developing the innovation is negatively correlated with its marginal profit, the integrated structure dominates the independent structure. The independent structure dominates in the opposite case. This paper therefore characterizes some forces which may explain the choice between external and in-house R&D.

The paper is organized as follows. Section 2 presents the model. Section 3 analyses the two organizational structures in the case of symmetric information. In section 4, we introduce asymmetric information when agent can commit not to renegotiate and not to collude. We allow renegotiation and collusion in section 5. We compare the two strutures performance in section 6. Section 8 concludes the paper.

2 The model

Two agents, a research unit RU and the consumer of the new technology or sell of the new product, firm C, coordinate their activities during the R&D process. At the research period, the research unit has access to a random research technology to produce an innovation. When investing I in research, RU obtains a high quality innovation h with probability $p(I)$ and a low quality innovation l $(l < h)$ with probability $1 - p(I)$. We suppose p increasing and concave, with $p(0) = 0$, $p'(0) = \infty$, $lim_{I \to \infty} p(I) = 1$. The innovation quality $\alpha \in \{l, h\}, l < h$, affects the costs and receipt.

The innovation is marketed by firm C. To sell the innovation, RU and C must operationalize its production. This is the development phase. During that phase, RU incurs a development cost $D(q, \alpha)$ depending on the scale of project q and on the innovation quality α. We assume that D is increasing and convex in q and that total and marginal development costs are decreasing in α:

$$D_q(q, \alpha) > 0,\ D_{qq}(q, \alpha) > 0,\ D(q, h) < D(q, l),\ D_q(q, h) < D_q(q, l)\ \forall q > 0.$$

Following the development phase, C can start producing and marketing the product. These activities yields to C a profit (before transfer) $P(q, \alpha)$, that is, its total revenu net of its production cost. This function is general in the way that it includes both process and product innovation. When the innovation is a new technology used by C, the new production cost depends on the innovation while the demand for the product is unchanged. When the innovation is a new product marketed by C, the firm faces a random demand which depends on the innovation quality. The function P is assumed increasing and concave on q.

$$P_q(q, \alpha) > 0,\ P_{qq}(q, \alpha) < 0,\ \forall 0 < q < \bar{q}.$$

To cover all cases, total and marginal profits can be increasing or decreasing in α. When total and marginal profits are decreasing (increasing) in α, they are positively (negatively) correlated with total and marginal development costs.

For an innovation level $\alpha \in \{l, h\}$, after investing I, the R&D process generates a global profit net of initial investment of

$$\pi_\alpha(q) = P(q, \alpha) - D(q, \alpha).$$

The global profit π_α is maximized at q^*_α.

RU's utility V depends on its income w net of development cost:

$$V(w, q, \alpha) = v(w - D(q, \alpha)).$$

We suppose that the research unit is risk averse therefore, v is increasing and concave ($v' > 0$, $v'' < 0$). The consumer firm C is risk neutral. Its utility U is linear in profits net of any payment w:

$$U(w, q, \alpha) = P(q, \alpha) - w.$$

The levels of investment and production depend on the organizational structure of R&D activities. We define two types of organizations. In an integrated structure, R&D activities are conducted in-house. The relationship between RU and C can be modeled as contract signed at the beginning of the research period between RU and C. This contract specifies an investment level I and an allocation $\{w_\alpha, q_\alpha\}_{\alpha=l}^h$ contingently on the innovation quality α, where w is a transfer of resources from C to RU. Firm C invests I in research, pays its research unit RU a wage w_α and produces q_α when the innovation quality is α. The players' expected utilities are:

- For RU: $E_\alpha[V(w_\alpha, q_\alpha, \alpha)|I]$
- For C: $E_\alpha[U(w_\alpha, q_\alpha, \alpha)|I] - I$

In an independent structure, RU is an autonomous firm. It must finance its research activities externally. A financial contract is signed at the beginning of the research period between RU and a bank or financial partner F. This contract specifies the investment I provided by F to RU and ex post repayments $\{R_\alpha\}_{\alpha=l}^h$ from RU to F contingently on the innovation quality α. After the research period and before the development period RU sells its innovation to C who markets it. RU and C negotiate a joint-venture agreement which specifies the project size q_α and RU's wage or royalties w_α contingently on innovation quality α. Players' expected utilities are:

- For F: $E_\alpha[R_\alpha|I] - I$
- For RU: $E_\alpha[V(w_\alpha - R_\alpha, q_\alpha, \alpha)|I]$
- For C: $E_\alpha[U(w_\alpha, q_\alpha, \alpha)|I]$

The objective of this paper is to study the optimal $R\&D$ organizational structure under various informational, commitment, and collusion assumptions. The relative efficiency of the two organizational structures depends on the informational structure, on the players commitment ability, and the collusion possibilities. The equilibrium allocations are characterized for the following cases:

- Symmetric information (Section 3)
- Asymmetric information with commitment not to renegotiate and not to collude (Section 4)
- Asymmetric information without commitment not to renegotiate and not to collude (Section 5).

In each case, we compare the relative performance of the two structures. We will denote by V_α^S and U_α^S respectively, RU and C equilibrium utility in the $S \in \{A, B\}$ structure, with A for integrated structure and B for independent structure, and in the $\alpha \in \{l, h\}$ state of nature. In all games, bargaining power is given to RU and F's and C's reservation utilities are normalized to zero.

3 Symmetric information

Before introducing asymmetric information in the model, it is useful to review the benchmark case where both players have full information about innovation quality. The full information allocation correspond to the first best allocation.

3.1 The integrated structure

In a integrated structure, RU offers to C a R&D contract which maximizes its expected utility subject to C's participation constraint. The equilibrium allocation $\{I^A,\ \{w_\alpha^A, q_\alpha^A\}_{\alpha=l}^h\}$ solves the following maximization program.

$$Max_{I,\{w_\alpha,q_\alpha\}_{\alpha=l}^h}\ E_\alpha[V(w_\alpha, q_\alpha, \alpha)|I]\ s/t$$

$$E_\alpha[U(w_\alpha, q_\alpha, \alpha)|I] - I\ \geq\ 0\ (RI^C)$$

The solution is characterized by the following relationships:

$$w_h^A - D(q_h^A, h) = w_l^A - D(q_l^A, l),\ q_h^A = q_h^*,\ q_l^A = q_l^*,\ p'(I^A)(\pi_h(q_h^*) - \pi_l(q_l^*)) = 1.$$

First, RU utility is equallized in the two states of nature. The risk neutral agent C provides full insurance to the risk averse principal RU via ex post wages. Hence, risk sharing is optimal. Second, for each innovation quality, the new product is produced at the efficient scale q_α^*. Third, the marginal benefits of the R&D investment equal its marginal costs. Investment is therefore efficient. The risk neutral agent C takes all risk and it receives all benefits from a high quality innovation. Hence, it invests optimally.

3.2 The independent structure

In a independent structure, RU offers a financial contract and a development contract respectively to F and to C which maximizes its expected utility subject to F's and C's participation constraints. The equilibrium allocation $\{I^B, \{R^B_\alpha, w^B_\alpha, q^B_\alpha\}^h_{\alpha=l}\}$ is the solution to the following maximization problem.

$$Max_{\{I,\{R_\alpha\}^l_{\alpha=m}\}} E_\alpha[V(w_\alpha - R_\alpha, q_\alpha, \alpha)|I] \ s/t$$

$$\begin{aligned} E_\alpha[R_\alpha|I] - I &\geq 0 \quad (IR^F) \\ U(w_\alpha, q_\alpha, \alpha) &\geq 0 \quad \forall\alpha = l, h \quad (IR^C_\alpha) \end{aligned}$$

The solution is characterized by the following relationships:

$w^B_h - R^B_h - D(q^*_h, h) = w^B_l - R^B_l - D(q^*_l, l)$;

$q^B_h = q^*_h$, $q^B_l = q^*_l$; $w^B_\alpha = P(q^*_\alpha, \alpha)$, $\forall\alpha \in \{l, h\}$;

$p'(I^B)(\pi_h(q^*_h) - \pi_l(q^*_l)) = 1$.

First, as in the integrated structure, RU utility is equal in the two states of nature. The financial agent now provides full insurance to the principal via ex post repayments. Second, for each innovation quality level, the new good is produced at the efficient scale. Third, wages are defined by the binding participation constraints of agent C. Fourth, the R&D initial investment provided by F is efficient since F gets all the marginal benefit from a high quality innovation.

It is easy to see that the two structures yield the same outcome. Under symmetric information, it is not possible to discriminate between the two structures. We now introduce asymmetric information.

4 Asymmetric Information with commitment not to renegotiate and not to collude

We now assume that RU has private information about the quality of the innovation. Under such assumption, the interaction between RU and C in an integrated structure proceeds as follows. The research unit negotiates ex ante a contract with C. Ex post, RU communicates (not necessarily truthfully) the results of the research process to C. Firm C then chooses the development project size, hence the production level implemented. All these decisions are coordinated by a contract.

In the independent structure, RU finances externally its research. After innovating, RU develops an application jointly with C. The application is then bought to the market. These interactions are coordinated by the two contracts, a financial one between RU and F, and a joint-venture one between RU and C.

The two structures are distinct in two important features. First, the contracting stage between

RU and C occurs ex ante in the integrated structure and ex post in the independent structure. In the integrated structure, RU and C negotiate in a moral-hazard hidden-information environment. In the independent structure, RU and C play a signalling game[3].

Second, the communication process between the informed principal and the uninformed agent is different. In the integrated organization, we assume that the decision right over production belongs to C. In the integrated structure, this right cannot be transferred from C to RU as the rule of law does not govern over such intrafirm transaction. For example, even if this right was transferable, C could always repossess it because it has hierarchical authority over RU. In terms of communication, this amounts to RU sending a direct report, namely the innovation quality, to C. This information is used by C when it decides how much to produce and sell. This corresponds formally to a direct mechanism. In the independent organization, the decision right over production initially belongs to C. Since C and RU are independent firms, this right can be "sold" from C to RU: the judicial system can enforce such transaction. Formally, this amounts to RU sending an indirect message to C and to F by effectively choosing production. No communication needs to occur between RU and C after the contract is signed. This corresponds formally to an indirect mechanism. We now characterize the optimal allocation under these two structures.

4.1 The integrated structure

In an integrated structure with asymmetric information and commitment, agents play the following game:

1. In the first stage, RU proposes a research and development contract $c_{RD} = \{I, \{w_{\hat{\alpha}}, q_{\hat{\alpha}}\}_{\hat{\alpha}=l}^{h}\}$ to C.

2. In the second stage, C accepts or rejects the contract.

3. In the third stage (if reached), RU observes the innovation quality α.

4. In the fourth stage, the contract is carried out; that is RU selects a message $\hat{\alpha} \in \{l, h\}$ and then the innovation is developed, produced and sold while transfers are paid as prescribed by the contract.

[3]See Maskin and Tirole (1992) for a general framework of those game situations with an informed principal and common values.

This game has two important features. First, the environment we have chosen is one of hidden information: the contract is signed with the two agents' having the same information, but production is carried out just after RU has privately observed the state of nature. As no renegotiation is allowed, once a contract has been chosen, there is no possibility of modifying it. Note that the full-information allocation is not an equilibrium allocation of this game. With this allocation, RU's dominant strategy would be to pretend that innovation quality is low to reduce its development cost while maintaining its wage. Expecting this behaviour, C would refuse the full-information contract if ever offered.

The strategy of player RU is represented by a tuple $\sigma_{RU} = \{c_{RD}, \hat{\alpha}(c_{RD}, \alpha)\}$, where c_{RD} is an initial contract offer and $\hat{\alpha}(c_{RD}, \alpha)$ represents RU's decision rule regarding the choice of a message $\hat{\alpha}$. The strategy of player C, σ_C is represented by the function $d(c_{RD}) \in \{0, 1\}$, which represents the decision rule concerning the acceptance or rejection of the initial contract offer with $d(c_{RD}) = 1$ if the contract is accepted and 0 otherwise.

Given this game, a *Perfect Bayesian Equilibrium* (PBE) is a pair of strategies σ_{RU} and σ_C that are best replies to one another given beliefs in every contingency in which agents are forced to make a choice, and a pair of beliefs that are updated using Bayes rule whenever possible.[4]

The following proposition provides a characterization of the equilibrium allocation. In the proof of the proposition, we give the equilibrium contract as well as strategies and beliefs that support this allocation as a PBE outcome.[5]

Proposition 1 *An allocation $\{I^A, \{w_\alpha^A, q_\alpha^A\}_{\alpha=l}^h\}$ is an equilibrium allocation if and only if it is a solution to the following maximization problem.*

(P_A) $\quad Max_{I, \{w_\alpha, q_\alpha\}_{\alpha=l}^h} \; E_\alpha[V(w_\alpha, q_\alpha, \alpha)|I] \quad s/t$

$$\begin{aligned} E_\alpha[U(w_\alpha, q_\alpha, \alpha)|I] - I &\geq 0 && (IR^C) \\ V(w_h, q_h, h) &\geq V(w_l, q_l, h) && (IC_h) \\ V(w_l, q_l, l) &\geq V(w_h, q_h, l) && (IC_l) \end{aligned}$$

Proposition 1 states the equivalence between the equilibrium allocation and the solution to a well-defined maximization problem. The equilibrium allocation is RU's preferred allocation among the set of allocations satisfying its incentive-compatibility constraints (IC_α) for each state of nature $\alpha \in \{l, h\}$ and C's participation or individual rationality constraint (IR^C). Because, in the integrated

[4]See Fudenberg and Tirole (1991) for a precise definition of a Perfect Bayesian Equilibrium.

[5]All proofs are provided in the Appendix.

structure, the R&D contract is negotiated ex ante, we assume that C's participation constraint must be satisfied only ex ante, that is, C cannot default on the contract once it is signed. The risk-neutral player C can then provide some insurance to the risk-averse Research Unit. In the following proposition, we characterized the solution to the P_A maximization problem.

Proposition 2 *The equilibrium allocation of the integrated structure commitment game satisfies the following relationships:* $q_l^A < q_l^*, q_h^A = q_h^*$, $w_h^A - w_l^A = D(q_h^*, h) - D(q_l^A, h)$,

$$p'(I^A)\{\frac{V_h^A - V_l^A}{E_\alpha[V_\alpha'^A|I^A]} + U_h^A - U_l^A\} = 1;$$

where V_α^A *and* U_α^A *are respectively RU and C equilibrium utility for an innovation quality* $\alpha \in \{l, h\}$*.*

Proposition 2 states first that there is underproduction for a low quality innovation and optimal production for a high quality innovation; second, that the integrated structure cannot share risk efficiently between the two agents as the wage difference is constrained by the high-innovation incentive-compatibility constraint. Third, investment is determined by the marginal benefit of a high quality innovation shared between the two agents.

This is the usual result in hidden information games. Under the symmetric information optimal allocation, RU has incentives to report a low quality innovation when she knows that the innovation quality is high. The incentive compatibility constraint for a high quality innovation is therefore not satisfied. Production for a low quality innovation is distorted and the wage difference is increased in order to satisfy IC_h. We now study the independent structure with commitment.

4.2 The independent structure

In an independent structure with asymmetric information and commitment, agents play the following game:

1. In the first stage, RU proposes a financial contract $c_F = \{I, \{R(q_\alpha)\}_{\alpha=l}^h\}$ to F.

2. In the second stage, F accepts or rejects the contract.

3. In the third stage (if reached), RU observes the innovation quality α.

4. In the fourth stage, RU proposes a development contract $c_D = \{w(q_\alpha), q_\alpha\}_{\alpha=l}^h$.

5. In the fifth stage, C accepts or rejects the contract.

6. In the sixth stage (if reached), the contract is carried out; that is, RU implements the production level $q_{\hat{\alpha}} \in \{q_l, q_h\}$ with C and it is observed by F, then the innovation is developed, produced and sold while transfers are paid as prescribed by the contract.

The commitment game has two important features. First, while the financial contract is signed and carried out in a hidden information environment, the development contract is negotiated in a adverse selection environment. Second, the development project size $q_{\hat{\alpha}}$ is observable by all the players, that is, this indirect message is publicly sent to C and F. In other words, it is as if the principal can commit to send the same message to the two agents. Note that the full information allocation is not an equilibrium allocation of this game: with this allocation, RU's dominant strategy would be to pretend that innovation quality is low to reduce its development costs while maintaining its wage net of financial cost. Expecting this behaviour, C and F would refuse the full information contract proposal.

The strategy of player RU is represented by a tuple $\sigma_{RU} = \{c_F, c_D(\alpha), q_{\hat{\alpha}}(c_F, c_D, \alpha)\}$ where c_F is a financial contract offer, $c_D(\alpha)$ is a development contract offer, $q_{\hat{\alpha}}(c_F, c_D, \alpha)$ represent RU's decision rule regarding the choice of the production level implemented and report sent to F. The strategy of player F, σ_F is represented by the function $d_F(c_F) \in \{0, 1\}$, which represents the decision rule concerning the acceptance or rejection of the development contract offer with $d_F(c_F) = 1$ if the contract is accepted and 0 otherwise. The strategy of player C, σ_C is represented by the function $d_C(c_D, c_F) \in \{0, 1\}$, which represents the decision rule concerning the acceptance or rejection of the development contract offer with $d_C(c_F, c_D) = 1$ if the contract is accepted and 0 otherwise. The beliefs of C are updated in stage 5 and are denoted $P(\alpha | c_F, c_D)$. The following proposition provides a characterization of the equilibrium allocations of the independent structure game.

Proposition 3 *An allocation $\{I^B, \{R^B(q_\alpha), w^B(q_\alpha), q_\alpha^B\}_{\alpha=l}^h\}$ is an equilibrium allocation if and only if it satisfies the following maximization problem.*

(P_B) $\quad Max_{I, \{R(q_\alpha), w(q_\alpha), q_\alpha\}_{\alpha=l}^h} E[V(w(q_\alpha) - R(q_\alpha), q_\alpha, \alpha))|I] \quad s/t$

$$
\begin{array}{rcll}
E_\alpha[R(q_\alpha)|I] - I & \geq & 0 & (IR^F) \\
U(w(q_h), q_h, h) & \geq & 0 & (IR_h^C) \\
U(w(q_l), q_l, l) & \geq & 0 & (IR_l^C) \\
V(w(q_h) - R(q_h), q_h, h) & \geq & V(w(q_l) - R(q_l), q_l, h) & (IC_h) \\
V(w(q_l) - R(q_l), q_l, l) & \geq & V(w(q_h) - R(q_h), q_h, l) & (IC_h)
\end{array}
$$

The equilibrium allocation is RU's preferred allocations among the set of allocation satisfying F's individual rationality constraint (IR^F), RU's incentive compatibility constraints (IC_α) and C's individual rationality constraint (IR_α^C) for each state of nature $\alpha \in \{l, h\}$. Note that the timing of the game requires that C's participation constraint must be satisfied for each state of nature, which implies that C is unable to share risk with the Research Unit. F's participation constraint, however, must be satisfied only in expectation, and thereby it provides room for explicit insurance.

Since the same message is sent to F and C, incentive compatibility constraints are similar to those of the previous integrated structure game. The two incentive compatibility constraints provide incentives to reveal its information because RU's private information is publicly disclosed. In the following proposition, we characterized the solution to the P_B maximization problem.

Proposition 4 *The equilibrium allocation of the independent structure commitment game satisfies the following relationships:*
$q_h^B = q_h^A = q_h^*$, $q_l^B = q_l^A < q_l^*$, $w^B(q_h) - R^B(q_h) = w_h^A$, $w^B(q_l) - R^B(q_l) = w_l^A$, $I^B = I^A$.
We have:
$w^B(q_\alpha) = P(q_\alpha^B, \alpha),\ \forall \alpha \in \{l, h\}$; $w^B(q_h) - R^B(q_h) - [w^B(q_l) - R^B(q_l)] = D(q_h^B, h) - D(q_l^B, h)$.

Proposition 4 states the equivalence between the two structures. Formally, it shows that the two maximization programs are equivalent. Risk sharing is provided by the risk-neutral bank via the financial contract. As in the previous game, truthfull revelation implies underproduction for a low quality innovation. As the report is public, incentive compatibility constraints are similar to those of the previous game. The financial partner is therefore able to provide partial insurance to the research unit as the consumer firm did in the integrated structure commitment game. RU receives the same transfer from its R&D activity for the same production level and, therefore, the same utility level as in the integrated structure for all states of nature. All participation constraints are binding, thus no rents are allocated to agents. The high quality innovation benefit is shared between RU and F in the same way as it was between RU and C in the previous subsection, which implies the same level of investment. The intuition for the equivalence of the two organizational structures is the following. Since informational reports must be the same to C and F, it is as if these two agents were the same. C and F can then provide insurance to RU as efficiently in the independent structure as C can in the integrated structure.

The two structures are equivalent when agents can commit not to renegotiate or not to collude. Hence, asymmetric information with commitment and without collusion cannot help to explain the existence of different organizational forms of R&D activities. In the next section, we characterize and compare the two structures in a no-commitment game, that is, when agents cannot commit not to renegotiate and not to collude.

5 Asymmetric information with renegotiation and collusion

We introduce in this section the possibility for players to renegotiate the initial contract and the possibility for players to collude to extract rents from a third party. Under our assumptions, renegotation is likely to affect the allocation under the integrated structure, while collusion becomes a distinct possibility in the independent structure.

There are two potential instances in which players may want to renegotiate a contract. First, the arrival of information may create some opportunity for renegotiation. In the integrated structure, players may therefore want to renegotiate immediately after RU observes the state of nature but before it chooses a message. In that case, renegotiation, called interim renegotiation, would occur after stage 3 but before stage 4. In the independent structure, RU may want to renegotiate with F after observing the state of nature between stages 3 and 4. In a similar environment, Beaudry and Poitevin (1995) point out that allowing for interim renegotiation does not affect the equilibrium allocation of the game (see also Holmström and Myerson, 1983; Maskin and Tirole, 1992). The reason is that, before selecting an element in the menu of the outstanding contract, an offer to renegotiate is simply cheap talk which has no effect on the allocation. Allowing for interim renegotiation would therefore not change the results.

Second, the actual selection by RU of an element in the menu of the outstanding contract may also create some opportunity for renegotiation. This is called ex-post renegotiation. Players could renegotiate after RU has selected an element in the menu but before actions are actually executed. In the integrated structure, renegotiation would therefore occur at stage 4 after the message is sent to to firm C but before the innovation is developed and produced. In the independent structure, information is conveyed to C and F by the actual production of the innovated good, that is, RU communicates indirectly its information to its partner C through the action it executes. After the production project is developed, there is no room for renegotiation. Therefore, in the independent structure, the indirect mechanism is a commitment device not to renegotiate (See Beaudry and Poitevin, 1994; Caillaud, Jullien and Picard, 1995, for a discussion on this issue). For the above reasons, we restrict ourselves to ex post renegotiation.

In the independent structure, a principal contracts successively with two agents. The principal may be tempted to secretly agree with the agent at the second contracting stage, not to behave as prescribed by the first contract. More specifically, the research unit could secretly agree with firm C not to reveal the level of production implemented to F. RU could then select the lower financial contract payment in the menu by lying, with C's approval, on the innovation quality. The way such collusion is modelled in our paper is similar to that in Laffont and Martimort (1997). We allow the principal to include a report manipulation function in the development contract which specifies the message sent to F for each level of production implemented. To make the analysis interesting, we therefore have to assume that F cannot observe the production level.

5.1 The integrated structure

In an integrated structure, when agents cannot commit, they play the following game:

1. In the first stage, RU proposes a research and development contract $c_{RD} = \{I, \{w_\alpha, q_\alpha\}_{\alpha=l}^{h}\}$ to C.

2. In the second stage, C accepts or rejects the contract.

3. In the third stage (if reached), RU observes the innovation quality α.

4. In the fourth stage, the contract is carried out; that is, RU selects a message $\hat{\alpha} \in \{l, h\}$.

   (a) RU proposes a contract $c_r = (w, q)$.

   (b) C accepts or rejects the contract offer. If it is rejected, the contract c_{RD} remains the outstanding contract. If c_r is accepted, it becomes the outstanding contract. The innovation is then developed, produced, and sold while transfers are paid as prescribed by the outstanding contract.

In this game, a strategy for RU is represented by $\sigma_{RU} = \{c_{RD}, \hat{\alpha}(c_{RD}, \alpha), c_r(c_{RD}, \hat{\alpha}, \alpha)\}$, where c_{RD} is an initial contract offer, $\hat{\alpha}(.)$ represents RU's decision rule regarding the choice of a message $\hat{\alpha}$ and $c_r(.)$ is the renegotiation contract offer. The strategy of player C, $\sigma_C = \{d(c_{RD}), d_r(c_{RD}, \hat{\alpha}, c_r)\}$, represents its decision rules concerning the acceptance or rejection of the initial contract offer and the renegotiation contract offer, respectively. The beliefs of C are updated after stage 4.a and are denoted $P(\alpha | c_{RD}, \hat{\alpha}, c_r)$.

In this section, we characterize the equilibrium allocations that are not renegotiated along the equilibrium path, namely, renegotiation-proof allocations. We restrict our attention to the set of equilibrium allocations that can be supported by equilibrium strategies that do not involve any renegotiation.

Clearly, the integrated structure equilibrium allocation $\{I^A, \{w_\alpha^A, q_\alpha^A\}_{\alpha=l}^h\}$ derived in the previous section is not renegotiation-proof. Suppose that marginal profits are decreasing in α and that $\alpha = h$. Consider the following actions in stages 4 and 4.a: RU selects the report $\alpha = l$ and then offers the renegotiation allocation (w, q) with $q = q_{lh}^*$, where $q_{lh}^* = Argmax_q\{P(q,l) - D(q,h)\}$, and $w = P(q_{lh}^*, l) - [P(q_l^A, l) - w_l]$. C always accepts this renegotiation offer. Compared to the status quo, its utility is the same if it believes that the innovation quality is l and higher if it believes that the innovation quality is h. Therefore, C accepts this renegotiation offer for any beliefs. RU utility would then be:

$$V(w,q,l) = v(w_h^A - D(q_h^A, h) + \pi_{lh}(q_{lh}^*) - \pi_l(q_l^A)),$$

where $\pi_{\alpha\alpha'}(q)$ denotes the global profit for a gross profit $P(q,\alpha)$ and a development cost $D(q,\alpha')$, $\alpha' \neq \alpha$. This utility is higher than that obtained without renegotiating. Hence, the equilibrium allocation of the previous section is not renegotiation-proof. The following proposition provides necessary conditions that an allocation must satisfy to be renegotiation-proof.

Proposition 5 *An equilibrium allocation $\{I^A, \{w_\alpha^A, q_\alpha^A\}_{\alpha=l}^h\}$ of the integrated structure no commitment game must satisfy the following conditions.*

$$\begin{aligned} V(w_h, q_h, h) \geq Max_{(w,q)}\{&V(w,q,h) \ s/t \\ &U(w,q,h) \geq U(w_{\hat\alpha}^A, q_{\hat\alpha}^A, h) \\ &U(w,q,l) \geq U(w_{\hat\alpha}^A, q_{\hat\alpha}^A, l)\} \ \forall \hat\alpha = l, h \quad (RP_h^{\hat\alpha}) \\ V(w_l, q_l, l) \geq Max_{(w,q)}\{&V(w,q,l) \ s/t \\ &U(w,q,h) \geq U(w_{\hat\alpha}^A, q_{\hat\alpha}^A, h) \\ &U(w,q,l) \geq U(w_{\hat\alpha}^A, q_{\hat\alpha}^A, l)\} \ \forall \hat\alpha = l, h \quad (RP_l^{\hat\alpha}) \end{aligned}$$

The set of renegotiation-proof constraints $\{RP_\alpha^{\hat\alpha}\}_{\alpha,\hat\alpha=l,l}^{h,h}$ in Proposition 5 clearly illustrates the effect of ex post renegotiation on the equilibrium contract. These constraints are more stringent than the usual incentive-compatibility constraints, and therefore, they represent generalized incentive-compatibility constraints that incorporate the possibility of ex post renegotiation. Each constraint $RP_\alpha^{\hat\alpha}$ implies that, given a status quo position $(w_{\hat\alpha}, q_{\hat\alpha})$, C only accepts those renegotiation offers that increase its utility regardless of its beliefs. They are called surely acceptable renegotiation offers. Suppose that constraint $RP_\alpha^{\hat{\alpha}}$ is satisfied at a status quo position $(w_{\hat{\alpha}}^A, q_{\hat{\alpha}}^A)$. For any offer that RU prefers to $(w_{\hat{\alpha}}^A, q_{\hat{\alpha}}^A)$, there exists a belief for C such that it is worse off under the new offer than under the status quo position. When assigned with this belief, C simply rejects the offer of RU. If an allocation satisfies the constraint set $\{RP_\alpha^{\hat{\alpha}}\}_{\alpha,\hat{\alpha}=l,l}^{h,h}$, it is not possible for RU to increase its utility by selecting a message $\hat{\alpha} \in \{l, h\}$ and then offer a surely acceptable renegotiation. It is in this sense that the renegotiation-proof constraints represent generalized incentive-compatibility constraints.

In Proposition 6, we characterize one such allocation as an equilibrium allocation, namely, the allocation that yields RU the highest expected utility.

Proposition 6 *The allocation $\{I^A, \{w_\alpha^A, q_\alpha^A\}_{\alpha=l}^h\}$ that solves the following maximization problem is an equilibrium allocation.*

$$(P_R) \qquad Max_{\{I,\{w_\alpha,q_\alpha\}_{\alpha=l}^h\}} E[V(w_\alpha, q_\alpha, \alpha))|I] \;\; s/t$$

$$\begin{array}{rcll}
E_\alpha[U(w_\alpha, q_\alpha, \alpha)|I] - I & = & 0 & (IR^C) \\
V(w_h, q_h, h) & \geq & Max_{(w,q)} & \{V(w, q, h) \;\; s/t \\
& & & U(w, q, h) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, h) \\
& & & U(w, q, l) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, l)\} \;\; \forall \hat{\alpha} = l, h \quad (RP_h^{\hat{\alpha}}) \\
V(w_l, q_l, l) & \geq & Max_{(w,q)} & \{V(w, q, l) \;\; s/t \\
& & & U(w, q, h) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, h) \\
& & & U(w, q, l) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, l)\} \;\; \forall \hat{\alpha} = l, h \quad (RP_l^{\hat{\alpha}})
\end{array}$$

We now characterize the allocation of Proposition 6.

Proposition 7 *The solution to the P_R maximization problem satisfies the following relationships:*

- *If the marginal profit is negatively correlated with the marginal development cost,*
  $q_h^A = q_h^*$, $q_l^A = q_l^*$,
  $w_h^A - w_l^A = D(q_h^*, h) + \pi_{lh}(q_{lh}^*) - P(q_l^*, l)$.

- *If the marginal profit is positively correlated with the marginal development cost,*
  $q_h^A = q_h^*$, $\pi_l'(q_l^A) = \frac{\pi_{hl}'(q_l^A)p(I)(V_h^{A\prime} - V_l^{A\prime})}{E_\alpha[V_\alpha^{A\prime}|I^A]}$,
  $w_h^A - w_l^A = P(q_h^*, h) - P(q_l^A, h)$.

- $p'(I^A)\{(\frac{V_h^A - V_l^A}{E_\alpha[V_\alpha'^A|I^A]} + U_h^A - U_l^A\} = 1$.

With commitment, underproduction was chosen by RU in equilibrium in order to satisfy the incentive compatibility constraints without taking too much risk. Here, when the marginal profit is negatively correlated with the marginal development cost, renegotiation constraints do not allow underproduction for the low quality innovation or overproduction for the high quality one. Hence, no distortion can be used ex ante to induce truth-telling. RU has therefore to take on more risk. In the other case, underproduction for the low quality innovation is renegotiation-proof. It therefore arises to mitigate risk allocated to RU. In all cases, the wage difference is defined by the $\alpha = h$ and $\hat{\alpha} = l$ renegotiation-proof constraint which is binding. Investment is defined by the usual first-order condition and depends on risk sharing. We now move to the independent structure game.

5.2 The independent structure

In an independent structure, when agents can collude, they play the following game:

1. In the first stage, RU proposes a financial contract $c_F = \{I, \{R_{m(q_\alpha)}\}_{\alpha=l}^{h}\}$ to F.
2. In the second stage, F accepts or rejects the contract.
3. In the third stage (if reached), RU observes the innovation quality α.
4. In the fourth stage, RU proposes to C a development contract $c_D = \{w(q_\alpha), q_\alpha, m(q_\alpha)\}_{\alpha=l}^{h}$ which includes a secret manipulation report function $m(q_\alpha)$.
5. In the fifth stage, C accepts or rejects the contract.
6. In the sixth stage (if reached), the contract is carried out; that is RU implements the production level $q_{\hat{\alpha}}$ and the corresponding report $m(q_{\hat{\alpha}})$ is sent to F. The innovation is then developed, produced and sold while transfers are paid as prescribed by the contract.

In this game, a strategy for RU is represented by $\sigma_{RU} = \{c_F, c_D(c_F, \alpha), q_{\hat{\alpha}}(c_F, c_D, \alpha)\}$, where c_F and c_D are respectly the financial and development contract offers, and $q_{\hat{\alpha}}$ represents RU's decision rule regarding the choice of a message $q_{\hat{\alpha}}$. The strategy of player F, $\sigma_F = \{d(c_F)\}$, represents its decision rule concerning the acceptance or rejection of the financial contract offer. The strategy of player C, $\sigma_C = \{d(c_F, c_D)\}$, represents its decision rule concerning the acceptance or rejection of the development contract offer. The beliefs of C are updated and are denoted $P(\alpha | c_F, c_D)$.

We model collusion between RU and C as a secret report manipulation function:

$$m(q_{\hat{\alpha}}) : \ \{q_l, q_h\} \to \{l, h\}.$$

This function defines a report $m(q_{\hat{\alpha}})$ for each level of production $q_{\hat{\alpha}}$. For an indirect message $q_{\hat{\alpha}} \in \{q_l, q_h\}$ selected by RU, C and RU secretly agree to report the message $m(q_{\hat{\alpha}})$ to F. This collusive agreement allows RU to report, possibly, different direct and indirect messages $m(q_{\hat{\alpha}})$ and $q_{\hat{\alpha}}$ to C and F. Moreover, using the report manipulation function, RU can coordinate its communication activity with C. Even if C is asked by F to report the innovation quality or production level implemented, the development contract tells C to act as prescribed by the report manipulation function.

Clearly, the equilibrium allocation with commitment is not an equilibrium of this game. Assume that $\alpha = h$. If RU proposes the collusion agreement $m^B(q_\alpha) = l$ for all $q_\alpha \in \{q_l, q_h\}$, that is to report a low quality innovation to F regardless of the indirect message $q_{\hat{\alpha}}$, then RU's ex post utility is $v(\pi_h(q_h^*) - R_l^B)$. Since $R_h^B > R_l^B$, RU's pay off is increased when RU and C secretly agree to report $m(q_{\hat{\alpha}}) = l$ when $\alpha = h$. Hence, this allocation is not robust to a collusive agreement between RU and C, that is, it is not collusion-proof. Expecting the collusion, F would refuse to sign this contract.

In order to find the PBE allocation, we proceed by backward induction. We first consider the development contracting "subgame" starting at stage 3. We provide necessary and sufficient conditions for a development contract to be an equilibrium of this subgame for any given financial contract. Given this development contracting subgame equilibrium, we derive the equilibrium financial contract offered in stage 1.

Proposition 8 *For a given financial contract $\{\bar{I}, \{\bar{R}(q_\alpha)\}_{\alpha=l}^h\}$, an allocation $\{w^B(q_\alpha), q_\alpha^B, m^B(\alpha)\}_{\alpha=l}^h$ is an equilibrium allocation of the development contracting independent structure no commitment subgame if and only if it satisfies the following maximization problem.*

(P_{CD}) $\quad Max_{\{w(q_\alpha), q_\alpha, m(q_\alpha)\}_{\alpha=l}^h} E[V(w(q_\alpha) - \bar{R}_{m(q_\alpha)}, q_\alpha, \alpha))|\bar{I}]$ $\ s/t$

$$\begin{array}{rcll} U(w(q_h), q_h, h) & \geq & 0 & (IR_h^C) \\ U(w(q_l), q_l, l) & \geq & 0 & (IR_l^C) \\ V(w(q_h) - \bar{R}_{m(q_h)}, q_h, h) & \geq & V(w(q_l) - \bar{R}_{m(q_l)}, q_l, h) & (IC_h) \\ V(w(q_l) - \bar{R}_{m(q_l)}, q_l, l) & \geq & V(w(q_h) - \bar{R}_{m(q_h)}, q_h, l) & (IC_h) \end{array}$$

The effect of the report manipulation is captured in the incentive compatibility constraints. They state that RU proposes a secret report agreement that provides it incentives to reveal its information to player C. In Proposition 9, we characterize the equilibrium allocation of this subgame.

Proposition 9 *For any financial contract $\{\bar{I}, \{\bar{R}_{m(q_\alpha)}\}_{\alpha=l}^{h}\}$, the subgame equilibrium development contract satisfies the following relationships:*

- $w^B(q_h) = P(q_h^B, h)$, $w^B(q_l) = P(q_l^B, l)$.
- *If the marginal profit is negatively correlated with the marginal development cost,*
  $q_l^B = q_l^*$, $q_h^B = \begin{cases} q_h^* & if \quad \pi_l(q_l^*) \geq \pi_{hl}(q_h^*) \\ q_h^S & otherwise \end{cases}$
  with $q_h^S > q_h^*$ such that $\pi_l(q_l^*) = \pi_{hl}(q_h^S)$;
- *If the marginal profit is positively correlated with the marginal development cost,*
  $q_h^B = q_h^*$, $q_l^B = \begin{cases} q_l^* & if \quad \pi_h(q_h^*) \geq \pi_{lh}(q_l^*) \\ q_l^S & otherwise \end{cases}$
  with $q_l^S < q_l^*$ such that $\pi_h(q_h^*) = \pi_{lh}(q_l^S)$;
- $m^B(.)$ *is such that* $m^B(q_\alpha) = argmin_\alpha\{\bar{R}_\alpha\}$, $\forall q_\alpha \in \{q_l, q_h\}$.

Equilibrium wages are still defined by C's ex post binding participation constraints. In order to satisfy the incentive-compatibility constraints, production may be distorted for one innovation quality. Note that the development contract does not depend on the given financial contract. We now move back to the financial contracting game.

Proposition 10 *The equilibrium financial contract allocation is such that $Min_\alpha\{R_\alpha^B\} = I^B$. Therefore, in equilibrium, repayments equal investment in all states of nature; I^B is defined by:*

$$p'(I^B)\frac{V_h^B - V_l^B}{E[V_\alpha'^B|I^B]} = 1.$$

The main consequence of collusion is that F cannot provide any insurance since equilibrium repayments are the same in each state of nature. This financial contract can therefore be interpreted as a debt contract in which the initial amount lent I^B must be paid back at the end of the R&D process. Since RU takes all the research risk, investment is therefore determined by the incremental value of a high quality innovation compared to low quality one. We have shown that ex post collusion constrains RU's financial proposal to be a debt contract. Therefore, the possibility for collusion reduces the efficiency of the independent structure. Since the equilibrium financial contract is a debt contract, no information needs to be revealed to F. The development contract is therefore negotiated in a two-agent signalling environment. C's individual rationality constraints are binding. When the binding incentive constraint is that for a low (high) quality innovation, RU may overproduce (underproduces) when innovation quality is high (low) in order to satisfy this constraint. In the next section, we endogenize the organizational choice of R&D activities.

6 Performance of the two structures without commitment

Suppose now that the organizational choice of R&D activities is endogenized. RU's decision as to whether produce an innovation in an integrated structure or in an independent structure depends on his expected utility under each structure. In this section, we compare the two organizational structures. The results of our comparative static analyses are summarized in Proposition 12.

Proposition 11 *When the marginal cost of developing the innovation is positively correlated with its marginal profit and if q_l^* is relatively close to q_h^*, the independent structure dominates. The integrated structure dominates in the opposite case.*

Proposition 12 states that, depending on the technology, a structure dominates. First, this result has a testable implication. The correlation between the marginal development cost and the marginal receipt of a new product must be negative (positive) for in-house (independent) R&D. The correlation between the marginal development cost and the marginal drasticity of a new process must be positive (negative) for in-house (independent) R&D. Second, we can identify industries, technologies or products for which one or the other condition holds.

For instance, consider the R&D process in the pharmaceutical industry described in the introduction. Development activities consist in testing the new drug. The development process starts from toxicology analyses and goes through clinical trial on animals, human volunteers and then patients (small samples and then large samples). The molecule must be patented before entering in the trial process. The patent-protection lasts twenty years and the trial process can take several years.[6] Saving time during the development phase is therefore particularly important. Every day saved on trial is an extra day of patent-protection saved. The trial period of an innovation costly to develop is long and therefore lowers its patent-protection and, finally, the gross profit of the pharmaceutical compagny. When this timming aspect is important, the R&D activities are more efficiently organized in-house.

[6]The Economist, February 21st, 1998, Tapon and Calsby (1996).

For technological innovation, it is often the case that when the cost to install a new technology is high, the saving on production cost is high. Consider the information technology industry. Suppose that a firm can reduce its costs by using a more efficient communication network. A new telecommunication network is costly to install but can treat a lot of information very quickly. An improvment of the existing network is cheap to install but it is usually less efficient. In this case, development costs are negatively correlated to production costs. Another example is the computer industry. When a new version of an existing software or system is adopted by a firm, the costs incured by the research unit (mostly the training of the user firm's employers) is low. When the software or the system is very different, and therefore needs more training, the saving on production costs could be very high. In these two cases, innovation tends to be produced by an independent firm.

7 Conclusion

This paper studies the optimal structure of R&D activities in a model with a random research process, asymmetric information about its outcome and heterogeneity in agents' attitude toward risk. We prove that, while the two structures are equivalent in a full commitment world, this result is not true when players are allowed to renegotiate and collude. In the integrated structure, RU has incentives to renegotiate after the report is made. It has to take more risk by proposing ex-post efficient production levels and by increasing the wage difference. In the independent structure, RU is tempted to secretly agree with C to manipulate the message sent to F. Therefore the financial contract must be a debt contract and F cannot provide any insurance to RU. However, RU can mitigate the risk taken by distorting the production level.

We found that the integrated structure dominates the independent struture when the marginal cost of developing the innovation is positively correlated with its marginal profit. That is when an innovation cheap to develop creates a more drastic process innovation or a product innovation with a higher market value. The independent structure may perform better than the integrated structure in the opposite case. This result provides a testable implication of our model. Our approach explains how the organizational structure of R&D activities depends on the technological properties of innovations for each industry.

A Proof of Proposition 1

We shall first show by contradiction that the equilibrium allocation must be the solution to problem P_A. Sufficiency will then be shown by constructing strategies and beliefs that support this equilibrium allocation as a PBE outcome of the game. Let c^c_{RD} represent a candidate equilibrium contract and let $\{I^c, \{w^c_\alpha, q^c_\alpha\}^h_{\alpha=l}\} \neq \{I^A, \{w^A_\alpha, q^A_\alpha\}^h_{\alpha=l}\}$ be the corresponding equilibrium allocation. Let us also assume that $\{I^c, \{w^c_\alpha, q^c_\alpha\}^h_{\alpha=l}\}$ is such that:

$$E_\alpha[V(w^c_\alpha, q^c_\alpha, \alpha)|I^c] > E_\alpha[V(w^A_\alpha, q^A_\alpha, \alpha)|I^A]$$

Then, this allocation does not satisfied one of the P_A maximization constraints.

- If $E_\alpha[U(w^c_\alpha, q^c_\alpha, \alpha)|I^c] - I^c < 0$, then C's best replies would be to refuse RU's offer. RU utility remains to its reservation level although it could earn a positive gain and then do better if it deviates and offers $\{I^A, \{w^A_\alpha, q^A_\alpha\}^h_{\alpha=l}\}$.
- If one of the two incentive compatibility constraints is not satisfied, that is if $\exists \alpha', \alpha'' \in \{l, h\}, \alpha' \neq \alpha''$ such that:

$$V(w^c_{\alpha''}, q^c_{\alpha''}, \alpha'') < V(w^c_{\alpha'}, q^c_{\alpha'}, \alpha'')$$
$$V(w^c_{\alpha'}, q^c_{\alpha'}, \alpha') \geq V(w^c_{\alpha''}, q^c_{\alpha''}, \alpha')$$

  In this case, in the sixth stage, RU's dominant strategy is to announce a quality innovation α' for all state of natures $\alpha \in \{l, h\}$. This behaviour is expected by C. Hence a necessary condition to accept such contract offer is that $E_\alpha[U(w^c_{\alpha'}, q^c_{\alpha'}, \alpha)|I^c] - I^c \geq 0$. RU's expected utility is $E_\alpha[V(w^c_{\alpha'}, q^c_{\alpha'}, \alpha)|I^c]$ which is less than $E_\alpha[V(w^A_\alpha, q^A_\alpha, \alpha)|I^A]$ since the allocation $\{I^c, \{(w^c_{\alpha'}, q^c_{\alpha'}), (w^c_{\alpha'}, q^c_{\alpha'})\}$ statisfies the incentive compatibility constraints.

Suppose now that $\{I^c, \{w^c_\alpha, q^c_\alpha\}^h_{\alpha=l}\}$ is such that:

$$E_\alpha[V(w^c_\alpha, q^c_\alpha, \alpha)|I^c] < E_\alpha[V(w^A_\alpha, q^A_\alpha, \alpha)|I^A]$$

Then $\exists$ an allocation $\{I^e, \{w^e_\alpha, q^e_\alpha\}^h_{\alpha=l}\}$ which satisfied the P_A maximization problem's constraints and such that:

$$E_\alpha[V(w^e_\alpha, q^e_\alpha, \alpha)|I^e] > E_\alpha[V(w^c_\alpha, q^c_\alpha, \alpha)|I^c]$$

The allocation $\{I^c, \{w^c_\alpha, q^c_\alpha\}^h_{\alpha=l}\}$ is not an equilibrium allocation because RU can increase its expected utility if it deviates and offers $\{I^e, \{w^e_\alpha, q^e_\alpha\}^h_{\alpha=l}\}$.

The following strategies and beliefs support the equilibrium allocation as a PBE outcome.

$$\sigma_{RU} = \begin{cases} c_{RD} = c^A_{RD} = \{I^A, \{w^A_\alpha, q^A_\alpha\}^h_{\alpha=l}\} \\ \hat{\alpha}(c_{RD}, \alpha) = argmax_{\hat{\alpha} \in \{l,h\}} V(w_{\hat{\alpha}}, q_{\hat{\alpha}}, \alpha) \end{cases}$$

$$\sigma_C = d_C(c_{RD}) = \begin{cases} 1 \quad if \quad E_\alpha[U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, \alpha)|I] - I \geq 0 \\ 0 \quad otherwise \end{cases}$$

It is easy to verify that these strategies and beliefs do in fact constitute a PBE. In stage 4, RU selects the element it prefers most in the menu given the outstanding contract c_{RD}. These strategies condition C's acceptance decision of the contract d_C in stage 2: it accepts only contract that satisfy its participation constraint given the expected resolution of c_{RD}, that is, given the incentive constraints of the principal and it choice $\hat{\alpha}(c_{RD}, \alpha)$. In the first stage, RU offers its most preferred contract in the set of contracts that are acceptable to C. Along the equilibrium path, we thus have $c_{RD} = c^A_{RD}$, $d_C(c^A_{RD}) = 1$ and $\hat{\alpha}(c^A_{RD}, \alpha) = \alpha$ for all α.

B Proof of Proposition 2

Let λ^C and μ_α be the multipliers associated with the constraints IR^C and IC_α respectively. The equilibrium allocation $\{I^A\{w^A_\alpha, q^A_\alpha\}^h_{\alpha=l}\}$ satisfies the following first order conditions (FOC):

$$\begin{aligned}
p(I^A)v'(w^A_h - D(q^A_h, h)) + (1-p(I^A))v'(w^A_l - D(q^A_l, l)) &= \lambda^C \\
P_q(q^A_h, h) - D_q(q^A_h, h) &= \frac{\mu_l}{\lambda^C p(I^A)}[D_q(q^A_h, h) - D_q(q^A_h, l)] \\
P_q(q^A_l, l) - D_q(q^A_l, l) &= \frac{\mu_h}{\lambda^C(1-p(I^A))}[D_q(q^A_l, l) - D_q(q^A_l, h)] \\
\frac{v(w^A_h - D(q^A_h, h)) - v(w^A_l - D(q^A_l, l))}{\lambda^C} & \\
+P(q^A_h, h) - w^A_h - [P(q^A_l, l) - w^A_l] &= \frac{1}{p'(I^A)}
\end{aligned}$$

We shall first show, in two steps and by contradiction, that the incentive constraint for state of nature h is binding, that is, $\mu_h > 0$.

Step 1: Proof that only one of the incentive compatibility constraints is binding.

Suppose that the two IC constraints are binding, that is $\mu_h > 0$ and $\mu_l > 0$ in the FOC. We have the following relationships:

$$v(w^A_h - D(q^A_h, h)) = v(w^A_l - D(q^A_l, h))$$

$$v(w^A_l - D(q^A_l, l)) = v(w^A_h - D(q^A_h, l))$$

which imply:

$$w^A_h - w^A_l = D(q^A_h, h) - D(q^A_l, h)$$

$$w^A_h - w^A_l = D(q^A_h, l) - D(q^A_l, l).$$

This is true only when $q^A_h = q^A_l$, that is, the equilibrium is pooling. However, it is a well known result that the solution is screening since the utility functions satisfy the single crossing property.

Step 2: Proof of $\mu_h > \mu_l$.

Suppose that $\mu_h < \mu_l$, by the FOC, we have $v'(w^A_h - D(q^A_h, h)) - \lambda = \mu_l - \mu_h$. Hence, under our assumption, $v'(w^A_h - D(q^A_h, h)) > \lambda$. Then,

$$v'(w^A_h - D(q^A_h, h)) > p(I^A)v'(w^A_h - D(q^A_h, h)) + (1-p(I^A))v'(w^A_l - D(q^A_l, l))$$

$$\Rightarrow v'(w^A_h - D(q^A_h, h) > v'(w^A_l - D(q^A_l, l))$$

$$\Rightarrow v(w^A_h - D(q^A_h, h)) < v(w^A_l - D(q^A_l, l))$$

This inequality implies that one of the incentive-compatibility constraints is not satisfied, therefore $\{I^A\{w^A_\alpha, q^A_\alpha\}^h_{\alpha=l}\}$ is not a solution to the maximization problem. In the third FOC, we have $\mu_h > 0$ and $D_q(q, h) - D_q(q, l) < 0$ $\forall q$ in the right-hand side, therefore the left-hand side is negative and there is underproduction for a low quality innovation. The wage gap is defined by the binding incentive constraint:

$$w^A_h - w^A_l = D(q^*_h, h) - D(q^A_l, h).$$

The first and the last FOCs give us the investment level I^A:

$$p'(I^A)\{\frac{V_h^A - V_l^A}{E_\alpha[V_\alpha'^A|I^A]} + U_h^A - U_l^A\} = 1.$$

C Proof of Proposition 3

We shall first show by contradiction that the equilibrium allocation must be the solution to problem P_B. Sufficiency will then be shown by constructing strategies and beliefs that support this equilibrium allocation as a PBE outcome of the game. Let $\{I^c, \{R^c(q_\alpha), w^c(q_\alpha), q_\alpha^c\}_{\alpha=l}^h\} \neq \{I^B, \{R^B(q_\alpha), w^B(q_\alpha), q_\alpha^B\}_{\alpha=l}^h\}$ represents a candidate allocation of the c_F^c and c_D^c corresponding financial and development contracts. Let us also assume that $\{I^c, \{R^c(q_\alpha), w^c(q_\alpha), q_\alpha^c\}_{\alpha=l}^h\}$ is such that:

$$E_\alpha[V(w^c(q_\alpha) - R^c(q_\alpha), q_\alpha^c, \alpha)|I^c] > E_\alpha[V(w^B(q_\alpha) - R^B(q_\alpha), q_\alpha^B, \alpha)|I^B]$$

Then, this allocation does not satisfy one of the P_B maximization constraints.

- If $E_\alpha[R^c(q_\alpha)|I^c] - I^c < 0$, then F's best reply would be to refuse RU's offer. RU utility remains to its reservation level although it could earn a positive gain and then do better if it deviates and offers $\{I^B, \{R^B(q_\alpha), w^B(q_\alpha), q_\alpha^B\}_{\alpha=l}^h\}$.
- If $\exists q_{\bar{\alpha}} \in \{q_l, q_h\} : U(w^c(q_{\bar{\alpha}}), q_{\bar{\alpha}}^c, \alpha) < 0$, then C's best reply would be to refuse RU's offer when $\alpha = \bar{\alpha}$. RU utility remains at its reservation level when $\alpha = \bar{\alpha}$ although it could earn a positive gain and then do better if it deviates and offers $\{I^B, \{R^B(q_\alpha), w^B(q_\alpha), q_\alpha^B\}_{\alpha=l}^h\}$.
- If one of the two incentive compatibility constraint is not satisfied, that is if $\exists \alpha', \alpha'' \in \{l, h\}, \alpha' \neq \alpha''$ such that:

  $$V(w^c(q_{\alpha''}) - R^c(q_{\alpha''}), q_{\alpha''}^c, \alpha'') < V(w^c(q_{\alpha'}) - R^c(q_{\alpha'}), q_{\alpha'}^c, \alpha'')$$

  $$V(w^c(q_{\alpha'}) - R^c(q_{\alpha'}), q_{\alpha'}^c, \alpha') \geq V(w^c(q_{\alpha''}) - R^c(q_{\alpha''}), q_{\alpha''}^c, \alpha')$$

  In this case, in the sixth stage, RU's dominant strategy is to implement $q_{\alpha'}$ for all states of nature $\alpha \in \{l, h\}$. This behaviour is then expected by F. Hence, a necessary condition to accept such contract offer is that $E_\alpha[R^c(q_{\alpha'})|I^c] - I^c \geq 0$ which implies that $R^c(q_\alpha) = I^c$, $\forall \alpha \in \{l, h\}$. However, RU's expected utility is higher with c_F^B and c_D^B than with any other allocation which satisfies this individual rationality constraint for F. This contradicts the fact that c_F^c and c_D^c is an equilibrium allocation of this game.

Suppose now that $\{I^c, \{R_\alpha^c, w_\alpha^c, q_\alpha^c\}_{\alpha=l}^h\}$ is such that:

$$E_\alpha[V(w^c(q_\alpha) - R^c(q_\alpha), q_\alpha^c, \alpha)|I^c] < E_\alpha[V(w^B(q_\alpha) - R^B(q_\alpha), q_\alpha^B, \alpha)|I^B].$$

Then there exists an allocation $\{I^e, \{R^e(q_\alpha), w^e(q_\alpha), q_\alpha^e\}_{\alpha=l}^h\}$ which satisfied the P_B maximization problem's constraints and such that:

$$E_\alpha[V(w^e(q_\alpha) - R^e(q_\alpha), q_\alpha^e, \alpha)|I^e] > E_\alpha[V(w^c(q_\alpha) - R^c(q_\alpha), q_\alpha^c, \alpha)|I^c]$$

The allocation $\{I^c, \{R^c(q_\alpha), w^c(q_\alpha), q_\alpha^c\}_{\alpha=l}^h\}$ is not an equilibrium allocation because RU can increase its expected utility if it deviates and offers $\{I^e, \{R^e(q_\alpha), w^e(q_\alpha), q_\alpha^e\}_{\alpha=l}^h\}$.

The following strategies and beliefs support the equilibrium allocation as a PBE outcome.

$$\sigma_{RU} = \begin{cases} c_F = c_F^B = \{I^B, \{R^B(q_\alpha)\}_{\alpha=l}^h\} \\ c_D(\alpha) = c_D^B = \{w^B(q_\alpha), q_\alpha^B\}_{\alpha=l}^h \\ q_{\hat{\alpha}}(c_F^B, c_D^B, \alpha) = argmax_{q_{\hat{\alpha}} \in \{q_l, q_h\}} V(w(q_{\hat{\alpha}}) - R(q_{\hat{\alpha}}), q_{\hat{\alpha}}, \alpha) \end{cases}$$

$$\sigma_F = d_F(c_F) = \begin{cases} 1 & if \quad E_\alpha[R_{\hat{\alpha}}|I] - I \geq 0 \\ 0 & otherwise \end{cases}$$

$$\sigma_C = d_C(c_D) = \begin{cases} 1 & if \quad U(w(q_{\hat{\alpha}}), q_{\hat{\alpha}}, \alpha) \geq 0 \quad \forall \alpha \in \{l, h\} \\ 0 & otherwise \end{cases}$$

$$P(h|c_D) = \begin{cases} 1 & if \quad argmax_{\hat{\alpha} \in \{l,h\}} V(w(q_{\hat{\alpha}}) - R(q_{\hat{\alpha}}), q_{\hat{\alpha}}, \alpha) = h \\ 0 & otherwise \end{cases}$$

$$P(l|c_D) = 1 - P(h|c_D)$$

We shall now argue that these strategies and beliefs do in fact constitute a PBE. In stage 4, RU selects the element it prefers most in the menu given the outstanding contracts c_D and c_F. These strategies condition C's acceptance decision of the contract d_C in stage 5: it accepts only those contracta which satisfy its participation constraints given the expected resolution of c_D, that is, given the incentive constraints of the principal and it choice $q_{\hat{\alpha}}(c_F^B, c_D^B, \alpha)$. These strategies condition also F's acceptance decision of the contract d_C in stage 2: he accepts only his participation constraint given the expected resolution of c_F. In the first stage, RU offers its most preferred contract in the set of contracts that are acceptable to C. Along the equilibrium path, we thus have $c_F = c_F^B$, $c_D = c_D^B$, $d_F(c_F^B) = 1$, $d_C(c_D^B) = 1$ and $q_{\hat{\alpha}}(c_F^B, c_D^B, \alpha) = q_\alpha^B$ for all α.

D Proof of Proposition 4

We shall first show by contradiction that C's individual rationality constraints are binding in equilibrium hence transfers are defined by this constraints. Then, we prove the equivalence of the two maximization problems P_A and P_B.

Suppose that $\exists \alpha \in \{l, h\}$ such that $P(q_\alpha^B, \alpha) - w^B(q_\alpha) > 0$. If we increase by the same amount $w^B(q_\alpha)$ and $R^B(q_\alpha)$, we could increase investment I^B without breaking up one of the P_B problem maximization constraints. RU's expected utility is increased by this alternative allocation thus the principal would gain by choosing it. The equilibrium allocation must satisfied $P(q_\alpha^B, \alpha) - w^B(q_\alpha) = 0$ $\forall \alpha \in \{l, h\}$. Wages are defined by the RI_α^C constraints $\forall \alpha \in \{l, h\}$: $w(q_\alpha) = P(q_\alpha, \alpha)$. We now define a new variable to show that the two maximization problems are equivalent. Suppose $x(q_\alpha) = w(q_\alpha) - R(q_\alpha)$.

The independent structure commitment game maximization program can be rewritten as:

$(P_B) \quad Max_{\{I, \{x(q_\alpha), q_\alpha\}_{\alpha=l}^h\}} E[V(x(q_\alpha), q_\alpha, \alpha))|I] \;\; s/t$

$$\begin{array}{rcll} p(I)(P(q_h, b) - x(q_h)) + (1 - p(I))(P(q_l, l) - x(q_l)) & \geq & 0 & (RI^F) \\ v(x(q_h) - D(q_h, h)) & \geq & v(x(q_l) - D(q_l, h)) & (IC_h) \\ v(x(q_l) - D(q_l, l)) & \geq & v(x(q_h) - D(q_h, l)) & (IC_l) \end{array}$$

This is P_A maximization problem.

E Proof of Proposition 5

We have to show that the constraints $RP_{\alpha}^{\hat{\alpha}}$ for all α and $\hat{\alpha}$ included in $\{l, h\}$ are necessary to describe equilibrium allocation of this game.

If the R&D contract is not renegotiated, it will be the implemented contract and it must therefore satisfy C's participation constraint in equilibrium. Suppose that for $\alpha' \in \{l, h\}$ and $\hat{\alpha} = \alpha'$, $RP_{\alpha'}^{\alpha'}$ is not satisfied. Consider the following strategies. In stage 4, RU selects $\hat{\alpha} = \alpha'$ if $\alpha = \alpha'$, in stage 4.a it proposes the allocation (w^*, q^*) that solves the $RP_{\alpha'}^{\hat{\alpha}'}$ maximization problem. In stage 4.b, it is an undominated strategy for C to accept this renegotiation offer since it increases its utility whatever its beliefs. The allocation is therefore not renegotiation-proof.

Suppose now that for $\alpha' \in \{l, h\}$ and $\hat{\alpha} = \alpha'' \neq \alpha'$, $RP_{\alpha'}^{\hat{\alpha}''}$ is not satisfied. Consider the following strategies. In stage 4, RU offers select $\hat{\alpha} = \alpha''$ if $\alpha = \alpha'$, in stage 4.a RU proposes the allocation (w^*, q^*) that solves the $RP_{\alpha'}^{\hat{\alpha}''}$ maximization problem. In stage 4.b, it is a undominated strategy for C to accept this renegotiation offer since it increases its utility whatever its beliefs. The allocation is therefore not renegotiation-proof. Hence, all constraints of Proposition 5 must be satisfies for an allocation to be renegotiation-proof.

F Proof of Proposition 6

Define $(w_{\alpha}^{*\hat{\alpha}}, q_{\alpha}^{*\hat{\alpha}}) = argmax_{(w,q)} V(w, q, \alpha)$ s/t $U(w, q, h) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, h)$ and $U(w, q, l) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, l)\}$. The following strategies and beliefs support the equilibrium allocation as a PBE outcome.

$$\sigma_{RU} = \begin{cases} c_{RD} = & c_{RD}^A = \{I^A, \{w_{\alpha}^A, q_{\alpha}^A\}_{\alpha=l}^h\} \\ \hat{\alpha}(c_{RD}, \alpha) = & argmax_{\tilde{\alpha} \in \{l,h\}} V(w_{\tilde{\alpha}}^{*\hat{\alpha}}, q_{\tilde{\alpha}}^{*\hat{\alpha}}, \alpha) \\ c_r(c_{RD}, \hat{\alpha}, \alpha) = & \begin{cases} (w_{\alpha}^{*\hat{\alpha}}, q_{\alpha}^{*\hat{\alpha}}) & if \quad V(w_{\alpha}^{*\hat{\alpha}}, q_{\alpha}^{*\hat{\alpha}}, \alpha) > V(w_{\hat{\alpha}}, q_{\hat{\alpha}}, \alpha) \\ \emptyset & otherwise. \end{cases} \end{cases}$$

$$\sigma_C = \begin{cases} d_C(c_{RD}) = & \begin{cases} 1 & if \quad E_{\alpha}[U(w_{\alpha}, q_{\alpha}, \alpha)|I] - I \geq 0 \\ 0 & otherwise \end{cases} \\ d_r(c_{RD}, \hat{\alpha}, c_r) = & \begin{cases} 1 & if \quad U(w, q, \alpha) \geq U(w_{\alpha}, q_{\alpha}, \alpha) \quad \forall \alpha \in \{l, h\} \\ 0 & otherwise \end{cases} \end{cases}$$

$$P(h|c_{RD}, \hat{\alpha}, c_r) = \begin{cases} 0 & if \quad c_r \neq \emptyset \quad and \quad U(w, q, h) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, h) \quad and \quad U(w, q, l) < U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, l) \\ 0 & if \quad c_r = \emptyset \quad and \quad \hat{\alpha} = l \\ 1 & otherwise \end{cases}$$

$$P(l|c_{RD}, \hat{\alpha}, c_r) = 1 - P(h|c_{RD}, \hat{\alpha}, c_r)$$

where $d = 1$ means acceptance and $d = 0$, rejection. We shall now argue that these strategies and beliefs do in fact constitute a PBE.

In stage 4.b, C accepts the new contract offer c_r if and only if (w, q) is preferred to the initial allocation selected $(w_{\hat{\alpha}}, q_{\hat{\alpha}})$ regardless of its beliefs. Given this acceptance rule by C, RU can do not better than offer in stage 4.a its preferred contract among those accepted by C. In stage 2, RU accepts all contract offers yielding an expected pay-off of 0 given the expected resolution of the game following the initial offer. Finally, in stage 1, RU offers its preferred contract among those expected to be accepted by C.

These strategies and beliefs imply the following equilibrium path. In stage 1, RU offers the contract c_{RD}^A which is accepted by player 2 in stage 2. In stage 4, for each innovation quality α, RU selects its preferred report $\hat{\alpha}$. In stage 4.a, it makes no offer. Given that $\{I^A, \{w_\alpha^A, q_\alpha^A\}_{\alpha=l}^h\}$ satisfies the constraints of the maximization problem, the contract c_{RD}^A cannot be renegotiated in stage 4.a given the equilibrium strategy of C. With this strategies along the equilibrium path, it is clear that the allocation is renegotiation proof.

G Proof of Proposition 7

Case 1: We first consider the case of a total and marginal profit decreasing with α, that is:

$$P(q,h) > P(q,l),\ P_q(q,h) > P_q(q,l)\ \forall q > 0.$$

The proof proceed as follow. First, we show that constraints RP_h^h and RP_l^l are respectively equivalent to $q_h \in [q_{lh}^*, q_h^*]$ and $q_l \in [q_l^*, q_{hl}^*]$. Second, we derive the solution to the constraints RP_h^l and RP_l^h maximization problem. Thirst, we prove that $q_h^A = q_h^*$ and $q_l^A = q_l^*$. Fourth, we show that RP_l^h is not binding so that the wage difference is defined by RP_h^l constraint. Then we derive the equilibrium allocation.

The renegotiation proof constraints can be rewritten:

$$\begin{aligned}
w_h - D(q_h,h) \geq Max_{(w,q)}\{&w - D(q,h)\ s/t \\
&P(q,h) - w \geq P(q_h,h) - w_h \\
&P(q,l) - w \geq P(q_h,l) - w_h\} \quad (RP_h^h) \\
w_h - D(q_h,h) \geq Max_{(w,q)}\{&w - D(q,h)\ s/t \\
&P(q,h) - w \geq P(q_l,h) - w_l \\
&P(q,l) - w \geq P(q_l,l) - w_l\} \quad (RP_h^l) \\
w_l - D(q_l,l) \geq Max_{(w,q)}\{&w - D(q,l)\ s/t \\
&P(q,h) - w \geq P(q_h,h) - w_h \\
&P(q,l) - w \geq P(q_h,l) - w_h\} \quad (RP_l^h) \\
w_l - D(q_l,l) \geq Max_{(w,q)}\{&w - D(q,l)\ s/t \\
&P(q,h) - w \geq P(q_l,h) - w_l \\
&P(q,l) - w \geq P(q_l,l) - w_l\} \quad (RP_l^l)
\end{aligned}$$

- Proof that RP_h^h and RP_l^l are equivalent to, respectively, $q_h \in [q_{lh}^*, q_h^*]$ and $q_l \in [q_l^*, q_{hl}^*]$.

  - Proof that RP_h^h implies $q_h \in [q_{lh}^*, q_h^*]$.

    Suppose that $q_h > q_h^*$. When $\alpha = h$, this allocation is not renegotiation-proof: RU can increase its gain by selecting $\hat{\alpha} = h$ and offering $q = q_h^*$ and $w = P(q_h^*, l) - [P(q_h, l)] + w_h$. This renegotiation offer is accepted by C for any beliefs and $v(w - D(q,h)) = v(w_h - D(q_h,h) + \pi_{lh}(q_h^*) - \pi_{lh}(q_h))$ which is higher than $v(w_h - D(q_h,h))$. Therefore, the renegotiation proof constraint for a innovation quality $\alpha = h$ and a message $\hat{\alpha} = h$ is not satisfied for all $q_h > q_h^*$.

    Suppose that $q_h < q_{hl}^*$. When $\alpha = h$, this allocation is not renegotiation-proof: RU can increase its gain by selecting $\hat{\alpha} = h$ and offering $q = q_{lh}^*$ and $w = P(q_{lh}^*, h) - [P(q_h, h) - w_h]$. This renegotiation offer is accepted by C for any beliefs and $v(w - D(q,h)) = v(w_h - D(q_h,h) + \pi_h(q_{lh}^*) - \pi_h(q_h))$ which is higher than $v(w_h - D(q_h,h))$.

Therefore, the renegotiation proof constraint for a innovation quality $\alpha = h$ and a message $\hat{\alpha} = h$ is not satisfied for all $q_h < q_{lh}^*$.

- Proof that any allocation such that $q_h \in [q_{lh}^*, q_h^*]$ satisfies RP_h^h.

  Assume that $q_h \in [q_{lh}^*, q_h^*]$. If RU proposes a production renegotiation offer $q < q_h$ then w must be less than $P(q,h) - [P(q_h,h)] + w_h$ to be accepted by C. RU's utility with an accepted renegotiation offer is at least $v(w - D(q,h)) = v(w_h - D(q_h,h) + \pi_h(q) - \pi_h(q_h))$ which is lower than $v(w_h - D(q_h,h))$.

  If RU proposes a production renegotiation offer $q > q_h$ then w must be less than $P(q,l) - [P(q_h,l) - w_h]$ to be accepted by C. RU's utility with this accepted renegotiation offer is at least $v(w - D(q,h)) = v(w_h - D(q_h,h) + \pi_{lh}(q) - \pi_{lh}(q_h))$ which is lower than $v(w_h - D(q_h,h))$.

- By a similar proof, we can show that RP_l^l is equivalent to $q_l \in [q_l^*, q_{hl}^*]$.

- Solution to the RP_h^l maximization problem.

Let (w_l^r, q_l^r) be the renegotiation offer solution to the RP_h^l maximization problem. We consider two cases: $q_l^r < q_l$ and $q_l^r \geq q_l$. Suppose that $q_l^r < q_l$, w_l^r is defined by the following constraint:

$$w_l^r = P(q_l^r, h) - [P(q_l,h) - w_l].$$

With this offer, RU's gain is:

$$w_l^r - D(q_l^r, h) = \pi_h(q_l^r) - \pi_h(q_l) + w_l - D(q_l,h),$$

which is less that $w_l - D(q_l,h)$. This allocation (w^*, q^*) is not a solution to RP_h^l problem: RU can be better off if it proposes (w_l, q_l) rather than (w_l^r, q_l^r).

Suppose now that $q_l^r \geq q_l$, w_l^r is defined by the following constraint:

$$w_l^r = P(q_l^r, l) - [P(q_l,l) - w_l].$$

With this offer, RU's gain is:

$$w_l^r - D(q_l^r, h) = \pi_{lh}(q_l^r) - \pi_{lh}(q_l) + w_l - D(q_l,h).$$

We now consider two cases.

1. If $q_l > q_{lh}^*$, then

$$\pi_{lh}(q_l^r) - \pi_{lh}(q_l) < 0, \forall q_l^r > q_l.$$

   Hence, the best surely acceptable renegotiation offer is $q_l^r = q_l$ and $w_l^r = w_l$. The solution to the RP_h^l maximization problem is:

$$w_l - D(q_l,h).$$

   In this case, RP_h^l is the usual incentive constraint.

2. If $q_l \le q_{lh}^*$, then the best surely acceptable renegotiation offer is $q_l^r = q_{lh}^*$, $w_l^r = P(q_{lh}^*, l) - [P(q_l, l) - w_l]$.

   The solution to the RP_h^l maximization problem is:

$$\pi_{lh}(q_{lh}^*) - \pi_{lh}(q_l) + w_l - D(q_l, h).$$

The constraint RP_h^l can be summarized by:

$$w_h - D(q_h, h) \ge \pi_{lh}(q_l^r) - \pi_{lh}(q_l) + w_l - D(q_l, h),$$

where $q_l^r = Max\{q_l, q_{lh}^*\}$.

- Solution to the RP_l^h maximization problem.

  By a similar proof, we can show that the constraint RP_l^h can be summarized by:

$$w_l - D(q_l, l) \ge \pi_{hl}(q_h^r) - \pi_{hl}(q_h) + w_h - D(q_h, l),$$

where $q_h^r = Min\{q_h, q_{hl}^*\}$.

- Proof that $q_h^A = q_h^*$.

  Suppose first that $q_h^A < q_{hl}^*$. We prove that, if q_h^A is increased by $\epsilon > 0$ and w_h^A is reduced by $\delta > 0$ such that $w_h^A - D(q_h^A, l) = (w_h^A - \delta) - D(q_h^A + \epsilon, l)$, then all constraints are satisfied and RU's utility is higher. With $\{I^A, (w_l^A, q_l^A), (w_h^A - \delta, q_h^A + \epsilon)\}$, the constraints RP_h^h, RP_l^l and RP_h^l are satisfied and we have:

$$P(q_h^A + \epsilon, h) - (w_h^A - \delta) = \pi_{hl}(q_h^A + \epsilon) - \pi_{hl}(q_h^A) + [P(q_h^A, h) - w_h^A].$$

Since $q_{hl}^* > q_h^A$, then $P(q_h^A + \epsilon, h) - (w_h^A - \delta) > P(q_h^A, h) - w_h^A$ and the constraint IR^C still holds. Moreover, we have:

$$(w_h^A - \delta) - D(q_h^A + \epsilon, h) = w_h^A - D(q_h^A, h) + D(q_h^A + \epsilon, l) - D(q_h^A, l) + D(q_h^A + \epsilon, h) - D(q_h^A, h).$$

Since $(w_h^A - \delta) - D(q_h^A + \epsilon, h) > w_h^A - D(q_h^A, h)$, the constraint RP_l^h is satisfied and $\{I^A, (w_l^A, q_l^A), (w_h^A - \delta, q_h^A + \epsilon)\}$ gives RU a higher expected pay-off than $\{I^A, (w_l^A, q_l^A), (w_h^A, q_h^A)\}$. We should have $q_h^A \ge q_{hl}^*$ and therefore $q_h^r = q_{hl}^*$.

Suppose that $q_h^A < q_h^*$. The constraint RP_l^h can be rewritten as:

$$w_l^A - D(q_l^A, l) \ge \pi_{hl}(q_{hl}^*) - [P(q_h^A, h) - w_h^A].$$

If q_h^A is increased by $\epsilon > 0$ and w_h^A is reduced by $\delta > 0$ such that $P(q_h^A, h) - w_h^A = P((q_h^A + \epsilon), h) - (w_h^A - \delta)$, then the constraints IR^C, RP_h^h, RP_l^l and RP_l^h are satisfied. Moreover, we show that RU's utility increases and therefore RP_h^l is satisfied. We have:

$$w_h^A - \delta + D((q_h^A + \epsilon), h) = w_h^A + D(q_h^A, h) + \pi_h(q_h^A + \epsilon) - \pi_h(q_h^A).$$

Hence, since $\pi_h(q_h^A + \epsilon) - \pi_h(q_h^A) > 0$, the constraint RP_h^l holds and $\{I^A, (w_l^A, q_l^A), (w_h^A - \delta, q_h^A + \epsilon)\}$ gives RU a higher expected pay-off than $\{I^A, (w_l^A, q_l^A), (w_h^A, q_h^A)\}$. Therefore, at the equilibrium, $q_h^A = q_h^*$.

- Proof that $q_l^A = q_l^*$.

  Suppose first that $q_l^A > q_{lh}^*$. We prove that, if q_l^A is reduced by $\epsilon > 0$ and w_l^A is increased by $\delta > 0$ such that

$w_l^A - D(q_l^A, h) = (w_l^A + \delta) - D(q_l^A - \epsilon, h)$, then all constraints are satisfied and RU's utility is higher. The constraints RP_h^h, RP_l^l and RP_l^h still hold and we have:

$$P(q_l^A - \epsilon, l) - (w_l^A + \delta) = \pi_{lh}(q_l^A - \epsilon) - \pi_{lh}(q_l^A) + [P(q_l^A, l) - w_l^A].$$

Since $q_{lh}^* > q_l^A$, then $P(q_l^A - \epsilon, l) - (w_l^A + \delta) > P(q_l^A, l) - w_l^A$ and the constraint IR still holds. Moreover, we have:

$$(w_l^A + \delta) - D(q_l^A - \epsilon, l) = w_l^A - D(q_l^A, l) + D(q_l^A, l) - D(q_l^A - \epsilon, l) + D(q_l^A, h) - D(q_l^A - \epsilon, h).$$

Since $(w_l^A + \delta) - D(q_l^A - \epsilon, l) > w_l^A - D(q_l^A, l)$, the constraint RP_l^h is satisfied and $\{I, (w_l^A + \delta, q_l^A - \epsilon), (w_h^A, q_h^A)\}$ gives RU a higher pay-off than $\{I, (w_l^A, q_l^A), (w_h^A, q_h^A)\}$. We should have $q_l^A \leq q_{lh}^*$ and therefore $q_l^r = q_{lh}^*$.

Suppose that $q_l^A > q_l^*$. If q_l^A is reduced by $\epsilon > 0$ and w_l^A is increased by $\delta > 0$ such that: $P(q_l^A, l) - w_l^A = P((q_l^A - \epsilon), l) - (w_l^A + \delta)$. Then all constraints are satisfied and $w_l^A + \delta + D((q_l^A - \epsilon), h) = w_l^A + D(q_l^A, l) + \pi_l(q_l^A - \epsilon) - \pi_l(q_l^A)$. Hence, since $\pi_l(q_l^A - \epsilon) - \pi_l(q_l^A) > 0$, $\{I^A, (w_l^A + \delta, q_l^A - \epsilon), (w_h^A, q_h^A)\}$ gives RU a higher expected pay-off than $\{I^A, (w_l^A, q_l^A), (w_h^A, q_h^A)\}$. Therefore, at the equilibrium, $q_l^A = q_l^*$.

- Proof that RP_l^h is not binding and that RP_h^l is binding.

Clearly, as in Proposition 2, one of the two constraint is binding. Suppose that the two constraints are binding. Then, we must have:

$$\pi_{hl}(q_{hl}^*) - \pi_{lh}(q_{lh}^*) = \pi_h(q_h^*) - \pi_l(q_l^*).$$

However, this case is impossible since cost functions are such that $\pi_h(q_h^*) - \pi_{lh}(q_{lh}^*) > \pi_{hl}(q_{hl}^*) - \pi_l(q_l^*)$.

Suppose now that RP_l^h is binding and that RP_h^l is not binding. Then $w_h^A - D(q_h^*, h) > w_l^A - D(q_l^*, l)$. For $\epsilon > 0$ sufficiently small such that if w_l^A is increased by $\frac{\epsilon}{1-p(I)}$ and w_h^A is decreased by $\frac{\epsilon}{p(I)}$, all constraints can still be satisfied and RU's expected utility can be increased. With this alternative allocation, RU's expected utility is:

$$p(I)v(w_h^A - D(q_h^*, h) - \frac{\epsilon}{p(I)}) + (1 - p(I))v(w_l^A - D(q_l^*, l) + \frac{\epsilon}{1 - p(I)}).$$

Since v is concave, this term is higher than:

$$p(I)v(w_h^A - D(q_h^*, h)) + (1 - p(I))v(w_l^A - D(q_l^*, l)) + \epsilon[v'(w_h^A - D(q_h^*, h) - \frac{\epsilon}{p(I)}) - v'(w_l^A - D(q_l^*, l) + \frac{\epsilon}{1 - p(I)})].$$

Hence, since $\epsilon > 0$,

$$p(I)v(w_h^A - D(q_h^*, h) - \frac{\epsilon}{p(I)}) + (1 - p(I))v(w_l^A - D(q_l^A, l) + \frac{\epsilon}{1 - p(I)}) > E_\alpha[V(w_\alpha^A, q_\alpha^A, \alpha)|I]$$

Therefore, $\{w_\alpha^A, q_\alpha^*\}_{\alpha=l}^h$ with RP_l^h binding is not an equilibrium allocation.

- Characterization of wages and investment implemented.

Because RP_h^l is binding, the low technology transfer w_l is defined by:

$w_l = w_h - D(q_h^*, h) + D(q_l^*, h) - \pi_{lh}(q_{lh}^*) + \pi_{lh}(q_l^*)$.

We now consider the following reduced program:

$$Max_{I,w_h} p(I)v(w_h - D(q_h,h)) + (1-p(I))v(\pi_{hl}(q^*_{hl}) - (P(q^*_h,h) - w_h)) \quad s/t$$
$$p(I)(P(q^*_h,h) - w_h) + (1-p(I))(P(q^*_l,l) - \pi_{hl}(q^*_{hl}) + (P(q^*_h,h) - w_h) + D(q^*_l,l)) \quad (IR^C).$$

The high technology transfer w_h is defined by IR^C. Investment I^A satisfies the following first order condition:
$p'(I^A)\{\frac{v(w_h^A - D(q_h^A,h)) - v(w_l^A - D(q_l^A,l))}{p(I^A)v'(w_h^A - D(q_h^A,h)) + (1-p(I^A))v'(w_l^A - D(q_l^A,l))} + P(q^*_h,h) - w_h^A - (P(q^*_l,l) - w_l^A)\} = 1.$

Case 2: We now build a similar proof for the case of a total and marginal profit increasing with α, that is:

$$P(q,h) < P(q,l),\ P_q(q,h) < P_q(q,l)\ \forall q > 0.$$

As above, we can show that RP^h_h and RP^l_l are equivalent to, respectively, $q_h \in [q^*_h, q^*_{lh}]$ and $q_l \in [q^*_{hl}, q^*_l]$.
We can also solve the RP^l_h and RP^l_h maximization programs and rewrite these two constraints as:

$$w_h - D(q_h,h) \geq \pi_h(q^*_h) - \pi_h(q_l) + w_l - D(q_l,h) \quad (RP^l_h)$$

$$w_l - D(q_l,l) \geq \pi_l(q^*_l) - \pi_l(q_h) + w_h - D(q_h,l) \quad (RP^h_l)$$

We now prove that RP^h_l is not binding and RP^l_h is binding. Suppose that $\{I\{w^A_\alpha, q^A_\alpha\}^h_{\alpha=l}\}$ is such that both constraints are binding. We have:
$\pi_h(q^*_h) - \pi_h(q^A_h) + D(q^A_h,h) - D(q^A_h,l) = \pi_l(q^*_l) - \pi_l(q^A_l) + D(q^A_l,l) - D(q^A_h,l)$
$\iff \pi_h(q^*_h) - \pi_l(q^*_l) = \pi_{hl}(q^A_l) - \pi_{lh}(q^A_h).$
Since $q^A_l \leq q^*_l < q^*_h \leq q^A_h$, the left-hand term is negative while the right-hand term is positive. This contradicts the fact that the two constraints are binding.
Suppose now that RP^h_l is binding and RP^l_h is not binding. Then,

$$\begin{aligned} w^A_h - D(q^A_h,h) - [w^A_l - D(q^A_l,l)] &= D(q^A_h,l) - D(q^A_h,h) - \pi_l(q^*_l) + \pi_l(q^A_h) \\ &= \pi_{lh}(q^A_h) - \pi_l(q^*_l). \end{aligned}$$

This term is strictly positive since $q^A_h \in [q^*_h, q^*_{lh}]$. Therefore, $w^A_h - D(q^A_h,h) > w^A_l - D(q^A_l,l)$. As in the proof of Proposition 7, we can show that, for $\epsilon > 0$ sufficiently small such that if w^A_l is increased by $\frac{\epsilon}{1-p(I)}$ and w^A_h is decreased by $\frac{\epsilon}{p(I)}$, all constraints can still be satisfied and RU's expected utility can be increased. This implies that RP^h_l is not binding and RP^l_h is binding. Therefore, $w_h - D(q_h,h) = \pi_h(q^*_h) - \pi_h(q_l) + w_l - D(q_l,h)$. Since the constraint IR^C is binding, we have:

$$p(I)(P(q_h,h) - w_h) + (1-p(I))(P(q_l,l) - w_l) - I = 0.$$

Using these two relationships, the integrated structure maximization program can be rewritten as:
$Max_{\{I,\{q\}^h_{\alpha=l}\}} p(I)v(p(I)\pi_h(q_h) + (1-p(I))\pi_h(q^*_h) + (1-p(I))[\pi_l(q_l) - \pi_{hl}(q_l)] - I) + (1-p(I))v(p(I)[\pi_h(q_h) - \pi_h(q^*_h)] + p(I)\pi_{hl}(q_l) + (1-p(I))\pi_l(q_l) - I) \quad s/t$

$$\begin{aligned} q_l - q^*_l &\leq 0 \\ q^*_{hl} - q_l &\leq 0 \\ q_h - q^*_{lh} &\leq 0 \\ q^*_h - q_h &\leq 0 \end{aligned}$$

Let the Lagrangian multiplier associated to each constraint be respectively μ_l, μ_{hl}, μ_{lh} and μ_h. The first order conditions are:

$$\begin{aligned}
\pi'_h(q_h^A) &= \tfrac{\mu_{lh}-\mu_h}{p(I)E_\alpha[V_\alpha^{A\prime}|I^A]} \\
\pi'_l(q_l^A) &= \tfrac{\pi'_{hl}(q_l^A)p(I)(V_h^{A\prime}-V_l^{A\prime})+\mu_l-\mu_{hl}}{E_\alpha[V_\alpha^{A\prime}|I^A]} \\
\tfrac{V_h^A-V_l^A}{E_\alpha[V_\alpha^{A\prime}|I^A]}+P(q_l^A,h)-P(q_l^A,l) &= \tfrac{1}{p'(I^A)}
\end{aligned}$$

We first show that $q_h^A = q_h^*$. One of the two multipliers μ_h or μ_{lh} must be nil. Suppose that $\mu_h = 0$ and $\mu_{lh} > 0$, then $q_h^A = q_h^*$. By first order condition $\pi'_h(q_h^A) < 0$ which contradict that $q_h^A = q_h^*$. Suppose $\mu_{lh} = 0$ and $\mu_h > 0$, then $q_h^A = q_{lh}^* > q_h^*$ and we have $\pi'_h(q_{lh}^*) < 0$. By first order condition $\pi'_h(q_h^A) > 0$ which contradict that $q_h^A = q_{lh}^*$. Since $\mu_h = 0$ and $\mu_{lh} = 0$, the first order condition is rewritten as $\pi'_h(q_h^A) = 0$. Hence $q_h^A = q_h^*$. We now characterize q_l^A. First, note that since the binding constraint RP_h^l implies that $w_h^A - D(q_h^A, h) = \pi_h(q_h^*) - \pi_{hl}(q_l^A) + w_l - D(q_l^A, l)$, then $V_h^A > V_l^A$ and, since v is concave, $V_h^{A\prime} < V_l^{A\prime}$. We now prove that the multipliers μ_l and μ_{hl} are nil. Suppose that $\mu_l > 0$, then $\mu_{hl} = 0$ and $q_l^A = q_l^*$. According to the first order condition, $\pi'_l(q_l^A) > 0$, which contradict that $q_l^A = q_l^*$. Suppose that $\mu_{hl} > 0$, then $\mu_l = 0$ and $q_l^A = q_{hl}^*$. According to the first order condition, $\pi'_l(q_l^A) < 0$, which contradicts that $q_l^A = q_{hl}^*$. Hence, $q_l^A \in (q_{hl}^*, q_l^*)$ is defined by the following order condition:

$$\pi'_l(q_l^A) = \frac{\pi'_{hl}(q_l^A)p(I)(V_h^{A\prime} - V_l^{A\prime})}{E_\alpha[V_\alpha^{A\prime}|I^A]}.$$

Finally, C's utility difference is $U_h^A - U_l^A = P(q_h^*, h) - w_h^A - [P(q_l^A, l) - w_l^A]$. The binding renegotiation-proof constraint RP_h^l yields $w_h^A - w_l^A = P(q_h^*, h) - P(q_l^A, h)$. Therefore, $U_h^A - U_l^A = P(q_l^A, h) - P(q_l^A, l)$. The last first order condition can be rewritten as:

$$\frac{V_h^A - V_l^A}{E_\alpha[V_\alpha^{A\prime}|I^A]} + U_h^A - U_l^A = \frac{1}{p'(I^A)}.$$

H Proof of Proposition 8

The proof of the necessary condition is similar to the proofs of Propositions 1 and 3, and it is therefore omitted. It is also straightforward to show sufficiency with the following strategies and beliefs.

$$\sigma_{RU} = \begin{cases} c_D(\alpha) = c_D^B = \{w^B(q_\alpha), q_\alpha^B, m^B(q_\alpha)\}_{\alpha=l}^h \\ q_{\hat\alpha}(c_F^B, c_D^B, \alpha) = argmax_{q_{\hat\alpha}\in\{q_l,q_h\}} V(w(q_{\hat\alpha}) - \bar R_{m(q_{\hat\alpha})}, q_{\hat\alpha}, \alpha) \end{cases}$$

$$\sigma_C = d_C(c_D) = \begin{cases} 1 \quad if \quad U(w(q_\alpha), q_\alpha, \alpha) \geq 0 \quad \forall \alpha \in \{l, h\} \\ 0 \quad otherwise \end{cases}$$

$$P(h|c_D) = \begin{cases} 1 \quad if \quad argmax_{\hat\alpha\in\{l,h\}} V(w(q_{\hat\alpha}) - \bar R_{m(q_{\hat\alpha})}, q_{\hat\alpha}, \alpha) = h \\ 0 \quad otherwise \end{cases}$$

I Proof of Proposition 9

A general proove is made when the gross marginal profit is negatively correlated with the the development marginal cost. For the other case, the proof is similar and it is therefore omitted.

We derive the best wages and productions for each feasible report manipulation function and then compare RU's expected utility to find the solution to the P_{CD} program. Then we characterise the equilibrium development contract for all given financial contract allocation. We could have the following the equilibrium report manipulation functions.

- $\forall q_{\hat{\alpha}}$, $m^B(q_{\hat{\alpha}}) = l$.

  We can now consider the following reduced program:

  $Max_{\{w(q_a),q_\alpha\}_{\alpha=l}^h} E[V(w(q_\alpha) - \bar{R}_l, q_\alpha, \alpha))|I]$ s/t

  $$\begin{array}{ll} P(q_h, h) - w(q_h) \geq 0 & (IR_h^C) \\ P(q_l, l) - w(q_l) \geq 0 & (IR_l^C) \\ w(q_h) - D(q_h, h) \geq w(q_l) - D(q_l, h) & (IC_h) \\ w(q_l) - D(q_l, l) \geq w(q_h) - D(q_h, l) & (IC_l) \end{array}$$

  The solution is:

  $w^B(q_h) = P(q_h^B, h)$, $w^B(q_l) = P(q_l^B, l)$, $q_l^B = q_l^*$,

  $q_h^B = \begin{cases} q_h^* & if \quad \pi_l(q_l^*) \geq \pi_{hl}(q_h^*) \\ q_h^S & otherwise \end{cases}$ with q_h^S such that $\pi_l(q_l^*) = \pi_{hl}(q_h^S)$.

  RU's expected utility is:

  $$p(I)v(\pi_h(q_b^B) - \bar{R}_l) + (1 - p(I))v(\pi_l(q_l^*) - \bar{R}_l).$$

- $\forall q_{\hat{\alpha}}$, $m^B(q_{\hat{\alpha}}) = h$.

  This case is symmetric to the first case. We have the same equilibrium wages and productions. RU's expected utility is:

  $$p(I)v(\pi_h(q_b^B) - \bar{R}_h) + (1 - p(I))v(\pi_l(q_l^*) - \bar{R}_h).$$

- $m^B(q_h) = h$, $m^B(q_l) = l$.

  The reduced program to consider is:

  $Max_{\{w(q_a),q_\alpha\}_{\alpha=l}^h} E[V(w(q_\alpha) - \bar{R}_{m(q_\alpha)}, q_\alpha, \alpha))|I]$ s/t

  $$\begin{array}{ll} P(q_h, h) - w(q_h) \geq 0 & (IR_h^C) \\ P(q_l, l) - w(q_l) \geq 0 & (IR_l^C) \\ w(q_h) - \bar{R}_h - D(q_h, h) \geq w(q_l) - \bar{R}_l - D(q_l, h) & (IC_h) \\ w(q_l) - \bar{R}_l - D(q_l, l) \geq w(q_h) - \bar{R}_h - D(q_h, l) & (IC_l) \end{array}$$

  To solve this maximization problem, we first show that incentive compatibility constraints are binding.

  1. Suppose that $P(q_h^B, h) - w^B(q_h) > 0$ and $P(q_l^B, l) - w^B(q_l) > 0$.

     If $w^B(q_h)$ and $w^B(q_l)$ are equally increased, the constraints are still satisfied and RU's expected utility is increased. This is not an equilibrium allocation.

  2. Suppose that $P(q_h^B, h) - w^B(q_h) > 0$ and $P(q_l^B, l) - w^B(q_l) = 0$.

     Then, there exists $\delta > 0$ and $\epsilon > 0$ such that $\delta = D(q_h^B + \epsilon, l) - D(q_h^B, l)$ and $P(q_h^B + \epsilon, h) - (w^B(q_h) + \delta) > 0$. The alternative allocation $\{w^B(q_l), q_l^B, w_h^B(q_l) + \delta, q_h^B + \epsilon\}$ increases RU's state h utility and satisfies the constraints. Individual rationality constraints are satisfied and it is easy to verified that IC_l constraint is satisfied since:

$$w^B(q_h) + \delta - D(q_h^B + \epsilon, l) = w^B(q_h) - D(q_h^B, l).$$

Constraint IC_h is satisfied since RU's state h utility is increased as shown below:

$$D(q_h^B + \epsilon, l) - D(q_h^B, l) > D(q_h^B + \epsilon, h) - D(q_h^B, h),\ \forall q_h^B > 0.$$

Hence,

$$w^B(q_h) + \delta - D(q_h^B + \epsilon, h) > w^B(q_h) - D(q_h^B, h) + D(q_h^B + \epsilon, l) - D(q_h^B, l)$$
$$\Rightarrow w^B(q_h) + \delta - D(q_h^B + \epsilon, h) > w^B(q_h) - D(q_h^B, h).$$

3. Suppose that $P(q_h^B, h) - w^B(q_h) = 0$ and $P(q_l^B, l) - w^B(q_l) > 0$.
   Then, there exists $\delta > 0$ and $\epsilon > 0$ such that $\delta = D(q_l^B, h) - D(q_l^B - \epsilon, h)$ and $P(q_h^B - \epsilon, h) - (w^B(q_h) - \delta) > 0$. The alternative allocation $\{w^B(q_l) - \delta, q_l^B - \epsilon, w^B(q_h), q_h^B\}$ increases RU's state l utility and satisfies the constraints. Individual rationality constraints are satisfied and it is easy to verified that IC_h constraint is satisfied since $w^B(q_l) - \delta - D(q_l^B - \epsilon, l) = w^B(q_l) - D(q_l^B, h)$. The constraint IC_l is satisfied since RU's state l utility is increased as shown below. We have:

$$D(q_l^B, l) - D(q_l^B - \epsilon, l) > D(q_l^B, h) - D(q_l^B - \epsilon, h), \forall q_l^B > 0.$$

   Hence,

$$w^B(q_l) - \delta - D(q_l^B - \epsilon, l) > w^B(q_l) - D(q_l^B, l) + D(q_l^B, h) - D(q_l^B - \epsilon, h)$$
$$\Rightarrow w^B(q_l) - \delta - D(q_l^B - \epsilon, l) > w^B(q_l) - D(q_l^B, l).$$

We just proved that equilibrium wages are defined by C's binding participation constraint $\forall \alpha \in \{l, h\}$: $w(q_\alpha) = P(q_\alpha, \alpha)$. We now have to solve the following reduced program:

$$Max_{\{q_h, q_l\}} p(I)v(\pi_h(q_h) - \bar{R}_h) + (1 - p(I))v(\pi_l(q_l) - \bar{R}_l)\ s/t$$

$$\begin{array}{rcll} \pi_h(q_h) - \bar{R}_h & \geq & \pi_{lh}(q_l) - \bar{R}_l & (IC_h) \\ \pi_l(q_l) - \bar{R}_l & \geq & \pi_{hl}(q_h) - \bar{R}_h & (IC_l) \end{array}$$

This program solution depends on repayments allocation $\{\bar{R}_\alpha\}_{\alpha=l}^h$. We identify three cases.

1. If $\pi_h(q_h^*) - \pi_{lh}(q_l^*) \geq \bar{R}_h - \bar{R}_l \geq \pi_{hl}(q_h^*) - \pi_l(q_l^*)$.
   Then the incentive compatibility constraints are not binding and efficient production can be implemented; $q_h^B = q_h^*$, $q_l^B = q_l^*$. RU's expected utility is:

$$p(I)v(\pi_h(q_h^*) - \bar{R}_h) + (1 - p(I))v(\pi_l(q_l^*) - \bar{R}_l).$$

2. If $\bar{R}_h - \bar{R}_l > \pi_h(q_h^*) - \pi_{lh}(q_l^*)$.
   Then IC_h is the binding constraint. The low technology production is distorted; $q_h^B = q_h^*$ and $q_l^B < q_l^*$ such that: $\pi_h(q_h^*) - \bar{R}_h = \pi_{lh}(q_l^*) - \bar{R}_l$. RU's expected utility is:

$$p(I)v(\pi_h(q_h^*) - \bar{R}_h) + (1 - p(I))v(\pi_l(q_l^B) - \bar{R}_l).$$

3. If $\bar{R}_h - \bar{R}_l < \pi_{hl}(q_h^*) - \pi_l(q_l^*)$.

   Then IC_l is the binding constraint. The high technology production is distorted; $q_l^B = q_l^*$ and $q_h^B > q_h^*$ such that: $\pi_l(q_l^*) - \bar{R}_l = \pi_{hl}(q_l^B) - \bar{R}_l$. RU's expected utility is:

$$p(I)v(\pi_h(q_h^B) - \bar{R}_h) + (1 - p(I))v(\pi_l(q_l^B) - \bar{R}_l).$$

- $m(q_h) = l$ and $m(q_l) = h$.

  It is a symmetric case to the previous case.

The equilibrium allocation depends on the equilibrium financial contract. For any assumptions about the equilibrium repayments, we shall show that RU proposes $m^B(q_\alpha) = argmin_\alpha\{\bar{R}_\alpha\}$: the equilibrium manipulation report function prescribes to report the innovation quality corresponding to the minimum repayment. We prove that this report manipulation function is preferred in equilibrium to the truth telling report manipulation function. It is straightforward to design a similar proof which shows that this report manipulation function is also preferred to the following report manipulation function $m(q_h) = l$, $m(q_l) = h$. This proof is therefore omitted.

- If $\bar{R}_h > \bar{R}_l$.

  We show that the equilibrium report manipulation function is $\forall \alpha \in \{l, h\}, m(q_\alpha) = l$; that is always report a low quality innovation.

  1. For $\bar{R}_h - \bar{R}_l \geq \pi_{hl}(q_h^*) - \pi_{lh}(q_l^*)$.

     The best manipulation function is $m^B(q_h) = h$ and $m^B(q_l) = l$ (and not $m^B(q_{\hat{\alpha}}) = l \ \forall q_{\hat{\alpha}}$) if:

     - For $\bar{R}_h - \bar{R}_l > \pi_h(q_h^*) - \pi_{lh}(q_l^*)$:

$$p(I)v(\pi_h(q_h^*) - \bar{R}_h) + (1 - p(I))v(\pi_l(q_l^B) - \bar{R}_l) \geq p(I)v(\pi_h(q_h^B) - \bar{R}_l) + (1 - p(I))v(\pi_l(q_l^B) - \bar{R}_l)$$

     - For $\bar{R}_h - \bar{R}_l \leq \pi_h(q_h^*) - \pi_{lh}(q_l^*)$:

$$p(I)v(\pi_h(q_h^*) - \bar{R}_h) + (1 - p(I))v(\pi_l(q_l^*) - \bar{R}_l) \geq p(I)v(\pi_h(q_h^B) - \bar{R}_l) + (1 - p(I))v(\pi_l(q_l^B) - \bar{R}_l)$$

     A necessary condition for one of those inequality to hold is that :

$$v(\pi_h(q_h^*) - \bar{R}_h) \geq v(\pi_h(q_h^B) - \bar{R}_l).$$

     Since $\bar{R}_h > \bar{R}_l$, this inequality is not satisfied if $q_h^B = q_h^*$. If $q_h^B = q_h^S$, we must have:

$$\pi_h(q_h^*) \geq \bar{R}_h + \pi_h(q_h^B) - \bar{R}_l$$

     Since $\bar{R}_h - \bar{R}_l \geq \pi_{hl}(q_h^*) - \pi_{lh}(q_l^*)$, it implies:

$$\pi_h(q_h^*) \geq \pi_h(q_h^S) + \pi_{hl}(q_h^*) - \pi_l(q_l^*).$$

     For all q, we have $\pi_h(q) = \pi_{hl}(q) - D(q, h) + D(q, l)$. Since $\pi_{lh}(q_h^S) = \pi_l(q_l^*)$, then $\pi_h(q_h^S) = \pi_l(q_l^*) + D(q_h^S, h) - D(q_h^S, l)$. This relationship and the previous inequality imply:

$$D(q_h^*, l) - D(q_h^*, h) \geq D(q_h^S, h) - D(q_h^S, l),$$

     which is false since $q_h^S > q_h^*$.

2. For $\bar{R}_h - \bar{R}_l < \pi_{hl}(q_h^*) - \pi_l(q_l^*)$.

The best report manipulation function is $m^B(q_h) = h$ and $m^B(q_l) = l$ and not $m^B(q_\alpha) = l$, $\forall\alpha$ if:

$$p(I)v(\pi_h(q_h^B) - \bar{R}_h) + (1-p(I))v(\pi_l(q_l^B) - \bar{R}_l) \geq p(I)v(\pi_h(q_h^B) - \bar{R}_l) + (1-p(I))v(\pi_l(q_l^B) - \bar{R}_l).$$

A necessary condition for this inequality to hold is that :

$$v(\pi_h(q_h^B) - \bar{R}_h) \geq v(\pi_h(q_h^S) - \bar{R}_l)$$

$$\iff \pi_{hl}(q_h^B) + D(q_h^B, l) - D(q_h^B, h) - \bar{R}_h \geq \pi_{hl}(q_h^S) + D(q_h^S, l) - D(q_h^S, h) - \bar{R}_l$$

where q_h^B and q_h^S are defined by $\pi_l(q_l^*) - \bar{R}_l = \pi_{hl}(q_h^B) - \bar{R}_h$ and $\pi_l(q_l^*) - \bar{R}_l = \pi_{hl}(q_h^S) - \bar{R}_l$. Therefore, we have:

$$D(q_h^B, l) - D(q_h^B, h) \geq D(q_h^S, h) - D(q_h^S, l),$$

which is false since $q_h^S > q_h^B$ when $\bar{R}_h > \bar{R}_l$.

- If $\bar{R}_h < \bar{R}_l$.

  By a similar proof, we can show that the equilibrium report manipulation function is $m^B(q_h) = m^B(q_l) = h$.

- If $\bar{R}_h = \bar{R}_l$, all report manipulation functions solve the program since they give the same expected utility to RU.

To conclude, we proved that the solution of program P_{CD} is:
$w^B(q_h) = P(q_h^B, h)$, $w^B(q_l) = P(q_l^B, l)$; $q_l^B = q_l^*$;
$$q_h^B = \begin{cases} q_h^* & if \quad \pi_l(q_l^*) \geq \pi_{hl}(q_h^*) \\ q_h^S & otherwise \end{cases}$$
with q_h^S such that $\pi_l(q_l^*) = \pi_{hl}(q_h^S)$;
$m^B(q_\alpha) = argmin_\alpha\{\bar{R}_\alpha\}$, $\forall\alpha \in \{l, h\}$.
RU's expected utility is:

$$p(I^B)v(\pi_h(q_b^B) - Min\{\bar{R}_h, \bar{R}_l\}) + (1-p(I))v(\pi_l(q_l^*) - Min\{\bar{R}_h, \bar{R}_l\}).$$

We can write similar proof if the gross marginal profit are positively correlated with the development marginal cost. The wages are defined by C's binding individual rationality constraints. The investment and the production level implemented solve the following program:

$(P'_{CD2}) \quad Max_{\{I,\{q_\alpha\}_{\alpha=l}^h\}} E[v(\pi_\alpha(q_\alpha) - I)|I] \quad s/t$

$$\begin{array}{rcll} \pi_h(q_h) & \geq & \pi_{lh}(q_l) & (IC_h) \\ \pi_l(q_l) & \geq & \pi_{hl}(q_h) & (IC_l) \end{array}$$

The solution is given by the following relationships:
$$q_h^B = q_h^*,\ q_l^B = \begin{cases} q_l^* & if \quad \pi_h(q_h^*) \geq \pi_{lh}(q_l^*) \\ q_l^S & otherwise \end{cases}$$
with q_l^S such that $\pi_h(q_h^*) = \pi_{lh}(q_l^S)$; $p'(I^B)\frac{V_h^B - V_l^B}{E[V_\alpha'^B|I^B]} = 1$.

J Proof of proposition 10

We shall prove that the financial contract equilibrium must be such that $Min\{R^B_\alpha\} = I^B$.

Suppose that $Min_\alpha\{R^B_\alpha\} > I^B$. F's expected gain is $E_\alpha[Min_\alpha\{R^B_\alpha\}] - I^B > 0$. Since RU can increase his gain by reducing ex post repayments, this allocation is not a PBE equilibrium. Suppose that $Min_\alpha\{R^B_\alpha\} < I^B$. F's expected gain is $E_\alpha[Min_\alpha\{R^B_\alpha\}] - I^B < 0$. F would prefer refuse this offer, and RU's gain is nil although it can be positive with $Min_\alpha\{R^B_\alpha\} = I^B$. As $m^B(\alpha) = argmin_\alpha\{R^B_\alpha\}$, along the equilibrium path, investment equal repayments for each state of nature $\alpha \in \{l, h\}$. Hence, $R^B_h = R^B_l = I^B$. The level of investment I^B solves the following maximization problem.

$$Max_I E[V(w^B(q_\alpha) - I, q^B_\alpha, \alpha)|I].$$

The first order conditions is:

$$p'(I^B)\frac{V^B_h - V^B_l}{E[V'^B_\alpha|I^B]} = 1.$$

K Proof of Proposition 12

We first prove the first part of Proposition 12. The allocation $\{I^A\{w^A_\alpha, q^A_\alpha\}^h_{\alpha=l}\}$ solves the following reduced maximization problem:

(P''_R) $\quad Max_{\{I,\{w_\alpha\}^h_{\alpha=l}\}} E[V(w_\alpha, q^*_\alpha, \alpha)|I] \;\; s/t$

$$\begin{aligned} & E_\alpha[U(w_\alpha, q^*_\alpha, \alpha)|I] - I = 0 && (IR) \\ & w_h - D(q^*_h, h) \geq \pi_{lh}(q^*_{lh}) - \pi_{lh}(q^*_l) + w_l - D(q^*_l, h) && (RP^l_h) \end{aligned}$$

We prove first that, when $\pi_l(q^*_l) \geq \pi_{hl}(q^*_h)$, the independent structure allocation satisfies the constraints of the P''_R program without solving it. Then we show that the independent structure performs better in the case $\pi_l(q^*_l) \geq \pi_{hl}(q^*_h)$ than otherwise.

- Suppose $\pi_l(q^*_l) \geq \pi_{hl}(q^*_h)$. Let $I^c = I^B$, $w^c_\alpha = w^B_\alpha - I^B$ and $q^c_\alpha = q^B_\alpha = q^*_\alpha$. The allocation $\{I^c\{w^c_\alpha, q^c_\alpha\}^h_{\alpha=l}\}$ satisfies C's individual rationality constraint. The renegotiation-proof constraint RP^l_h is rewritten as:

  $$\pi_h(q^*_h) \geq \pi_{lh}(q^*_{lh}),$$

  which is satisfied. However, since the renegotiation-proof constraint RP^h_l is not satisfied with $\{I^c\{w^c_\alpha, q^c_\alpha\}^h_{\alpha=l}\}$, then $\{I^c\{w^c_\alpha, q^c_\alpha\}^h_{\alpha=l}\} \neq \{I^A\{w^A_\alpha, q^A_\alpha\}^h_{\alpha=l}\}$. Therefore, the program objective is higher with $\{I^A, \{w^A_\alpha, q^A_\alpha\}^l_{\alpha=h}\}$ than with $\{I^c, \{w^c_\alpha, q^c_\alpha\}^l_{\alpha=h}\}$:

  $$E_\alpha[V(w^A_\alpha, q^A_\alpha, \alpha)|I^A] > E_\alpha[V(w^c_\alpha, q^c_\alpha, \alpha)|I^c] = E_\alpha[V(w^B(q_\alpha) - I^B, q^B_\alpha, \alpha)|I^B].$$

- Suppose $\pi_l(q^*_l) < \pi_{hl}(q^*_h)$. Since $w^B(q_\alpha) = P(q^B_\alpha, \alpha)$, RU's equilibrium expected utility is the independent structure can be found by solving:

  (P''_{CD}) $\;Max_{\{I,\{q_\alpha\}^h_{\alpha=l}\}} E_\alpha[V(P(q_\alpha, \alpha) - I, q_\alpha, \alpha)|I]$

  $$\begin{aligned} \pi_h(q_h) &\geq \pi_{hl}(q_l) && (IC^C_h) \\ \pi_l(q_l) &\geq \pi_{lh}(q_h) && (IC^C_l) \end{aligned}$$

Let the allocation $\{I^d, \{q_\alpha^d\}_{\alpha=l}^h\}$ solves the following program:

$$Max_{\{I,\{q_\alpha\}_{\alpha=l}^h\}} E_\alpha[V(P(q_\alpha,\alpha) - I, q_\alpha, \alpha)|I].$$

The first order conditions are:

$$\begin{aligned} p(I^d)V_h'^d\pi_h'(q_h^d) &= 0 \\ (1-p(I^d))V_l'^d\pi_l'(q_l^d) &= 0 \\ p'(I^d)(V_h^d - V_l^d) - E[V_\alpha'^d|I^d] &= 0 \end{aligned}$$

Therefore $q_\alpha^d = q_\alpha^*$, $\forall \alpha \in \{l,h\}$.

Since the constraint of the P_R' program are satisfied with the allocation $\{I^d, \{w_\alpha^d, q_\alpha^*\}_{\alpha=h}^l\}$, where $w_\alpha^d = P(q_\alpha^*,\alpha) - I^d$, we can show that RU's expected utility is higher with $\{I^A, \{w_\alpha^A, q_\alpha^A\}_{\alpha=h}^l\}$ than with $\{I^d, \{w_\alpha^d, q_\alpha^*\}_{\alpha=h}^l\}$:

$$E_\alpha[V(w_\alpha^A, q_\alpha^A, \alpha)|I^A] > E_\alpha[V(P(q_\alpha^*,\alpha) - I^d, q_\alpha^*, \alpha)|I^d].$$

Clearly, since one of the two incentive compatibility constraints in the P_{CD}'' program is binding, we have:

$$E_\alpha[V(P(q_\alpha^*,\alpha) - I^d, q_\alpha^*, \alpha)|I^A] > E_\alpha[V(P(q_\alpha^B,\alpha) - I^B, q_\alpha^B, \alpha)|I^B].$$

Hence,

$$E_\alpha[V(w_\alpha^A, q_\alpha^A, \alpha)|I^A] > E_\alpha[V(w^B(q_\alpha) - I^B, q_\alpha^B, \alpha)|I^B].$$

We now prove the second part of Proposition 12, that is if $q_l^B \geq q_l^A$, then $E[V_\alpha^B|I^B] > E[V_\alpha^A|I^A]$. This case includes the case $q_l^B = q_l^*$ which is satisfied when q_l^* is relatively close to q_h^*.
RU's expected utility in the integrated structure is:
$E[V_\alpha^A|I^A] = p(I^A)v(\pi_h(q_h^*) + (1-p(I^A))(\pi_l(q_l^A) - \pi_{hl}(q_l^A)) - I^A) + (1-p(I^A))v(\pi_l(q_l^A) - p(I^A)(\pi_l(q_l^A) - \pi_{hl}(q_l^A)) - I^A)$
RU's expected utility in the independent structure is $E[V_\alpha^B|I^B] = p(I^B)v(\pi_h(q_h^*) - I^B) + (1-p(I^B))v(\pi_l(q_l^B) - I^B)$.
Since v is strictly concave, we have $\forall x > y$, $v(x) - v(y) < v'(y)(x-y)$ and $v(x) - v(y) > v'(x)(x-y)$. Hence,

$$v(\pi_h(q_h^*) + (1-p(I^A))(\pi_l(q_l^A) - \pi_{hl}(q_l^A)) - I^A) - v(\pi_h(q_h^*) - I^A) < v'(\pi_h(q_h^*)) - I^A)(1-p(I^A))(\pi_l(q_l^A) - \pi_{hl}(q_l^A)),$$

and,

$$v(\pi_l(q_l^A - I^A) - v(\pi_l(q_l^A) - p(I^A)(\pi_l(q_l^A) - \pi_{hl}(q_l^A)) - I^A) > v'(\pi_l(q_l^*)) - I)p(I^A)(\pi_l(q_l^A) - \pi_{hl}(q_l^A)).$$

Since $\pi_l(q_l^B) \geq \pi_l(q_l^A)$, using the two preceeding relationships, we find that:
$p(I^A)v(\pi_h(q_h^*) - I^A) + (1-p(I^A))v(\pi_l(q_l^B) - I^A) > E_\alpha[V_\alpha^A|I^A] + (\pi_l(q_l^A) - \pi_{hl}(q_l^A))p(I^A)(1-p(I^A))[v'(\pi_l(q_l^A) - I^A) - v'(\pi_h(q_h^*) - I^A)]$.
Since $\pi_l(q_l^A) > \pi_{hl}(q_l^A)$ and $v'(\pi_l(q_l^A - I^A) > v'(\pi_h(q_h^*) - I^A)$, therefore,

$$p(I^A)v(\pi_h(q_h^*) - I^A) + (1-p(I^A))v(\pi_l(q_l^B) - I^A) > E_\alpha[V_\alpha^A|I^A].$$

Since I^B solves $Max_I p(I)v(\pi_h(q_h^*) - I) + (1-p(I))v(\pi_l(q_l^B) - I)$, therefore,

$$E[V_\alpha^B|I^B] > p(I^A)v(\pi_h(q_h^*) - I^A) + (1-p(I^A))v(\pi_l(q_l^B) - I^A).$$

Using the two preceeding inequalities, we conclude that $E[V_\alpha^B|I^B] > E[V_\alpha^A|I^A]$.

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