Organizational design of R&D activities

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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. We find that the integrated structure dominates when an innovation costly to develop is also a less drastic technology or a product less valued by consumers. The independent structure dominates in the opposite case. We then discuss the empirical implications of our result.

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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 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

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

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 generate 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.

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

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 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 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 proceed as follows. Section 2 presents the model. Section 3 introduces the two organizational structures. Section 4 analyzes the integrated structure. Section 5 studies the independent structure. Section 6 compares the performance of the two structures. Section 7 concludes the paper.

2 The model

Two agents, a research unit RU and the consumer of the new technology, 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 is marketed by firm C. To sell the innovation, RU and C must operationalize its production. This is the development 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. C earns a profit $P(q, \alpha)$. The function P is increasing and concave in q at least on $[0, \bar{q}]$ with $\bar{q}$ large.

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

This function can encompass both process and product innovations. For a process innovation, the innovation quality affects profits mainly through costs. For a product innovation, the innovation quality affects profits mainly through revenues. We consider two types of innovations.

- Major innovation

  A high-quality innovation generates higher profits and marginal profits than a low-quality one. Formally,

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

- Minor innovation

  A high-quality innovation generates lower profits and marginal profits than a low-quality one. Formally,

$$P(q,h) < P(q,l),\ P_q(q,h) < P_q(q,l)\ \forall\ 0 < q < \bar{q}.$$

For a major innovation, moving from a low-quality innovation to a high-quality innovation reduces development costs and increases profits, that is, development costs and profits are negatively correlated. The opposite holds for a minor innovation. It turns out that the sign of this correlation plays a significant role in our analysis.[3]

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

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

We assume that a high-quality innovation, be it major or minor, is globally more profitable than a low-quality one, that is, $\pi(q,h) > \pi(q,l)$. We denote by q^*_α the project size which maximizes global profit $\pi(q,\alpha)$. It is assumed that $q^*_h \geq q^*_l$, that is, the high-quality innovation is marginally more profitable than a low-quality one, regardless of the type of innovation. We also denote by I^* the investment level which maximizes the expected global profit

$$p(I)\pi(q^*_h,h) + (1-p(I))\pi(q^*_l,l) - I.$$

[3]In Section 6, we give concrete examples for these two types of innovation.

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

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

We suppose that RU is risk averse, that is, v is increasing and concave ($v' > 0$, $v'' < 0$). Firm C is risk neutral. Its utility U is linear in profits net of any transfer payment w:

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

Its reservation utility is normalized to zero.

3 The organization of R&D activities

We define two types of organizations. In an *integrated structure*, R&D activities are conducted internally within firm C. Player RU can be seen as a division or a department of firm C. Firm C then invests and finances the investment in research I, pays its research unit RU a wage $w_{\hat{\alpha}}$ and develops a project of scale $q_{\hat{\alpha}}$ when RU reports that the innovation quality is $\hat{\alpha} \in \{l, h\}$.

In an *independent structure*, RU is an autonomous firm, which implies that it must finance its research activities externally. A financial contract is signed at the beginning of the research period between RU and a competitive bank or financial partner F. This contract specifies the investment I provided by F to RU and ex post repayments $\{R_{\hat{\alpha}}\}_{\hat{\alpha}=l}^{h}$ from RU to F contingent on the report $\hat{\alpha} \in \{l, h\}$ RU makes of the innovation quality. 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 $q_{\tilde{\alpha}}$ and RU's wage or royalties $w_{\tilde{\alpha}}$ contingent on the project size implemented $q_{\tilde{\alpha}}$.

There are three objectives to pursue when players interact. First, incentives must be provided for an appropriate investment I in R&D. Second, once the innovation has been concretized, incentives must be provided to undertake an appropriate project size q. Finally, insurance must be given to RU against the risk inherent in the innovation process. The two structures are likely to differ in their relative ability to pursue these objectives. The two structures differ in two important aspects. First, the transferability of property rights is governed by different rules in each structure. In an integrated organization, the property right over the project belongs to C. This right cannot be credibly transferred from C to RU as the rule of law does not govern over such intrafirm transaction. For example, even if this right was transferred to RU, C could always repossess it because it has hierarchical authority over RU. In a private-information environment, this implies that RU is communicating its information about the innovation quality to C who then uses it to decide on the project size.

In an independent organization, the property right over the project initially belongs to C. Since C and RU are independent firms, this right can be "sold" from C to RU, and the judicial system can enforce such transaction. Formally, this amounts to RU choosing the project size, using its own private information about the innovation quality.[4] We show that the way information is communicated and used has implications for the efficiency of each structure.

Second, the financing of investment is subject to different agency costs. In an integrated structure, financing the investment is done internally. In an independent structure, RU must finance externally. We assume here, as in most of the literature in corporate finance, that external financing is subject to larger agency costs than internal financing. To capture this idea, we assume that project size and payoffs are observable to C and RU, but unobservable to F. The financial contract with F then has to take this unobservability into account when specifying financial repayments. The performance of the two structures is compared under the assumptions that property rights cannot be credibly transferred in an integrated structure and that external financing is costlier than internal financing. As we show below, this yields an interesting trade-off in the choice of the organization of R&D. Throughout, we assume that RU has the bargaining power when negotiating a contract with C and F. This assumption makes the comparison of the two structures more tractable.

[4] Klibanoff and Poitevin (1999) explore further the issue of rights and commitment in a general model.

Before solving for the optimal allocation in each structure and comparing their relative efficiency, we provide as a benchmark the symmetric-information solution for either structure. The symmetric-information solution is characterized by the following relationships.

- $I = I^*$, $q_\alpha = q_\alpha^*$ for $\alpha = l, h$.
- In the integrated structure, $v(w_h^A - D(q_h^*, h)) = v(w_l^A - D(q_l^*, l))$.
- In the independent (autonomous) structure, $v(w^B(q_h^B) - R_h^B - D(q_h^*, h)) = v(w^B(q_l^B) - R_l^B - D(q_l^*, l))$.
- $v(w_\alpha^A - D(q_\alpha^*, \alpha)) = v(w^B(q_\alpha^B) - R_\alpha^B - D(q_\alpha^*, \alpha))$ for all $\alpha \in \{l, h\}$.

First, allocative efficiency is attained for investment and project size for both qualities of innovation. For both structures, RU is fully insured against the risk of innovation. Insurance is provided by C in the integrated structure, and by F, in the independent structure. Finally, RU has the same payoff in both structures.[5]

4 The integrated structure

The fact that, in the integrated structure, property rights cannot be credibly transferred from C to RU implies that RU must communicate its private information to C who then decides on the project size. Formally, this form of communication raises the possibility for C and RU to renegotiate the initial contract after RU has communicated its private information to C.[6] The possibility for renegotiation has to be formally taken into account when specifying the strategic interaction between RU and C.

[5]It is easy to show that, under symmetric information, both structures yield the same equilibrium allocation from the point of view of RU.

[6]Holmstrom and Myerson (1983), Maskin and Tirole (1992), and Beaudry and Poitevin (1995) all argue that this is in fact the only instance where renegotiation can have an effect. Renegotiating after the arrival of private information but before it has been communicated (after stage 2) has no effect on the initial contract.

The contractual negotiation and implementation is formalized in 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.

We characterize the equilibrium allocations that are not renegotiated along the equilibrium path, namely, renegotiation-proof allocations, that is, allocations that can be supported by equilibrium strategies that do not involve any renegotiation along the equilibrium path. A renegotiation-proof allocation $\{w_\alpha, q_\alpha\}_{\alpha=l}^{h}$ must satisfy the following inequalities.[7]

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

These constraints are more stringent than the usual incentive-compatibility constraints, and therefore, they represent generalized incentive-compatibility constraints that incorporate

[7] This is shown formally in Beaudry and Poitevin (1995).

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 these constraints, 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.

We characterize one equilibrium allocation, namely, the allocation that yields RU the highest expected utility.[8] This equilibrium allocation solves the following maximization problem.

$$(P_R) \quad \max_{\{I,\{w_\alpha, q_\alpha\}_{\alpha=l}^h\}} p(I)V(w_h, q_h, h) + (1-p(I))V(w_l, q_l, l) \;\; \text{s/t}$$

$$\begin{aligned}
p(I)U(w_h, q_h, h) + (1-p(I))U(w_l, q_l, l) - I &= 0 && (IR^C) \\
V(w_h, q_h, h) &\geq \max_{(w,q)}\{V(w,q,h) \;\; s/t \\
&\quad U(w,q,h) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, h) \\
&\quad U(w,q,l) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, l)\} \;\; \forall \hat{\alpha} = l, h && (RP_h^{\hat{\alpha}}) \\
V(w_l, q_l, l) &\geq \max_{(w,q)}\{V(w,q,l) \;\; s/t \\
&\quad U(w,q,h) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, h) \\
&\quad U(w,q,l) \geq U(w_{\hat{\alpha}}, q_{\hat{\alpha}}, l)\} \;\; \forall \hat{\alpha} = l, h && (RP_l^{\hat{\alpha}})
\end{aligned}$$

In this problem, RU's expected utility is maximized subject to C's participation constraint (IR^C) and the set of incentive renegotiation-proof constraints.

Proposition 1 *The solution to the P_R maximization problem satisfies the following rela-*

[8] There may be multiple equilibria depending on the assignment of out-of-equilibrium beliefs. We focus here on the equilibrium allocation that RU prefers. This facilitates later comparisons to the independent structure.

tionships:

- Major innovation

  $q_h^A = q_h^*$, $q_l^A = q_l^*$;

  $w_h^A - D(q_h^*, h) > w_l^A - D(q_l^*, l)$.

- Minor innovation

  $q_h^A = q_h^*$, $q_l^A < q_l^*$;

  $w_h^A - D(q_h^*, h) > w_l^A - D(q_l^A, l)$.

- $p'(I^A)\left\{\frac{V_h^A - V_l^A}{\mathrm{E}[V_\alpha^{A\prime}|I^A]} + U_h^A - U_l^A\right\} = 1$, *where* V_α^A *and* U_α^A *are respectively RU's and C's equilibrium utility and* $V_\alpha^{A\prime}$*, RU's marginal utility for an innovation quality* $\alpha \in \{l, h\}$.

With symmetric information, RU's utility is equalized in both states. This implies that $w_l > w_h$ since development costs are higher in state l. Under asymmetric information, RU then has incentives to report type l when its true type is h to obtain a higher wage. The binding renegotiation-proof constraint is therefore RP_h^l, that is, when the innovation quality is high and RU announces a low-quality innovation. To prevent type h from mimicking type l, the contract increases the wage gap and imposes more risk on RU. When the innovation is major, no distortion in q_l can be used ex ante to induce truth-telling because any such distortion would be renegotiated away in stage 3. For a minor innovation, some underproduction for the low-quality innovation is renegotiation-proof. It therefore arises to mitigate the risk allocated to RU. Finally, the normalized sum of marginal benefits to investment defines the optimal investment policy. We now move to the independent-structure game.

5 The independent structure

In an independent structure, RU must finance externally before starting the research phase. Agents then play the following game.

1. In the first stage, RU proposes a financial contract $c_F = \{I, \{R_\alpha\}_{\alpha=l}^{h}\}$ to F who can accept or reject it.

2. In the second stage (if reached), RU observes the innovation quality α.

3. In the third stage, RU proposes to C a development contract $c_D = \{w(q_\alpha), q_\alpha\}_{\alpha=l}^{h}$ who can accept or reject it.

4. In the fourth stage (if reached), the contract is carried out: RU implements the project size $q_{\tilde{\alpha}} \in \{q_l, q_h\}$, and a report $\hat{\alpha} \in \{l, h\}$ is sent to F; the innovation is then developed, produced and sold while transfers are paid as prescribed by the contract.

The difference between this game and the one played in the interated structure underlines the assumptions we pose for each structure. Property rights are transferable only in the independent structure. The development contract allows for these rights to be transferred from C to RU. RU effectively chooses the project size. In the integrated structure, project size is chosen by C after RU has communicated its private information to C. Financing is done externally in the independent structure, which implies that RU and F must enter into a formal agreement.

Since the project size $q_{\tilde{\alpha}}$ and profits are not observable to F, the financial repayments depend on a report $\hat{\alpha} \in \{l, h\}$ that RU sends to F. In Lemma 1, we characterize the optimal financial contract.

Lemma 1 *Without loss of generality, the equilibrium financial contract $\{I^B, \{R_\alpha^B\}_{\alpha=l}^{h}\}$ is such that $R_l^B = R_h^B = I^B$.*

Because F cannot observe output nor profit, the optimal financial contract is a debt contract, and the financial repayment is independent of the quality of the innovation.[9] Furthermore, this payment is equal to the lent amount, I^B, so that F breaks even. Given this result,

[9]Note that we implicitly assume that the debt contract is riskless. Incorporating the possibility of default would not alter our main conclusions provided that F could audit RU at a cost (Townsend, 1979).

it is easy to show that the separating-equilibrium allocation of the independent structure, $\left\{I^B, \{w^B(q_\alpha), q_\alpha^B\}_{\alpha=l}^h\right\}$, that maximizes the expected utility of RU is the solution to the following maximization problem.[10]

$$\max_{\left\{I, \{w(q_\alpha), q_\alpha\}_{\alpha=l}^h\right\}} p(I)V(w(q_h) - I, q_h, h)) + (1 - p(I))V(w(q_l) - I, q_l, l)$$

$$\begin{array}{llcll} \text{s/t} & U(w(q_h), q_h, h) & \geq & 0 & (IR_h^C) \\ & U(w(q_l), q_l, l) & \geq & 0 & (IR_l^C) \\ & V(w(q_h) - I, q_h, h) & \geq & V(w(q_l) - I, q_l, h) & (IC_h) \\ & V(w(q_l) - I, q_l, l) & \geq & V(w(q_h) - I, q_h, l) & (IC_h) \end{array}$$

In this problem, RU's expected utility is maximized subject to C's participation constraints (IR_α^C) and RU's incentive-compatibility constraints (IC_α).

Proposition 2 *This equilibrium allocation satisfies the following relationships.*

- $P(q_\alpha^B, \alpha) - w^B(q_\alpha^B) = 0 \ \forall \ \alpha \in \{l, h\}$.

- Major innovation
  $q_l^B = q_l^*,\ q_h^B = \begin{cases} q_h^* & if\ \pi(q_l^*, l) \geq P(q_h^*, h) - D(q_h^*, l) \\ q_h^S & otherwise \end{cases}$
  with $q_h^S > q_h^*$ *such that* $\pi(q_l^*, l) = P(q_h^S, h) - D(q_h^S, l)$.

- Minor innovation
  $q_h^B = q_h^*,\ q_l^B = \begin{cases} q_l^* & if\ \pi(q_h^*, h) \geq P(q_l^*, l) - D(q_l^*, h) \\ q_l^S & otherwise \end{cases}$
  with $q_l^S < q_l^*$ *such that* $\pi(q_h^*, h) = P(q_l^S, l) - D(q_l^S, h)$.

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

[10]It would be easy to show that this is the only equilibrium that survives the application of the Intuitive criterion of Cho and Kreps (1987).

The main consequence of imperfect external financing is that F cannot provide any insurance to RU since financial repayments are the same in each state of nature. RU supports all the research risk, and investment is therefore determined by the incremental value for RU of a high-quality innovation compared to a low-quality one. The development contract is negotiated in a signaling environment where beliefs do not affect the separating allocation. Since the financial contract only influences beliefs (through the choice of investment), the specifics of the development contract do not depend on the financial contract. In the development contract, C's individual-rationality constraints are binding. For a major innovation, C's profits are higher for a high-quality innovation. RU can therefore extract more royalties from C. RU then wants to overstate the quality of the innovation, and the binding incentive constraint is that for a low-quality innovation. RU may then overproduce to satisfy its incentive constraint. The exact opposite holds for a minor innovation. In the next section, we endogenize the organizational choice of R&D activities by comparing the performance of the two structures.

6 Performance of the two structures

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 its expected utility under each structure. To make the comparison simple, we introduce the following assumption on the innovation profit.

Assumption 1 *There exists* $\lambda \in \left(0, \frac{\pi(q_h^*,h)+D(q_l^*,h)}{P(q_l^*,h)}\right]$ *such that* $P(q,l) = \lambda P(q,h)$, $\forall\, q \in [0,\bar{q}]$.

This characterization gives us a simple interpretation of so-called innovation drasticity. A major innovation is represented by $\lambda < 1$, while a minor innovation is the case $\lambda > 1$. When $\lambda = 1$, the innovation quality does not effect the profit. Such an innovation is called neutral.[11]

Proposition 3 *For major (minor) innovations, the integrated (independent) structure dominates. For a neutral innovation, both structures are equivalents.*

Proposition 3 states that, the choice of structure depends on the technology. The intuition of this result can be given in terms of the effects of contractual imperfections of the extent of risk sharing provided to RU. Agency costs come from the fact that the contract is used to insure RU against the risk of innovation. The achievement of this goal conflicts with asymmetric information and non-commitment. To understand the result, it is useful to assess the relative impact of these factors on risk-sharing. Suppose first that C's revenues are independent of the quality of innovation ($\lambda = 1$ in the example). As shown in the proposition, both organizational structures are equivalent. External financing and renegotiation have the same effects on the extent of risk-sharing as all risk is shifted to firm RU.

Suppose that a low-quality innovation generates slightly higher marginal revenues than a high-quality one ($\lambda > 1$). In the independent structure, this improves risk sharing as the difference between V_h and V_l shrinks. This difference shrinks since increasing λ increases the profitability of the low-quality innovation. Since firm C gets its reservation value in each state and financing is achieved through debt, firm RU gets all benefits from such increase, thus increasing its expected payoff and improving risk sharing. In the integrated structure, increasing λ makes the renegotiation-proof constraint less stringent and therefore allows for some distortion in q_l to improve risk sharing. Such distortion implies that RU cannot appropriate the whole surplus generated by the increase in λ. The independent structure then dominates the integrated structure.

Now suppose that a low-quality innovation generates slightly lower marginal revenues than a high-quality one ($\lambda < 1$). In the independent structure, this worsens risk sharing

[11] Note that the upper bound on λ depends on optimal productions. However, as long as $q_l^* < q_h^*$, this upper bound exceeds 1 and therefore a minor innovation is allowed. Also note that Assumption 1 is used *only* to prove that the independent structure dominates for minor innovations when λ is "not too high".

as the difference between V_h and V_l increases. It increases since decreasing λ decreases the profitability of the low-quality innovation. As in the previous case, firm RU supports the full loss from such decrease, thus reducing its expected payoff and suffering more risk. In the integrated structure, risk-sharing is unaffected as all increase in risk is supported by firm C. Firm RU, however, still supports the full loss in the profitability of the low-quality innovation. The integrated structure then dominates the independent structure.

The difference between the two cases stems from the effect of technology on the amount of risk in the venture. From a situation where there is no revenue risk ($\lambda = 1$), increasing λ reduces the total risk, that is, the risk of $P(q, \alpha) - D(q, \alpha)$. In the independent structure, RU supports all risk. It can therefore gain from the increase in revenue as well as from the reduction in risk. The independent structure is then optimal. When λ is decreased, the opposite holds. Total risk is increased. In the independent structure, RU support all this extra risk while also losing from the loss in revenue. The integrated structure is then optimal.

This result has a testable implication. The innovation must be major (minor) for in-house (independent) R&D. 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 with toxicology analyses and goes through clinical trials 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.[12] 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 is long and costly, and therefore lowers its patent-protection and, hence the gross profit of the pharmaceutical company. This negative correlation between development costs and revenues corresponds to the case of a major innovation.

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

Our model then predicts that the R&D activities are more efficiently organized in-house. For a technological innovation, it is often the case that when the cost to develop and install a new technology is high, savings on production cost are also 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 improvement of the existing network is cheap to install but it is usually less efficient. Another example is the software industry. When a new version of an existing software or system is adopted by a firm, the costs incurred by the research unit (mostly the training of the user firm's employers) are low and savings are also low. When the new software or the system is very different, and therefore needs more training, savings on production costs can be very high. In these two examples, the positive correlation between development and installation costs and revenues corresponds to the case of a minor innovation. Our model then predicts that the innovation should be produced by an independent firm.

These examples seem to fit with stylized facts. Most research in the pharmaceutical industry tends to be produced in-house. And most research in information technology seems to be produced by independent firms. Our model rests its explanation of these facts on different contractual imperfections. Integrated firms tend to be inefficient because it is easy to deviate from an initial plan, which we model here as renegotiation. Independent firms incur agency costs when seeking external financing, which we model here as collusion. We believe that a different formulation for these agency costs would still yield a tradeoff between the two structures, albeit maybe different. The advantage of our modeling assumptions is that it yields a definitive tradeoff which seems to broadly fit some stylized facts.

Our model makes sharp predictions about the organization of R&D. In reality, firms may do some R&D activities in-house as well as buy some innovations from independent firms. This can easily be reconciled with our results. Minor innovations would mostly be acquired on the market while major innovations would tend to be produced in-house. Finally, in some industries, both types of innovations may be possible. Suppose that firms do not know in advance whether the innovation will be major or minor. The organization of R&D activities would then depend on the relative likelihood of both types of innovations.

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. The two structures defined induce different agency costs. In an integrated structure, the way information is communicated leads to renegotiation. In an independent structure, external financing from a bank is more costly.

It turns out that the integrated structure dominates the independent structure when an innovation which is cheap to develop creates a more drastic process innovation or a product innovation with a higher market value. The independent structure performs better than the integrated structure in the opposite case. This result provides a testable implication of our model.

A Proof of Proposition 1

We characterize the solution to a relaxed maximization problem in which only constraints (IR^C) and (RP_h^l) are included. We then show that, at this solution the omitted constraints are satisfied. The proof treats alternatively the cases of major and minor innovations.

MAJOR INNOVATION.

Since the only incentive constraint is (RP_h^l), it follows that $q_h^A = q_h^*$. The constraint (RP_h^l) is strictly binding which implies that the curve $U(w_l^A, q_l^A, l)$ is tangent to $V(w_h^A, q_h^*, h)$, that is, by mimicking type l, the best renegotiation offer that RU can make and that C is sure to accept is along the curve $U(w_l^A, q_l^A, l)$. Furthermore, doing so would give type h exactly its equilibrium payoff. The equilibrium contract of type l is therefore on the curve $U(w, q, l)$ that is tangent to $V(w_h^A, q_h^*, h)$. It is the preferred contract on this curve from the point of view of type l. It is easy to show that this implies that $q_l^A = q_l^*$. Project size has now been determined for each type. Wages are adjusted such that (IR^C) and (RP_h^l) are strictly binding. Since project sizes are efficient, the constraints (RP_α^α) are satisfied. And, it is easy to show that, if (RP_h^l) is strictly binding, then (RP_l^h) is satisfied. Finally, since both utility curves (for the two types) are tangent to the same $U(w, q, l)$ curve and since type h has lower development costs, we have $w_h^A - D(q_h^*, h) > w_l^A - D(q_l^A, l)$.

MINOR INNOVATION.

Since the only incentive constraint is (RP_h^l), it follows that $q_h^A = q_h^*$. The constraint (RP_h^l) is strictly binding which implies that the curve $U(w_l^A, q_l^A, h)$ is tangent to $V(w_h^A, q_h^*, h)$, that is, by mimicking type l, the best renegotiation offer that RU can make and that C is sure to accept is along the curve $U(w_l^A, q_l^A, h)$.[13] Furthermore, doing so would give type h exactly its equilibrium payoff. The equilibrium contract of type l is therefore on the curve $U(w, q, h)$ that is tangent to $V(w_h^A, q_h^*, h)$. It is the preferred contract on this curve from the point of view of type l. It is easy to show that this implies that $q_l^A < q_l^*$ since a type h-innovation generates less revenue than a type l-innovation. Project size has now been determined for each type. Wages are adjusted such that (IR^C) and (RP_h^l) are strictly binding. Since the project size $q_h^A = q_h^*$, the constraint (RP_h^h) is satisfied. Since q_l^A is such that $V(w, q, l)$ is tangent to $U(w, q, h)$, the constraint (RP_l^l) is satisfied. And, it is easy to show that, if (RP_h^l) is strictly binding, then (RP_l^h) is satisfied. Finally, since both utility curves (for the two types) are tangent to the same $U(w, q, h)$ curve and since type h has lower development costs, we have $w_h^A - D(q_h^*, h) > w_l^A - D(q_l^A, l)$.

[13]The assumption about the relative profitability of the high-quality innovation with respect to the low-quality innovation explains the difference in the set of renegotiation offers that C is sure to accept for the cases of major and minor innovations.

We now determine investment. C's marginal benefit from a high-quality innovation 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, $U_h^A - U_l^A = P(q_l^A, h) - P(q_l^A, l)$. Substituting for this in the constraint (IR^C) and computing the first-order condition with respect to investment yields:

$$p'(I^A)(V_h^A - V_l^A) + \lambda(p'(I^A)(U_h^A - U_l^a) - 1) = 0,$$

where λ is the Lagrange multiplier on constraint (IR^C). It is easy to show (from the other first-order conditions) that $\lambda =$E$[V_\alpha^{A\prime}|I^A]$. The first-order condition can be rewritten as:

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

Finally, we give an informal description of strategies and beliefs that support this allocation as a PBE of the game. We start with the last stage. In stage 3a and 3b, RU offers its preferred contract within the set of contracts that C accepts, that is, contracts which increase C's payoff regardless of its beliefs. C rejects all other contracts on the belief that it was offered by the type on which C would lose if it was accepted. In stage 3, RU selects the message which yields the highest payoff taking into account the possibilities for a successful renegotiation. In the first stage, RU proposes the contract characterized above. C accepts all contracts that yield zero expected profit taking into account the reporting strategy and its own acceptance decision at the renegotiation stage. Along the path, RU proposes the characterized contract which C accepts. RU truthfully reveals its type when reporting, and makes no renegotiation offer. *Q.E.D.*

B Proof of Lemma 1

Suppose that $R_l^B \neq R_h^B$. In stage 4, RU would report $\hat{\alpha} = \arg\min_\alpha R_\alpha^B$. Without loss of generality, F would therefore accept a contract such that $R_l^B = R_h^B$. To break even, it would be the case that $R_l^B = R_h^B = I^B$. *Q.E.D.*

C Proof of Proposition 2

The subgame starting in stage 2 is a signalling game played between RU and C. We characterize the separating equilibrium that maximizes RU's expected utility. This equilibrium would also be the one that would survive the application of the Intuitive criterion (Cho and Kreps, 1987). In this equilibrium, C earns zero profit, which implies that $w^B(q^B_\alpha) = P(q^B_\alpha, \alpha)$ for all α.

Major innovation.

Since $P(q, h) > P(q, l)$ for all $q > 0$, it is type l that may have incentive in mimicking type h to obtain a higher wage. This implies that there is no distortion in type l's project size, that is, $q^B_l = q^*_l$. After substituting for the equilibrium wages, contraint (IC_l) reduces to

$$V(P(q^*_l, l) - I^B - D(q^*_l, l)) \geq V(P(q^B_h, h) - I^B - D(q^B_h, l)),$$

which is equivalent to

$$\pi(q^*_l, l) \geq P(q^B_h, h) - D(q^B_h, l).$$

If this is satisfied at $q^B_h = q^*_h$, then this is the solution. If not, $q^B_h = q^S_h$ where q^S_h is the maximal solution to

$$\pi(q^*_l, l) = P(q^B_h, h) - D(q^B_h, l).$$

Minor innovation.

Since $P(q, h) < P(q, l)$ for all $q > 0$, it is type h that may have incentive in mimicking type l to obtain a higher wage. This implies that there is no distortion in type h's project size, that is, $q^B_h = q^*_h$. After substituting for the equilibrium wages, contraint (IC_h) reduces to

$$V(P(q^*_h, h) - I^B - D(q^*_h, h)) \geq V(P(q^B_l, l) - I^B - D(q^B_l, h)),$$

which is equivalent to

$$\pi(q^*_h, h) \geq P(q^B_l, l) - D(q^B_l, h).$$

If this is satisfied at $q^B_l = q^*_l$, then this is the solution. If not, $q^B_l = q^S_l$ where q^S_l is the minimal solution to

$$\pi(q^*_h, h) = P(q^B_l, l) - D(q^B_l, h).$$

Investment is determined using first-order conditions in a similar fashion as in the proof of Proposition 1. These steps are not reproduced here. Finally, we give an informal description of strategies and beliefs that support this allocation as a PBE of the game. We start with the last stage. In the fourth stage, RU reports to F the type that minimizes its financial repayment. In stage 3, RU proposes the contract characterized above, and C accepts all contracts that yield zero expected profits on each type. All other contracts are rejected on the belief that they were offered by type l when the innovation is major and type h when the innovation is minor. In stage, 1, RU offers the financial contract characterized above and in Lemma 1. All contracts yielding negative expected profits are rejected by F. These contracts are evaluated taking into account that RU always pays the lowest repayment specified in the contract. *Q.E.D.*

D Proof of Proposition 3

We first prove the first part of Proposition 3. Suppose that innovation is major. The allocation $\{I^A\{w_\alpha^A, q_\alpha^A\}_{\alpha=l}^h\}$ solves the following reduced maximization problem:

(P_R'') $\quad \max_{\{I,\{w_\alpha\}_{\alpha=l}^h\}} E[V(w_\alpha, q_\alpha^*, \alpha)|I] \;\; s/t$

$$E[U(w_\alpha, q_\alpha^*, \alpha)|I] - I = 0 \qquad (IR)$$
$$w_h - D(q_h^*, h) \geq \pi(q_{lh}^*, lh) - \pi(q_l^*, lh) + w_l - D(q_l^*, h) \qquad (RP_h^l)$$

We prove first that, when $\pi(q_l^*, l) \geq \pi(q_h^*, hl)$ (no-distortion case), the independent structure allocation satisfies the constraints of the P_R'' program without solving it. Therefore, RU's expected utility in the independent structure is dominated by the integrated structure one. Then we show that the independent structure performs better in the case $\pi(q_l^*, l) \geq \pi(q_h^*, hl)$ than otherwise.

- Suppose $\pi(q_l^*, l) \geq \pi(q_h^*, hl)$. Let $I^c = I^B$, $w_\alpha^c = w_\alpha^B - I^B$ and $q_\alpha^c = q_\alpha^B = q_\alpha^*$. The allocation $\{I^c\{w_\alpha^c, q_\alpha^c\}_{\alpha=l}^h\}$ satisfies C's individual rationality constraint. The renegotiation-proof constraint RP_h^l is rewritten as:

  $$\pi(q_h^*, h) \geq \pi(q_{lh}^*, lh),$$

  which is satisfied. However, since the renegotiation-proof constraint RP_l^h is not satisfied with $\{I^c\{w_\alpha^c, q_\alpha^c\}_{\alpha=l}^h\}$, then $\{I^c\{w_\alpha^c, q_\alpha^c\}_{\alpha=l}^h\} \neq \{I^A\{w_\alpha^A, q_\alpha^A\}_{\alpha=l}^h\}$. Therefore, the program objective is higher with $\{I^A, \{w_\alpha^A, q_\alpha^A\}_{\alpha=h}^l\}$ than with $\{I^c, \{w_\alpha^c, q_\alpha^c\}_{\alpha=h}^l\}$:

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

- Suppose $\pi(q_l^*, l) < \pi(q_h^*, hl)$. Since $w^B(q_\alpha) = P(q_\alpha^B, \alpha)$, RU's equilibrium expected utility in the independent structure can be found by solving:

  (P_{CD}'') $\quad \max_{\{I,\{q_\alpha\}_{\alpha=l}^h\}} E[V(P(q_\alpha, \alpha) - I, q_\alpha, \alpha)|I]$

  $$\pi(q_h, h) \geq \pi(q_l, hl) \quad (IC_h^C)$$
  $$\pi(q_l, l) \geq \pi(q_h, lh) \quad (IC_l^C)$$

Let the allocation $\{I^d, \{q^d_\alpha\}^h_{\alpha=l}\}$ solves the following program:

$$\max_{\{I,\{q_\alpha\}^h_{\alpha=l}\}} E[V(P(q_\alpha,\alpha) - I, q_\alpha, \alpha)|I].$$

The first order conditions are:

$$\begin{aligned} p(I^d)V'^d_h\pi'(q^d_h, h) &= 0 \\ (1-p(I^d))V'^d_l\pi'(q^d_l, l) &= 0 \\ p'(I^d)(V^d_h - V^d_l) - E[V'^d_\alpha|I^d] &= 0 \end{aligned}$$

Therefore $q^d_\alpha = q^*_\alpha$, $\forall \alpha \in \{l, h\}$.

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

$$E[V(P(q^*_\alpha,\alpha) - I^d, q^*_\alpha, \alpha)|I^A] > E[V(P(q^B_\alpha,\alpha) - I^B, q^B_\alpha, \alpha)|I^B].$$

Since allocation $\{I^d, \{w^d_\alpha, q^*_\alpha\}^l_{\alpha=h}\}$ where $w^d_\alpha = P(q^*_\alpha,\alpha) - I^d$ satisfies P''_R without solving it, RU's expected utility is higher with $\{I^A, \{w^A_\alpha, q^A_\alpha\}^l_{\alpha=h}\}$ than with $\{I^d, \{w^d_\alpha, q^*_\alpha\}^l_{\alpha=h}\}$:

$$E[V(w^A_\alpha, q^A_\alpha, \alpha)|I^A] > E[V(P(q^*_\alpha,\alpha) - I^d, q^*_\alpha, \alpha)|I^d].$$

Uses the two preceeding relationships and obtain:

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

We now show that if $q^B_l \geq q^A_l$ and $\lambda > 1$, then $E[V^B_\alpha|I^B] > E[V^A_\alpha|I^A]$. This case includes the case $q^B_l = q^*_l$ which is satisfied by definition under Assumption 1.

RU's expected utility in the integrated structure is:

$E[V^A_\alpha|I^A] = p(I^A)v(\pi(q^*_h, h) + (1-p(I^A))(P(q^A_l, l) - P(q^A_l, h)) - I^A) + (1-p(I^A))v(\pi(q^A_l, l) - p(I^A)(P(q^A_l, l) - P(q^A_l, h)) - I^A)$

RU's expected utility in the independent structure is $E[V^B_\alpha|I^B] = p(I^B)v(\pi(q^*_h, h) - I^B) + (1-p(I^B))v(\pi(q^B_l, l) - I^B)$.

Now, 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,

$$v(\pi(q^*_h, h) + (1-p(I^A))(P(q^A_l, l) - P(q^A_l, h)) - I^A) - v(\pi(q^*_h, h) - I^A) < v'(\pi(q^*_h, h)) - I^A)(1-p(I^A))(P(q^A_l, l) - P(q^A_l, h)),$$

and,

$$v(\pi(q^A_l, l) - I^A) - v(\pi(q^A_l, l) - p(I^A)(P(q^A_l, l) - P(q^A_l, h)) - I^A) > v'(\pi(q^*_l, l) - I)p(I^A)(P(q^A_l, l) - P(q^A_l, h)).$$

Since $\pi(q_l^B, l) \geq \pi(q_l^A, l)$, using the two preceeding relationships, we find that:
$p(I^A)v(\pi(q_h^*, h)-I^A)+(1-p(I^A))v(\pi(q_l^B, l)-I^A) > E[V_\alpha^A|I^A]+(P(q_l^A, l)-P(q_l^A, h))p(I^A)(1-p(I^A))[v'(\pi(q_l^A, l)-I^A) - v'(\pi(q_h^*, h) - I^A)]$.
Since $P(q_l^A, l) \geq P(q_l^A, h)$ and $v'(\pi(q_l^A, l) - I^A) > v'(\pi(q_h^*, h) - I^A)$, therefore,

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

Since I^B solves $\max_I p(I)v(\pi(q_h^*, h) - I) + (1 - p(I))v(\pi(q_l^B, l) - I)$, therefore,

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

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

When $\lambda = 1$ (neutral innovation), then $q_\alpha^A = q_\alpha^B$, for every $\alpha \in \{l, h\}$. In this case, RU's expected utility is:
$E[V_\alpha^A|I^A] = E[V_\alpha^B|I^B] = p(I^B)v(\pi(q_h^*, h) - I^B) + (1 - p(I^B))v(\pi(q_l^B, l) - I^B)$.

Q.E.D.

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