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ON THE MANAGEMENT OF INNOVATION

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Abstract

Empirical and theoretical analyses of the management of innovation must carefully disentangle its several dimensions: Who finances R&D expenditures? Who has decision rights over the R&D process and property rights over the innovation? Who receives the return streams derived from the innovation?

This paper is a first attempt at opening the R&D blackbox. It studies the foundations for co-financing by investors and users of the innovation and for employment features such as shop rights, trailer clauses and the hired-for doctrine. It investigates the theoretical validity of Schumpeterian hypotheses. Last it analyses the incentive costs and benefits of research joint ventures.
1 Introduction.

Following Schumpeter's (1942) persuasive case that R&D is a major determinant of economic growth and welfare, empirical research in industrial organization has investigated the sources of innovation and their incentives. It has extensively tested hypotheses enunciated by Schumpeter and his disciples, that a firm's incentives for R&D would be higher, the larger the scale, scope, initial monopoly power and financial resources of the firm. The resulting large body of evidence has yielded ambiguous conclusions concerning these determinants of R&D (Cohen-Levin (1989)). Another strand of the literature investigates the nature of research rather than the R&D effort or its output. For example, empirical work has started to test (with mixed results) the idea that established firms would pursue incremental rather than radical innovations (Henderson (1991)).

Surprisingly, little attention has been devoted to the theoretical validation of these hypotheses. Nor has one more generally derived a theory of the organization of the R&D activity\footnote{There is a large theoretical literature on the study of patent races and incentives to license. The focus of this literature is the persistence of R&D and product market monopoly power and not the management of innovation.}. Theoretical foundations are needed at several levels: to interpret existing findings, to suggest new designs for testing, to build efficient private organization of research, and to guide government intervention in the R&D market. The purpose of this paper is to offer a first step in this direction.

In our view, empirical and theoretical analyses of the management of R&D must carefully disentangle its three dimensions: Who finances R&D expenditures? Who owns (has property rights over) the innovation? Who receives the return streams derived from the innovation? To analyze these
distinct dimensions, let us note that research is usually not performed by a firm, but by a person or group of persons, the research unit. For reasons that will become clear later, the non research parties also involved in the organization of research must be divided into two categories: customers, and financiers or investors. Customers are those parties that will directly benefit from the innovation; namely, the manufacturers who will commercialize the innovation, the users who will purchase the resulting product, and the suppliers of complementary products or of inputs used by the manufacturer. (Which of these three kinds of customers finances the innovation depends on the industry (von Hippel (1988)) and will only be briefly discussed in the paper; for now we can content ourselves with a single aggregated customer.)

The customer and the research unit may or may not belong to the same firm. It is interesting to note that, in some sectors such as biotechnology, customers spend a large fraction of their R&D budget on sponsoring external R&D.²

In contrast to customers, investors benefit from the innovation only to the extent that they share the royalties from the sale or licensing of the research unit's patent or trade secret. Again there are several categories of investors: banks or venture capitalists who acquire shares or other securities in the research unit; and parent companies (including research companies) that own the research unit and operate in an industry or product line different from that of the customers, and therefore will not benefit directly from the innovation.³

²The relative proportion of in-house R&D and externally sponsored R&D is not always known with precision, as data often record only the total R&D budget. Pisano, Shan and Teece (1988) for example report that Monsanto spent in 1982 $40 million out of an R&D budget of $62 million on outside contracts.

³One may rightly argue that the distinction between customer and investor is less clear cut than it appears. An investor might enlarge the scope of its activities and start commercializing the innovation. The theory developed below is straightforwardly reinterpreted to
There is a wide range in the distribution of property rights. Consider for instance the case of integration in which the research is performed within the customer or another firm. The research unit is then an “employee”\(^4\). The employee relationship does not quite imply that the employer receives property rights on all employee-generated inventions. Employment contracts as well as the law relate ownership to the nature of the invention. With some variations, property rights normally go to the employer. However an innovation that the employee was “not hired for” and which was performed outside the firm usually belongs to the employee. Innovations that fall in between, namely those for which the employee was not hired, but that made use of the employer’s facilities or data or benefited from the assistance from fellow employees, exhibit split ownership rights: The employee owns the innovation, but the employer has a “shop right” to receive a nonexclusive, nonassignable and royalty-free license\(^5\). A related, but different allocation of property rights confers ownership to the employer for inventions that are “in-line”, i.e. that relate to the employer’s business, and to the employee for inventions that are “not-in-line” in the sense that they pertain to another business. An intertemporal version of such distinctions among inventions is the different treatment of innovations made during or just after the employee’s tenure in the firm and those made long after the breakaway.

Another important dimension of R&D contracting is the distribution of

\(^4\)Incidentally, Schumpeter (1942) and Galbraith (1952) were struck by the fact that innovation often takes place in R&D labs administered by large corporations. Indeed, Stedman (chapter 2 in Neumeyer (1971)) notes that, despite the fact that creation is essentially a personal act, 60% of the patents issued by the U.S. Patent Office in 1954 went to corporations, as opposed to 35% in the mid 30’s.

\(^5\)There are some exemptions to this pattern. Neumeyer (1971) records that, unlike the three other big US aircraft manufacturers, Boeing permits its employees to retain ownership of their inventions provided Boeing receives a shop right.
return streams between the research unit and the customer or investor, when the innovation is sold to third parties (other customers). Venture capitalists routinely take shares in high tech research units. And many corporations specify the division of return streams for innovations generated by their employees and sold to third parties\(^6\). The sharing of return streams does not covary perfectly with the property rights\(^7\). This does not mean that there is no relationship between ownership and royalty sharing, as both should be determined simultaneously as part of an optimal incentive package\(^8\).

This paper develops a simple model that sheds light on static and dynamic configurations of property rights and sharing rules in research organizations. The paper is structured as follows: Section 2 analyzes the basic relationship between a research unit and a customer (manufacturer, user, or supplier of related components). The customer is the only potential customer or else signs an exclusivity contract with the research unit. The research unit performs the creative task but has no independent resource to pay for salaries, equipment or data. It must therefore look for outside financing. In a first step, we assume that the financing is provided by the customer. We posit that the exact nature of the innovation is ill defined ex ante and that the

\(^6\)For instance, the four largest US aircraft manufacturers offer their employees shares of 10% to 30% on income collected from royalties (Neumeyer (1971, chap. 4)). Some universities give 15% of the royalties to their researchers.

\(^7\)For example, property rights go to the employee in universities and to the employer in aircraft manufacturers even though the sharing rules are similar (see previous footnote). Another case in point is that venture capitalists or customers who purchase a majority of shares in a venture may not ask for control rights (The Economist, August 29, 1992, p53-54). When Hoffman-Laroche bought a 60% stake in Genentech in 1990, it demanded only 2 of Genentech’s 13 board seats.

\(^8\)Furthermore, the very feasibility of royalty sharing may depend on the ownership structure. In the above aircraft manufacturers example, the manufacturers sometimes expropriate the employees’ share of royalties by granting each other free licensing of their inventions. This expropriation would not occur under employee ownership. In another illustration of the difficulty in guaranteeing the intended use of the invention by its owner, the US government forces its employee-owners to exploit their inventions diligently through compulsory licensing.
two parties cannot contract for delivery of a specific innovation. The contract specifies a verifiable amount of customer investment, the allocation of property rights on any forthcoming innovation and, possibly, a sharing rule on the profit (license fee) obtained by the research unit.  

In the integrated case, the customer owns and freely uses the innovation. In the nonintegrated case, the research unit owns the innovation and, once the innovation is made, bargains with the customer over the license fee. The sharing rule contracted upon ex ante is shown to be irrelevant. The study then boils down to the classic one of choosing property rights so as to best protect the two parties' specific investments in the relationship.  

Giving property rights to the research unit is optimal when it is more important to encourage the unit's effort to discover than to boost the customer's financial (and nonfinancial) investment in the research, or when the customer is subject to financial constraints (the long-purse effect).  

Our framework also provides a rigorous evaluation of the Schumpeterian hypotheses. It questions the robustness of the Schumpeterian conjectures mentioned earlier to variations in the allocation of property rights on innovation. Once this allocation is endogenized as part of the contractual arrangements between customers and research units, one should not expect a clear empirical aggregate relationship between R&D input or output and parameters such as scale, scope or monopoly power.  

Is it optimal to have a single provider of funds, namely the customer? In

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9 We can allow the research unit to own some shares of the customer stock or profit. As discussed in section 2, this hardly affects the analysis.  
10 It will be obvious to the reader that our basic model borrows considerably from the property rights analysis of Grossman-Hart (1986). There are a couple of differences in the treatments. First, we allow equity participation by the trading partner as well as by third parties. Second, we introduce contractible (as well as noncontractible) investment and point at the role of cash constraints. These features account for a couple of results of independent interest such as the rationale for cofinancing or the possible inefficiency of the allocation of property rights.
section 3, we show that it may be strictly optimal for the customer to give property rights to the research unit and to demand cofinancing by an investor (such as a venture capitalist, a research firm or a parent company not in the customer's business). The investor then takes some share in the research unit. The research unit will resist cofinancing as it dilutes its share of the pie, but can only consent to give shares to an investor if it is in a weak bargaining position ex ante or else if the customer does not break even in the absence of cofinancing. Furthermore, this arrangement cannot be duplicated by transferring the investor's share in the research unit to the customer, since the customer then faces conflicting objectives when bargaining with the research unit. We thus obtain a theory of the existence of multiple principals.

Section 4 considers product market competition among customers. It in particular analyzes the validity of the common claim that independent research units have more incentives to pursue radical research than a research division of an incumbent customer. We study a choice among research lines and analyze the tradeoff between innovating with a higher probability (or faster) and making a more drastic discovery. We show that the research unit's preferred choice of technology depends on the relative willingness to pay for the innovation of the incumbent customer and of potential entrants. We conclude that without more specific assumptions, there is no presumption that independent research units have more incentive to make drastic innovations. Indeed, in the case of Bertrand competition in the product market, it has less incentives.

Shop rights, property rights contingent on the nature of the innovation and rules governing breakaway research are instances of multiple, split prop-

\footnote{On the other hand, investors may not want to fully finance the research, as part of the value of innovation goes to the customer.}
erty rights. Section 5 rationalizes these institutions by introducing multiple customers or multiple innovations. The allocation of property rights between the customer and the research unit is then designed to provide maximal incentives to both parties. The basic principle is to give property rights to a party on those activities for which it has a comparative advantage in creating value.

The discussion of breakaway research in section 5 leads naturally to a study of the dynamic management of innovations. *Vertical research joint ventures* (RJVs), which constitute a substantial fraction of RJVs, are designed to bring together complementary assets, usually research capacity and manufacturing or marketing. Starting a vertical RJV consists for the two partners in identifying a research project, creating a separate entity, defining control rights over this entity, specifying (contractible) inputs, and distributing equity participations. In a static context with a single innovation in sight, an RJV is but a special (nonintegrated) way of managing the innovation, that is of allocating the financing, the control rights and the profits. Section 6 follows the business economics literature by stressing the specific dynamics of the RJV. Indeed an RJV has a specific objective and is limited in scope and/or in time. It thus pursues some current innovation and keeps the partners independent for future activities. The short-term horizon of the RJV matters when the research unit cannot protect its intellectual property. By releasing its technological knowledge to its partner, the research unit raises the probability of success of the joint venture, but also creates its own

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12 We leave for future research the analysis of two other kinds of RJVs: unrelated RJVs (at least two customers serving different product markets join forces to develop a common input) and horizontal RJVs (the customers compete on the same product market). Horizontal RJVs are of course subject to the strictest antitrust scrutiny (antitrust tradeoffs are discussed in Katz-Ordover (1990) and the *Journal of Economic Perspectives* symposium on the topic (1990)). Also some of the large horizontal RJVs exhibit a substantial government involvement.
competition in the future. RJVs are thus not very conducive to technology transfers, although future competition can be softened by letting the customer take an equity participation in the research unit. Vertical integration reduces the research unit's incentive to hold back the transfer of knowledge by reducing its payoff from having exclusive knowledge of the technology tomorrow. We show however that integration imperils future technological progress.

Last, section 7 summarizes the main insights of the paper, and discusses some directions for research.

2 The research unit-customer relationship.

2.1 Research Technology.

A research unit (RU) performs research for a customer (C). The value of innovation for the customer is $V > 0$. The probability of discovery, $p(e, E)$, depends on the noncontractible effort cost $e$ by RU and on the investment $E$ by C. The probability is increasing and strictly concave in $(e, E)$. We will also assume that $p(e, E) < 1$ in the relevant range and that the marginal productivities of effort and investment at their zero level is infinite so as to guarantee interior solutions. The minimum level of effort of the research unit, that is the level of effort induced by its researchers’ intellectual curiosity, ego, career concerns and prospects of informal rewards, is normalized to be 0. So is the minimum level of investment by the customer. We will make two opposite assumptions concerning the customer’s investment. In the first case $E$ is monetary and contractible. In the second case $E$ stands for proprietary technological information freely supplied to the research unit, or for interaction with the research unit to tailor the innovation to the final
demand; $E$ will then be assumed to be noncontractible. We would of course expect a mixture of contractible and noncontractible investments in reality. The results for the two cases are most often identical and so we will state the results with both cases in mind, unless they differ, in which case we will note the points of departure.

Without loss of insights, we posit a separable form for the technology: $p(e, E) = q(e) + r(E)$. Our theory can be straightforwardly extended to non-separable technologies; the new feature is then that the optimal specification of the customer’s investment (if it is contractible) reflects its influence on the research unit’s effort through complementarities or substitutabilities in the production function.

Both parties are income risk neutral and have reservation utility 0. Furthermore $RU$’s income cannot be negative. Let us define the socially optimal effort and investment $e^*(V)$ and $E^*(V)$ by

$$\max_{\{e, E\}} \{p(e, E)V - e - E\},$$

or

$$q'(e^*(V))V = r'(E^*(V))V = 1.$$ 

### 2.2 Contracts.

$RU$ has no money and therefore investment must be fully financed by $C$. The two parties cannot specify the innovation ex ante. They can allocate the property right on the innovation to one or the other. Furthermore, $C$ takes a (nonvoting) equity share $(1 - \alpha)$ in $RU$, so that $RU$ retains a fraction $\alpha$ of the licensing fee\(^{13}\). We later show that one can choose $\alpha = 1$ without loss of

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\(^{13}\)In the whole paper we restrict attention to linear sharing rules for simplicity. However, as we shall argue in subsection 2.4, introducing non-linear sharing-rules will not modify our main conclusions for the research unit-customer relationship, as long as the two parties can by mutual consent tear up the initial contract and renegotiate.
generality. [For expositional simplicity, we do not, but easily could allow for RU's owning an equity participation in C. This equity participation can be shown to have no effect if RU has property rights over the innovation, and to raise RU's incentives if C has the property rights. Ignoring this equity participation is a good first approximation when RU is a small high-tech venture and C a large pharmaceutical or computer company.]

Under C ownership, C freely uses the innovation. Under RU ownership, C and RU bargain over the licensing fee after the innovation appears. The bargaining process is the standard alternating-offers game (Rubinstein (1982), Ståhl (1972)). It is well known (Binmore (1981)) that this bargaining process yields a licensing fee equal to $V/2$ when the time period between offers converges to zero, which we will assume. Of course, the exact split of the pie is theoretically arbitrary in that it is sensitive to the bargaining process that is posited; we also would expect a variety of splits in practice. But we should note that the industry rule of thumb is that the innovator receives between 25% and 50% of the pie (Caves et al (1983), Barton et al (1988)).

Because utility in the ex post bargaining game is transferable in the relevant range (in which C pays for the innovation), focusing on the equal split case involves no loss in insights, in that the qualitative adjustments are straightforward for different splits. In contrast, utility is not always transferable in the relevant range in the ex ante bargaining over the allocation of property rights and sharing rule. For, it may be the case that RU would like to obtain property rights from C, resulting in a higher total surplus $(pV - e - E)$ and that RU is unable to make the compensating transfer to C because it is cash constrained. Results may then qualitatively depend on the division of the ex ante bargaining power. All the qualitative conclusions may however be obtained by looking, as we will do, at the two polar cases in
which one of the parties makes a take-or-leave-it contract offer and therefore has all the bargaining power ex ante.

Remark: By focusing on ownership of the innovation, we have ignored the possibility of $RU$ owning $C$. Suppose thus that $C$ is a division owned by $RU$. We will then assume that ownership of $C$ does not imply that $RU$ can force $C$ to produce and that $C$'s indispensibility in the production process allows it to extract $V/2$ from $RU$ by threatening not to produce. $RU$ then gains nothing from owning $C$ instead of only the innovation, and our focus on the ownership of innovation involves no loss of generality. [Our analysis is straightforwardly generalized when $RU$ can force $C$ to produce. We will not develop the analysis under this alternative assumption for the sake of brevity.]

2.3 Optimal property rights when $C$ holds no equity in $RU$.

Suppose in a first step that $\alpha = 1$ ($C$ has no equity in $RU$).

Under $C$ ownership, $RU$ receives no reward for innovating and therefore $e = 0$. On the other hand, $C$ has appropriate incentives to invest. It maximizes $[p(0, E)V - E]$ and therefore chooses $E = E^*(V)$. Utilities are

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14This is in the spirit of Hart-Moore (1991). Our assumption may be weaker than the one made in Hart-Moore where parties are bound by a complete contract. Here, unlike in Hart-Moore, the nature of production is ex ante ill-defined and cannot be described in a contract. Note also that we do not make a similar assumption for $RU$ (although we could). We rather assume that $RU$ cannot promise (contract on) the innovation before it is made.

15To be certain, there exists some noncontractual or informal sharing in that firms reward successful researchers ex post through salary increases, cash awards, fringe benefits, stocks or promotions. Such rewards are generally not commensurate with the value of the innovation (Neumeyer (1971, chapter 3)). They play a slightly larger role for government employees, perhaps because the employer's profit motive is lower (Neumeyer (1971, chapter 5)). As we mentioned earlier, $e = 0$ is a normalization for the level of effort exerted in the absence of formal rewards.
then (possibly up to a lump sum transfer from $C$ to $RU$):

$$U_{RU} = 0$$  \tag{1}$$

and

$$U_C = p(0, E^*(V))V - E^*(V).$$

Under $RU$ ownership, each receives $\frac{V}{2}$ in case of innovation. $RU$ maximizes $[p(e, E)\frac{V}{2} - e]$ and so chooses $e = e^*(\frac{V}{2})$. If either $E$ is noncontractible or $E$ is contractible and $C$ has the bargaining power ex ante\textsuperscript{16}, $C$ chooses its investment so as to maximize $[p(e, E)\frac{V}{2} - E]$, resulting in $E = E^*(\frac{V}{2})$. Note that underinvestment by $C$ occurs even when $E$ is contractible, because $RU$ cannot ex ante compensate $C$ for an increase in investment. Utilities are then (possibly up to a lump sum transfer from $C$ to $RU$):

$$\tilde{U}_{RU} = p(e^*(\frac{V}{2}), E^*(\frac{V}{2}))\frac{V}{2} - e^*(\frac{V}{2})$$  \tag{2}$$

and

$$\tilde{U}_C = p(e^*(\frac{V}{2}), E^*(\frac{V}{2}))\frac{V}{2} - E^*(\frac{V}{2}).$$

How are property rights determined? Clearly $\tilde{U}_{RU} > U_{RU}$: $RU$ prefers having the property rights. If $RU$'s effort is important enough that $\tilde{U}_C >$

\textsuperscript{16}If $E$ is contractible and $RU$ has the bargaining power ex ante, $RU$ will demand a level of investment $E$ together with a cash transfer $a$ from $C$ to $RU$ such that $C$ breaks even:

$$a + E = p(e^*(\frac{V}{2}), E)\frac{V}{2}.$$  

Assuming $a > 0$, $RU$ chooses $E$ so as to maximize

$$p(e^*(\frac{V}{2}), E)\frac{V}{2} - e^*(\frac{V}{2}) + a = p(e^*(\frac{V}{2}), E)V - e^*(\frac{V}{2}) - E,$$

and so investment is socially optimal: $E = E^*(V)$.

If $p(e^*(\frac{V}{2}), E^*(V))\frac{V}{2} < E^*(V)$, then $RU$ should compensate $C$ for choosing the socially optimal investment, which is impossible. $RU$ then demands the highest investment consistent with $C$'s participation, and no cash transfer.
$U_C$, then property rights are allocated to $RU$. If $U_C < U_R$, the allocation of property rights depends on the ex ante relative bargaining strength. If $RU$ has the bargaining power ex ante, the allocation of property rights is efficient in that $RU$ receives ownership if and only if $\bar{U}_{RU} + \bar{U}_C \geq U_{RU} + U_C$. For, if $RU$ ownership is efficient, $RU$ allocates the property rights to itself. If $C$ ownership is efficient, $RU$ gives the property rights to $C$ in exchange of a cash transfer. In contrast, if $C$ has the bargaining power, $C$ always keeps property rights as $RU$ is cash constrained. So, when $\bar{U}_{RU} + \bar{U}_C > U_{RU} + U_C$, an inefficient allocation of property rights occurs. We have thus vindicated our earlier claim that ex ante bargaining power influences not only the distribution of the pie, but also its size.

Proposition 1 The allocation of the property rights on an innovation between a research unit and a customer is determined by two factors:

(i) underinvestment by both parties. Property rights are allocated to the research unit when the marginal efficiency of its effort is large enough relative to that of the customer's investment.

(ii) ex ante bargaining power of the two parties. The allocation of property rights is always efficient when the research unit has the bargaining power ex ante, while the research unit’s cash constraint may induce the customer to inefficiently retain ownership when having the bargaining power ex ante.

\[ q(e) = \frac{2\lambda}{\sqrt{\lambda}} \text{ and } r(E) = \frac{2\mu}{\sqrt{\mu}}. \text{ Then } U_C = \mu^2V^2, \bar{U}_C = \left(\frac{\mu^2}{4} + \frac{\mu^2}{2}\right)V^2 \text{ and } \bar{U}_{RU} = \left(\frac{\lambda^2}{4} + \frac{\lambda^2}{2}\right)V^2. C \text{ prefers } RU \text{ ownership if and only if } \lambda \geq \frac{\lambda^2}{\mu}, \text{ i.e. if the marginal efficiency of } RU \text{'s effort sufficiently exceeds that of } C \text{'s investment.} \]

\[ 17 \text{For example, let } q(e) = \frac{2\lambda}{\sqrt{\lambda}} \text{ and } r(E) = \frac{2\mu}{\sqrt{\mu}}. \text{ Then } U_C = \mu^2V^2, \bar{U}_C = \left(\frac{\mu^2}{4} + \frac{\mu^2}{2}\right)V^2 \text{ and } \bar{U}_{RU} = \left(\frac{\lambda^2}{4} + \frac{\lambda^2}{2}\right)V^2. C \text{ prefers } RU \text{ ownership if and only if } \lambda \geq \frac{\lambda^2}{\mu}, \text{ i.e. if the marginal efficiency of } RU \text{'s effort sufficiently exceeds that of } C \text{'s investment.} \]

\[ 18 \text{The idea that cash constraints reduce the efficiency of bargaining processes has been used in the field of corporate finance (see Aghion-Bolton (1992)).} \]
2.4 The irrelevance of C’s equity in RU.

Suppose that C is given $(1 - \alpha)$ (nonvoting) shares in RU. The real license fee paid by C when they agree on a nominal license fee $\ell$ is then $\hat{\ell} = \ell - (1 - \alpha)\ell = \alpha \ell$. The two parties then bargain over $\hat{\ell}$, and nothing is affected by the introduction of an equity participation (the reader will check this more formally using the alternating-offers bargaining model). As explained in the introduction, the customer is handicapped by the fact that its share in the research unit makes it softer in the bargaining process. A similar reasoning shows that RU’s taking a share in C has no effect on the net license fee and is therefore irrelevant.

**Remark 1:** The irrelevance result also holds for nonlinear sharing rules as long as the two parties can by mutual consent tear up the initial contract and write a new one. The real license fee is again driven by time impatience and not by the sharing rule. It can furthermore be shown in the alternating-offer bargaining game that forcing one party (here the customer, since the research unit has no cash) to put up an hostage and pay a flow payment to the other until “some agreement is reached” has no effect on the incentives for R & D.

**Remark 2:** We do not wish to imply that customers should never take equity in the independent research units they sponsor. Equity participation here does not raise the customer’s investment since it has no effect on the real transfer price. But it could affect other moral hazard components of the customer’s activity. For instance, in the presence of alternative customers (see subsection 5.1), if there were appropriability problems so that the customer could resell the technology to other customers, an equity participation in the research unit would mitigate the customer’s incentive to expropriate the
research unit (Rodriguez (1992)). It would also soften future competition between the research unit and the customer (see section 6 below).

2.5 Schumpeterian hypotheses.

The second most tested set of hypotheses in industrial organization (after the cross sectional analysis of the structure-conduct-performance paradigm) relates R&D input (R&D expenditures or personnel engaged in R&D) or output (as measured by the number of “significant” innovations) to variables that presumably alter the incentives for R&D. The scale effect states somewhat vaguely that a “larger” firm has more incentives for R&D. A first interpretation of this scale effect is that a larger market for a good that benefits from a process innovation raises the value of the innovation. The relevant explanatory variable is then the size of the business unit rather than the size of the firm. An alternative view takes the size of the firm as the relevant empirical variable. Relatedly, the scope effect (Nelson (1959)) posits that a more diversified firm exploits innovations more easily than a specialized firm and “therefore” has more incentives to innovate. The market power effect presumes that firms with market power gain more from an innovation. How do these hypotheses fit in our framework? Let us assume that the scale, scope and market power effect all boil down to a change in $V^{19}$.

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19Providing general conditions linking these effects and the value of the innovation is tangential to the paper, but it is useful to give a few illustrative examples. For instance, it seems natural to identify the first interpretation of the scale effect with an increase in $V$. An innovation that reduces the customer’s marginal cost of production is valued more, the higher the output. An increase in the firm’s scope may also be viewed under some (strong) conditions as an increase in $V$. To illustrate this, suppose that the customer may produce two goods, $A$ and $B$, that may benefit from the innovation. Starting a product line involves a fixed cost $K$. The innovation benefits either product line $A$ or product line $B$ with equal probabilities and increases profit by $V$ on the relevant product line. A firm that already produces $A$ and $B$ has value $\frac{1}{2}V + \frac{1}{2}V = V$, whereas a firm that has entered product line $A$ only values the innovation $\frac{1}{2}V + \frac{1}{2}(V - K) < V$ (assuming $V \geq K$). On the other hand, one can think of circumstances under which a larger scope reduces the incentive to innovate. Like in the case of a single good, an established firm using an old
First, one can study how R&D inputs and output react to an increase in the value of innovation, *taking the organizational form as given* (in the case of cofinancing, the investor’s share in the research unit is kept fixed). It is easily shown that effort, investment and probability of discovery all increase with $V$.

Second, we ought to ask how the organizational form ($C$ ownership, $RU$ ownership with or without cofinancing) is affected by a change in $C$'s value $V$ for the innovation. To see why a change in $V$ has ambiguous implications, let us suppose that the customer has the ex ante bargaining power and ignore, as in this section, cofinancing (in our examples we will make assumptions so that cofinancing is indeed suboptimal). Consider a $V$ such that the customer is indifferent between keeping property rights and allocating them to the research unit. Using the superscripts $^{RU}$ and $^C$ to designate the owner of the innovation, such a $V$ must satisfy:

$$p^{RU} \frac{V}{2} - E^{RU} = p^C V - E^C,$$

where $E^{RU} = E^*(\frac{V}{2}), E^C = E^*(V), p^{RU} = p(e^*(\frac{V}{2}), E^*(\frac{V}{2}))$ and $p^C = p(0, E^*(V))$.

Consider a small increase in $V$. A first effect is that $C$ ownership should now be preferred by $C$, since $C$ is residual claimant under $C$ ownership and not under $RU$ ownership. For instance, if $p^{RU} = p^C = p$, \( \frac{\partial}{\partial V}(p^C V - p^{RU} \frac{V}{2}) = p/2 > 0 \). The second effect goes in the other direction: The research unit's technology may have less incentives to discover a new technology than if it were starting from scratch (this is the familiar replacement effect). A variation of the scope argument is the idea of “absorptive capacity” (Cohen-Levinthal (1990)): It has been argued that a firm’s ability to recognize the value of external innovation and assimilate it properly is a function of the firm’s level of prior related knowledge generated in particular by its own R&D effort. Lastly, the market power effect can also in some circumstances be formalized by an increase in $V$. If either an increase in market power raises the output produced (to the detriment of product market rivals) or the innovation cannot be perfectly protected by a patent, trade secret or internal use and therefore spills over to rivals, an increase in market power may well raise the firm’s valuation for the innovation.
effort increases with $V$ under $RU$ ownership but is unaffected under $C$ ownership. There is a third and more ambiguous effect resulting from the fact that $p^C$ in general differs from $p^{RU}$. But the first two effects clearly show why one cannot draw any general conclusion about the effect of scale, scope or market power on the management of innovation. When innovating becomes more important, the customer wants to appropriate more of it through $C$ ownership, but also to raise the research unit’s incentives through $RU$ ownership. Appendix 1 illustrates this with two simple examples. The changes in ownership structure have important consequences for Schumpeterian relationships. Consider a switch from $C$ ownership to $RU$ ownership. The available input measure, the customer’s monetary investment, declines. The output measure, here the probability of discovery, on the other hand may well increase due to improved incentives of the research unit. Input and output measures then move in opposite directions because part of the input cannot be measured\textsuperscript{20}. Furthermore, there is no clear relationship between either measure and the value of the innovation and therefore the Schumpeterian parameters.

Remark: The analysis of section 3 will point at still another theoretical difficulty with empirical work using R&D input or output, but not the organizational form, as dependant variables (besides the traditional issues concerning the measurement of variables: see Cohen-Levin (1989) for a summary discussion of these issues): Input measures may also be misleading because a firm’s commitment to R&D cannot be simply measured by its R&D effort even if we assume that this effort is purely monetary. In our model the customer may choose to alleviate its investment burden by demanding cofinancing. Its

\textsuperscript{20}See example 2 in Appendix 1 for an illustration. Fisher and Temin (1973) provide an empirical discussion of input and output measures of R & D activity, focusing on the joint hypothesis of increasing returns within R & D and the scale effect.
own R&D expenditures may decrease while consolidated (customer plus investor) R&D expenditures increase. It therefore seems natural not to attach too much significance to firm level R&D input viewed in isolation.

3 Multiple financing.

3.1 The rationale for cofinancing.

Parties that do not directly benefit from the innovation, namely banks, venture capitalists or a parent company often contribute to the financing of the research unit. To explain this, we must come to grips with the issue of what such investors do that customers could not do themselves; that is, why can’t customers take on the share held by investors? We argue that the desire to extract the research unit’s rent provides a rationale for this institution.

As observed in section 2.4, C’s acquisition of a stake in RU actually does not dilute RU’s return from innovation: C cannot have the cake and eat it too. In contrast, suppose that an investor claims a fraction \((1 - \alpha)\) of RU’s income (under RU ownership). We keep assuming that RU and C bargain over the licensing fee after the innovation occurs. Even though the research unit receives only a fraction \(\alpha\) of the fee, the bargaining process between RU and C is unaffected. RU then receives a return \(\alpha V/2\) for the innovation as compared with \(V/2\) when the \((1- \alpha)\) shares are held by the customer instead of the investors. Note that in the bargaining process the investors and the research unit have congruent interests, namely to extract as much from the customer as is possible; therefore the investors have no incentive to enter the bargaining process or to collude with the research unit.\(^{21}\)

\(^{21}\)The lack of incentive to collude comes from the linear sharing rule. The corporate finance literature has demonstrated that, in the absence of renegotiation or collusion, a nonlinear contract between an investor and an agent, such as a debt contract, can strengthen the agent’s bargaining position with a third party. Nonlinear contracts on the
Remark: That the research unit’s return from innovating is affected by who (customer, investor) owns its shares carries over to the situation where the investor is drawn into the bargaining process. To illustrate this, suppose that the three parties bargain according to (a three-party extension of) the alternating-offer model: Each period, one of the three parties is drawn, with equal probabilities, to make an offer to the other two. Let the initial contract specify that the investor needs the agreement of the other two parties while an offer of the research unit (resp. the customer) yields an agreement if the customer (resp. the research unit) accepts it. That is, the customer and the research unit can strike a deal between them without needing the investor’s agreement; the investor is protected only by its share \((1 - \alpha)\) in whatever the research unit receives. In a stationary equilibrium of this bargaining game, the research unit’s payoff is equal to \(\alpha V/(3 - \delta)\), where \(\delta\) is the discount factor between offers. It thus converges to the same payoff as above \((\alpha V/2)\) as the offers become very frequent. The payoffs of the investor and the customer also converge to those obtained when the investor is not part of the bargaining process. To summarize, under alternating-offer bargaining, initial property rights can be chosen so as to yield the same sharing rule as when only the customer and the research unit bargain.

Our analysis studies the best case for cofinancing, namely when customer and investor investments are contractible and perfect substitutes. When \(RU\) has the bargaining power ex ante and \(C\)’s participation constraint is not binding in the absence of cash transfer, then \(RU\) does not offer cofinancing other hand are sensitive to the possibility of secret renegotiation between the investor and the agent. Indeed if the research unit and the customer bargain together, it is optimal for the research unit and the investor to secretly renegotiate towards a linear sharing rule so as to obtain congruence.
because this would dilute its share and lower its research effort. That is, for a given level of financing by C, offering a claim for a fraction \((1 - \alpha)\) of RU's income to investors yields RU less in cash than it loses from reduced incentives. If however C does not want to invest in R&D even in the absence of cash transfer, RU may want to alleviate C's financing burden by resorting to an investor\(^{22}\).

When C has the bargaining power ex ante and RU's incentives are sufficiently important that RU ownership is optimal for C, C demands cofinancing \(E_I\) from a competitive investor in exchange of a claim of a fraction \((1 - \alpha)\) of RU's profit, where

\[
E_I = p(e^*(\alpha \frac{V}{2}), E_I + E_C)(1 - \alpha) \frac{V}{2},
\]

and where we ignore any transfer \(a_I\) from the investor to the customer for the moment. C's profit is then

\[
p(e^*(\alpha \frac{V}{2}), E) \frac{V}{2} - E_C = p(e^*(\alpha \frac{V}{2}), E)(1 - \alpha) V - E,
\]

where \(E = E_C + E_I\) is total investment. The optimal total investment for the customer is \(E = E^*((1 - \frac{\alpha}{2})V)\). Cofinancing thus allows the customer to give

\(^{22}\)Formally, let \(E_C\) and \(E_I\) denote customer and investor investments (total investment is \(E = E_C + E_I\)), and \(a_C \geq 0\) and \(a_I \geq 0\) denote their cash payments to RU. The research unit must guarantee that the customer and the investor get their individual rationality levels:

\[
E_C + a_C \leq p(e^*(\alpha \frac{V}{2}), E) \frac{V}{2}
\]

and

\[
E_I + a_I \leq p(e^*(\alpha \frac{V}{2}), E)(1 - \alpha) \frac{V}{2}.
\]

The Lagrangian for the maximization of RU's utility over \(\alpha \in [0, 1]\) is:

\[
L = p(\alpha \frac{V}{2} - e + a_C + a_I + \mu \left[ p \frac{V}{2} - E_C - a_C \right] + \lambda \left[ p(1 - \alpha) \frac{V}{2} - E_I - a_I \right] + \gamma a_C + \xi a_I.
\]

So either \(\mu = \lambda = 1\), and then for any \(E\), this Lagrangian increases with \(\alpha\) since \(\frac{\partial L}{\partial \alpha} (e^*(\alpha \frac{V}{2}), E) (\frac{\partial V}{2}) = 1\). So, \(\alpha = 1\) and \(a_I = E_I = 0\). Or \(\mu = \lambda > 1\) and \(a_I = a_C = 0\). The Lagrangian then may decrease with \(\alpha\) at \(\alpha = 1\). This is in particular the case when \(e\) is inelastic in \(\alpha\), so cofinancing relaxes the customer's participation constraint without worsening incentives.
the research unit any fraction of the value of the innovation between 0 (C ownership) and 1/2 (pure RU ownership). With contractible, perfectly substitutable investments, cofinancing transforms a discrete choice of governance structure into a continuous one.

The choice of $\alpha$ is based on two considerations. First, a lower $\alpha$ allows cofinancing and thus reduces the customer's investment burden. Second, the dilution of RU's share reduces its incentives and reduces the probability of discovery. Using RU’s first-order condition $(q'(e^*(\frac{aV}{2}))\frac{aV}{2} = 1)$, the derivative of $C$’s profit with respect to $\alpha$ is equal to $[-\frac{aV}{2} + \frac{2a}{a^2}(-\frac{q''}{q'})]$. The first term in this derivative is the rent extraction effect and the second the incentive effect. That $\alpha = 0$ is never optimal implies that $C$-ownership is not optimal either. Pure customer financing ($\alpha = 1$) may or may not be optimal depending on the size of the incentive effect. If effort is quite sensitive to dilution (that is, if $-q''/q'$ is large), then $\alpha = 1$ is indeed optimal. But if effort is relatively inelastic, the rent extraction effect dominates and cofinancing occurs. The amount of investor financing for the optimal $\alpha^*$ is then given by

$$E^* = p(e^*(\frac{\alpha^* V}{2}), E^*((1 - \frac{\alpha^*}{2})V))(1 - \alpha^*) \frac{V}{2}.$$

**Remark 1**: Not requiring any transfer from the investor is optimal as long as $E^*_I \leq E^*((1 - \frac{\alpha^*}{2})V)$. If this inequality is not satisfied, one optimal policy for the customer is to let the investor finance the whole investment $E^*((1 - \frac{\alpha^*}{2})V)$ and ask for a transfer $a_I = E^*_I - E^*((1 - \frac{\alpha^*}{2})V)$.

**Remark 2**: When customer and investor investments are contractible and perfect substitutes, as was presumed here, $C$ ownership is never optimal. The research unit’s incentives under $C$ ownership can be duplicated by setting $\alpha = 0$, and the investor’s benefit can be used either to reduce the customer’s investment burden or as a cash transfer to the customer. Further
thermore, increasing $\alpha$ slightly above 0 under RU ownership strictly raises the customer's welfare unless the effort supply is completely inelastic.

$C$ ownership can be optimal when the customer sinks noncontractible investment such as advice on design or release of proprietary technological information. Then $C$ ownership cannot be duplicated by RU ownership with cofinancing at $\alpha = 0$ if $E_I$ and $E_C$ are not perfect substitutes in the production function. A move to RU ownership reduces the customer's investment and this investment cannot be perfectly offset by an increase in the investor's financing. We conclude that customer ownership can result from the existence of noncontractible investment by the customer.

Remark 3: While the model predicts that cofinancing can occur, it does not distinguish among types of investors. To predict whether the investor should be a bank, a venture capitalist or a parent company requires a richer framework. For instance, it may be that a research firm (as a parent company) may help the research unit through the noncontractual release of technological advice. Or a parent company may have better information than the financial market about this type of technology and therefore be more willing to invest in it. Conversely, independent financing by financial intermediaries may be desirable in the absence of a perfect capital market.

Proposition 2.

(i) Suppose the customer's and the investor's investments are contractible and perfect substitutes. Customer ownership is never optimal. Ownership by the research unit involves no cofinancing by an investor if either the research unit has ex ante bargaining power and the customer is willing to participate or the research unit's effort decreases rapidly with a dilution of its equity. Other-
wise cofinancing can occur.

(ii) Customer ownership can be rationalized by the existence of non-contractible investment by the customer.

3.2 The long-purse effect.

This subsection studies another aspect of the financing of R&D. A well-known Schumpeterian hypothesis relates a firm's R&D investment to its size through its ability to raise funds. It has been argued that being large is positively correlated with having a long purse, and that, in an imperfect capital market, a long purse permits more investment, in particular R&D investment.

That a firm's wealth lowers the cost of investment when creditors have incomplete information about its activities has been well established by the corporate finance literature. But the long-purse effect is subject to caveats similar to those in subsection 2.5. Suppose for instance that C ownership is optimal when the customer can finance $E^*(V)$ without going on the capital market. Consider now the situation in which the customer has less than $E^*(V)$ and must borrow. The management of the innovation may be affected by the need to borrow in an imperfect capital market.

First, RU ownership becomes relatively more attractive since it requires a lower monetary investment $E^*\left(\frac{V}{2}\right) < E^* (V)$. Second, cofinancing also allows a reduction in the investment burden of the customer. A move from C ownership to RU ownership or cofinancing indeed lowers the customer's R & D investment, as predicted by the long purse effect. But this move may actually increase the probability of innovation. Appendix 2 illustrates this in an example where in the absence of credit-constraints, RU-ownership is dominated by C-ownership whereas the opposite holds once credit-constraints are introduced.
Another conclusion is the initial distribution of assets influences the allocations of property rights on innovations. In particular we would expect new firms or firms which have experienced hard times to farm out more their R&D activity than established, healthy firms. In this sense the prediction that monetary R&D investment should be positively correlated with assets is not invalidated by our analysis.

4 Property rights and the drasticity of innovations.

This section investigates the relationship between property rights and the nature of the innovation: Does an independent research unit have more incentives to pursue radical (drastic) vs incremental (nondrastic) innovations compared with the same research unit within an integrated firm?

“Drasticity” here refers to the size of the technological or quality improvement brought about by the innovation. For example, the larger the marginal cost reduction, the more drastic the process innovation is. We consider a single innovation and assume that the probability of discovery decreases with the size of the innovation. To focus on the choice of technology, we ignore the inputs e and E in the notation and denote the probability of discovery by \( p(\gamma) \). The parameter \( \gamma \geq 1 \) indexes the “size of the innovation” or “research line”, with \( \gamma = 1 \) corresponding to the existing technology. What was previously said about inputs still applies and of course influences the distribution of property rights.

Following the patent race literature, we refer to the current customer \( C \) as

\(^{23}\) See Aghion-Howitt (1992) for a general equilibrium model of vertical innovations where the size of quality improvements is also treated as a choice variable available to research firms. However, as in the whole literature on R&D and patent races, ownership aspects are left aside.
the "incumbent" and to other potential customers as "entrants". Let \( \pi_1^m(\gamma) \) denote the incumbent's profit when he obtains an exclusive license for the innovation, and let \( \pi_0^m = \pi_1^m(1) \) denote the incumbent's (monopoly) profit in the absence of innovation; finally, \( \pi_1(\gamma) \) is the profit of an entrant who has purchased an exclusive license. One has \( \pi_1(\gamma) \leq \pi_1^m(\gamma) \), with equality only if the innovation is "drastic", in the sense that the entrant owning the new technology is not constrained by the competitive pressure of the incumbent. Since \( \gamma \) indexes the size of the innovation, \( \pi_1^m(\cdot) \) and \( \pi_1(\cdot) \) are both increasing.

We now compare the sizes \( \gamma_C \) and \( \gamma_{RU} \) of the innovation that obtain when \( C \) (respectively \( RU \)) has property rights on the innovation and chooses its size. [We will also allow property rights to be split from control rights over the process.]

Under \( C \) ownership, we have:

\[
\gamma_C = \arg \max_{\gamma > 1} p(\gamma) \left[ \pi_1^m(\gamma) - \pi_0^m \right].
\]

Note that \( \gamma_C \) is the efficient research line for the industry. By a revealed preference argument, the larger \( \pi_0^m \), the more drastic the innovation\(^{24}\). This is a version of Arrow's (1962) celebrated replacement effect. The incumbent prefers a lower probability – higher payoff research technology if its profit in the absence of innovation is high.

Note that the same choice \( \gamma_C \) would be made under \( C \)-ownership with the research unit controlling the research line, since in that case \( RU \) has no bargaining power and no payoff ex post and therefore is willing to choose \( \gamma_C \). So there is no gain in splitting property rights and control rights.

Consider now \( RU \) ownership (with or without cofinancing). Note that in the absence of potential entrants, the research unit gets half of the value of

\(^{24}\)As usual, this is a set comparison if there are several optima.
the innovation in either case and therefore chooses the technology preferred by $C$: $\gamma_{RU} = \gamma_C$. This congruence between the research unit's and the incumbent's preferences disappears when the research unit can sell to an entrant. Although in equilibrium the research unit optimally sells an exclusive license to the incumbent, an entrant acts as a threat and creates an *appropriation effect*.

More precisely, if the innovation is licensed by $RU$ to a potential entrant (instead of being licensed to the incumbent), the entrant can generate a profit equal to $\pi_1(\gamma)$. In other words, the research unit has the outside option to sell an exclusive license to an entrant at price $\pi_1(\gamma)$. A well-known result in Binmore et al (1986) then shows that, under alternating-offers bargaining with this outside option, the research unit can obtain a license fee equal to $\max\left(\frac{\pi^m_{RU}(\gamma) - \pi^m_{C}}{2}, \pi_1(\gamma)\right)$ from $C$.

Suppose first that the optimal choice $\gamma_{RU}$ by the research unit is such that:

$$\frac{\pi^m_{1}(\gamma_{RU}) - \pi^m_{0}}{2} \geq \pi_1(\gamma_{RU}).$$

Then, the outside option of selling to an entrant is irrelevant and therefore, as in the absence of a potential entrant, the research unit chooses the same technology (or technologies if there are multiple optima) as the incumbent customer: $\gamma_{RU} = \gamma_C$.

On the other hand, if $\pi_1(\gamma_{RU}) > \frac{\pi^m_{1}(\gamma_{RU}) - \pi^m_{0}}{2}$, the research unit's choice $\gamma_{RU}$ will generally differ from the incumbent's $\gamma_C$ since now the outside option of selling to an entrant becomes credible and the incumbent must pay $\pi_1(\gamma_{RU})$ to obtain the license. More precisely, by definition of $\gamma_{RU}$ and $\gamma_C$, we have:

$$p(\gamma_C) [\pi^m_{1}(\gamma_C) - \pi^m_{0}] \geq p(\gamma_{RU}) [\pi^m_{1}(\gamma_{RU}) - \pi^m_{0}]$$

and

$$p(\gamma_{RU}) \pi_1(\gamma_{RU}) \geq p(\gamma_C) \pi_1(\gamma_C).$$
Multiplying these two inequalities, we obtain:

\[
\frac{\pi_1(\gamma_{RU})}{\pi_1^m(\gamma_{RU}) - \pi_0^m} \geq \frac{\pi_1(\gamma_C)}{\pi_1^m(\gamma_C) - \pi_0^m}.
\]

In particular, we have established the following proposition:

**Proposition 3:** Interests may diverge as to the choice of the research line when there are potential entrants. Let \( r(\gamma) \equiv \frac{\pi_1(\gamma)}{\pi_1^m(\gamma) - \pi_0^m} \) denote the appropriability ratio or relative willingness to pay of an entrant w.r.t. the incumbent for the innovation. Then:

\[
\gamma_{RU} \geq \gamma_C \quad \text{if} \quad r \text{ is strictly increasing, and}
\]

\[
\gamma_{RU} \leq \gamma_C \quad \text{if} \quad r \text{ is strictly decreasing.}
\]

In other words, if the relative willingness to pay of a potential entrant increases with the size of the innovation, then the research unit will tend to choose a more drastic innovation than the incumbent, since by doing so it is able to appropriate a higher fraction of the surplus of the incumbent. Similarly, if the relative willingness to pay of a potential entrant decreases with the size of the innovation, the research unit appropriates more of the surplus by choosing a less drastic innovation\(^{25}\). If \( r \) is strictly increasing over an interval and strictly decreasing over another, then it is possible to find two research technologies \( p(\cdot) \) and \( \tilde{p}(\cdot) \) such that (with obvious notation) \( \gamma_{RU} < \gamma_C \) and \( \tilde{\gamma}_{RU} > \tilde{\gamma}_C \).

\(^{25}\)The patent race literature (Gilbert-Newbery (1982), Reinganum (1983)) has stressed that an incumbent is more likely to innovate before an entrant when the innovation is minor, and conversely when the innovation is drastic. On the one hand, the replacement effect implies that the incumbent is not in a hurry to innovate; on the other hand, competition destroys industry profit and therefore the incumbent gains more from remaining a monopoly than an entrant from becoming a duopolist. The latter efficiency effect is absent here, since the research unit sells to the incumbent anyway. Our analysis, which also hinges on the willingness to innovate of the incumbent and the entrant, has a very different focus, namely the choice of research technology for a single research unit rather than the race between two research units with fixed research technologies.
What about split property and control rights? Suppose $C$ is able to impose the research line, but that ownership of the innovation remains with $RU$. Then $C$ chooses to maximize his expected net gain from the innovation:

$$
\gamma^* = \arg \max_{\gamma \geq 1} \left\{ p(\gamma) \min \left( \frac{\pi^m_1(\gamma) - \pi^m_0}{2}, \pi^m_1(\gamma) - \pi^m_0 - \pi_1(\gamma) \right) \right\}.
$$

Clearly, $C$ would never choose a drastic innovation, since he would prefer not to innovate (choose $\gamma = 1$ and obtain 0). If $\frac{\pi^m_1(\gamma) - \pi^m_0}{2} \geq \pi_1(\gamma)$, then $\gamma^* = \gamma_C$. If $\frac{\pi^m_1(\gamma) - \pi^m_0}{2} < \pi_1(\gamma)$, then noticing that $\pi^m_1(\gamma) - \pi^m_0 - \pi_1(\gamma) = (\pi^m_1(\gamma) - \pi^m_0)(1 - r(\gamma))$, $\gamma^* \geq \gamma_C$ if $r$ is strictly decreasing and $\gamma^* \leq \gamma_C$ if $r$ is strictly increasing. Quite naturally, we find that the incumbent prefers to reduce the research unit's bargaining power and thus imposes a bias in the research orientation opposite to that desired by the research unit.

**Example:** Process innovation in an homogenous good industry: The incumbent monopolist produces at marginal cost $c_0$. The potential innovation is a process innovation that reduces the marginal cost to $c \leq c_0$. So $\gamma = c_0/c$. If an entrant purchases the exclusive license, the two firms wage Bertrand competition. Letting $D(p)$ denote the demand curve. One has (abusing notation slightly)

$$
\pi^m_1(c) - \pi^m_0 = \int_c^{\infty} D(p^m(x)) \, dx
$$

$$
\pi_1(c) = \min \{ D(c_0) (c_0 - c), D(p^m(c)) (p^m(c) - c) \}.
$$

As is well known, an entrant has more incentive to innovate than an incumbent due to the replacement effect so $r > 1$. A fortiori, $\pi_1(c) > \frac{\pi^m_1(c) - \pi^m_0}{2}$, so that the outside option is binding regardless of the size of the process innovation. Furthermore, $r$ decreases from $D(c_0) / D(p^m(c_0))$ to 1 as $c$ decreases ($\gamma$ increases). *In an homogenous good industry, an independent research unit will pursue less drastic innovations than an integrated one.* Appendix 3
studies two other standard models of industry behavior, that yield ambiguous conclusions as to the monotonicity of the appropriability ratio.

**Remark 1** (exclusive dealing). We have seen that when \( \pi_1(\gamma_{RU}) > \frac{\pi^n(\gamma_{RU}) - \pi^n}{2} \), the research unit chooses an inefficient research line in order to increase its bargaining power. This inefficiency can be eliminated while leaving ownership and control rights to the research unit by signing an exclusivity contract. The outside option being removed, the research unit’s interests would then match the customer’s. However, letting the research unit’s trade with entrants raises its payoff in case of innovation and thereby its incentives to exert effort. There is a strong analogy here with the comparison between a genuine M-form and a corrupted M-form (see Holmström-Tirole (1991)). In a corrupted M-form, each division is prohibited from trading with outside partners and chooses the socially optimal specialization of its investment. In a genuine M-form, divisions can trade with outside partners. They then do not specialize their investments in order to gain a bargaining power; but the existence of competition gives them more incentives to invest than in a corrupted M-form.

**Remark 2** (antitrust law). Suppose that an antitrust law prevents the research unit from licensing to the incumbent. The research unit (if independent) then chooses \( \gamma_{RU} \) so as to maximize \( p(\gamma)\pi_1(\gamma) \). The comparison between \( \gamma_{RU} \) and \( \gamma_C \) (the level chosen by an integrated firm) is as given in Proposition 3. However, \( \gamma_C \) no longer maximizes the sum of the two units’ profits under \( RU \) ownership because efficient licensing negotiation is precluded\(^{26}\).

\(^{26}\)Letting \( \pi_0(\gamma) \) denote the incumbent’s profit when an entrant obtains an exclusive license, the joint incentive to innovate is \( [\pi_1(\gamma) + (\pi_0(\gamma) - \pi^n_0)] \leq \pi^n(\gamma) - \pi^n_0 \) (with equality for a drastic innovation).
5 Split property rights.

We have analyzed the allocation of a single property right. In practice the innovation may have more than one customer or there may be more than one innovation. There is then more than one property right to allocate, and property rights can, and often are split.

5.1 A rationale for shop rights.

This subsection derives foundations for the observed practice of employers allocating ownership to employees while keeping a royalty-free, nonassignable licence for themselves. Consider the following situation. An innovation designed and managed through a contract between a research unit RU and a customer $C_1$ can ex post be sold to a second, yet unidentified customer $C_2$ as well as to $C_1$. $C_1$ and $C_2$ do not compete on the product market; let $V_1$ and $V_2$ denote their valuations of the innovation, where $V_1$ may reflect some non-contractible investment $\tilde{E}$ by $C_1$, that increases $C_1$’s willingness to pay for the innovation [e.g., $V_1 = V_0 + \tilde{E}$, where $V_0$ is a constant.] We adopt the convention that $C_2$ purchases the innovation at price $V_2$. So $C_2$ competes with other firms in its industry. More generally “$V_2$” could stand for the price at which $C_2$ purchases the innovation (so, if $C_2$ is a monopsonist in its industry, $V_2$ would be equal to half of $C_2$’s valuation in the Nash bargaining solution).

Let $V_{RU}$ and $V_{C_1}$ denote $RU$’s and $C_1$’s stakes in the innovation, that is the extra payoffs they obtain when innovation occurs. One has

$$V_{RU} + V_{C_1} = V_1 + V_2$$

and

$$V_{RU} \leq \frac{V_1}{2} + V_2.$$
The latter inequality comes from the fact that $RU$ does not extract more than $V_1/2$ from $C_1$ even if it owns the innovation. Because both parties never have an incentive to overinvest (their individual stakes never exceed $V_1 + V_2$), an optimal contract must maximize the stake of either party in the innovation given the other party's stake\footnote{This is the case if both parties incur some (even negligible) non contractible investment. It is only when the customer's whole investment is contractible that the customer's stake becomes irrelevant.}. Let $\alpha_1$ and $\alpha_2$ denote $RU$’s share of $V_1$ and $V_2$. When there is no customer investment in raising the value of innovation ($\tilde{E} \equiv 0$), an optimal contract must in particular solve:

$$\max \{(1 - \alpha_1) V_1 + (1 - \alpha_2) V_2\}$$

subject to

$$\alpha_1 V_1 + \alpha_2 V_2 \geq V_{RU}$$

and

$$0 \leq \alpha_1 \leq \frac{1}{2}, \quad 0 \leq \alpha_2 \leq 1.$$

We thus focus only on the allocation of incentives; the optimal $V^*_{RU}$ is determined by the same considerations (incentives, ex ante bargaining powers) as in section 2. In this program $\alpha_1$ is indeterminate, as both incentives depend only on $RU$’s total share ($\alpha_1 V_1 + \alpha_2 V_2$). However, when $C_1$’s investment does not only affect the probability of discovery, but also its own valuation $V_1$ for the innovation ($\tilde{E} \geq 0$), the optimal contract must give maximal incentives to $C_1$ on its own use of the innovation. In particular $\alpha_1 = 0$ if $\alpha_2 < 1$. In words, if $C_1$ can affect $V_1$ but not $V_2$, its relative share should be tilted as much as possible towards the first use. Indeed, if $V^*_{RU} \leq V_2$, the optimal contract gives a shop right to $C_1$ and allocates the licensing fees in proportions $\alpha_2^* \equiv V^*_{RU} / V_2$ to $RU$ and $1 - \alpha_2^*$ to $C_1$. We thus obtain a rationale for shop
rights 28.

5.2 Multiple innovations: contingent property rights.

We observed in the introduction that both employment contracts and the law allocate property rights on the basis of how much customer investment was used by the research unit and of whether the research unit had been hired for the innovation and made it during normal working hours. We argue that these contingent property rights stem from incentive considerations.

Coming back to the single customer case, suppose that the effort $e$ and the investment $E$ can yield one in a subset $T \subseteq \mathbb{R}^+$ of types of innovation. With probability $x_t$, with $\sum_{t \in T} x_t = 1$, innovation $t$, with value $V_t$, is the relevant one. Some types of innovation are consumed by the customer, some others are purchased at price $V_t$ by alternative customers (so the "customer" can be both a customer and an investor in our terminology). Innovation $t$ may also be demanded by both, as in subsection 3.1. Besides their value, types of innovation differ in the extent they make use of the customer's investment. Namely, we assume that the probability of discovery conditional on innovation $t$ being the relevant one is $p(e, E, t) = q(e) + tr(E)$. We also assume that $e$ and $E$ are chosen before the parties know which innovation is relevant 29. Let $\alpha_t$ denote RU's share of the value of the innovation of type $t$. Note that the nature of innovation is contractible. As in subsection 3.1, we maximize $C$'s incentive subject to RU's incentive exceeding some level:

$$\max \sum_{t \in T} x_t (1 - \alpha_t) V_t$$

28When $V_{RU}^* > V_2$, a shop right does not enable RU to appropriate enough of the innovation. Other contracts (possibly including cofinancing) must then be used.

29This is the simplest version of the model. One could alternatively assume that effort and investment are contingent on feasible types of innovation.
subject to
\[ \sum_{t \in T} x_t \alpha_t V_t \geq V_{RU} \]
and
\[ 0 \leq \alpha_t \leq \bar{\alpha}_t, \]
where (as in subsection 3.1) \( \bar{\alpha}_t = 1/2 \) if \( C \) consumes the innovation and \( \bar{\alpha}_t = 1 \) if an alternative customer uses the innovation. The solution to this program satisfies for some \( t_0 \in T \):

\[
\begin{align*}
    t > t_0 \implies \alpha_t &= 0 \quad (C \text{ ownership}) \\
    t < t_0 \implies \alpha_t &= \bar{\alpha}_t \quad \text{(pure RU ownership)} \\
    t = t_0 \implies 0 \leq \alpha_t \leq \bar{\alpha}_{t_0} \quad \text{(sharing)}.
\end{align*}
\]

The optimal policy is thus very similar to the contingent splits described in the introduction. If the innovation makes much use (respectively, little) use of the customer's investment, the customer (respectively, the research unit) owns the innovation. In the middle case, they split the benefit \( V_{t_0} \).

For example, if innovation \( t_0 \) is used both by the customer and alternative customers, this split may take the form of a shop right. [If only alternative customers use innovation \( t_0 \), the optimal contract gives \( RU \) a share \( \alpha_{t_0} \) of the licensing fees on innovation \( t_0 \). If only the customer uses the innovation, cofinancing is required unless \( \alpha_{t_0} = 0 \) or \( 1/2 \). As shown in section 3, an investor ought to purchase a fraction \( (1 - 2\alpha_{t_0}) \) of \( RU \)'s equity.]

This analysis rationalizes not only the usual contingent split of property rights but also the "hired for" doctrine. Presumably, the innovations for which the employee is hired make more use of the employer's investment and therefore should be owned by the employer.

A caveat is that our assumption of a single effort has swept aside a potential inefficiency in the allocation of effort created by contingent property rights. If not monitored, the agent has an incentive to concentrate her atten-
tion on those potential innovations with the highest $\alpha_t$. Such effort allocation raises the desirability of uniform property rights.  

A similar point applies to noncontractible investment by the customer.] This caveat rationalizes the distinctions made between research done at home and at work. Presumably the employer can better monitor the effort allocation when the employee is at work.

5.3 Multiple innovations: sequential property rights.

Many employment contracts specify that an innovation made by a breakaway employee shortly after quitting the firm belong to the former employer. An efficiency rationale for this practice can be obtained by following the lines of the previous subsection, replacing the nature of the innovation by its date. To the extent that the current innovation has a higher current employer investment content than the future one, it seems reasonable to

---

30 This reasoning is familiar from multitask models. See, e.g., Holmström-Milgrom (1991) for the case of agent risk aversion, Laffont-Tirole (1993, chapters 3, 4 and 8) for the case of adverse selection, and the related literatures on optimal taxation and Ramsey pricing.

31 This is so despite the facts that such contracts may inefficiently restrict the mobility of employees and that they may be vulnerable to legal attacks. Neumeyer (1971, chapter 3) describes some such “trailer clauses”, for instance:

"At Polaroid, the provisions of the [assignment] contract are valid for all inventions made or acquired during employment or for one year after termination of employment”. “The agreement is also equipped with a trailer clause valid for two years after the termination of employment ... The employee will not contribute his knowledge to ... any corporation or person engaged in competition with Polaroid.”

At Gulf Oil, “[employees in technical or scientific work] agree ... for one year after employment not to engage in the same type of work for a competitor within the same geographical area or territory. This second part of the [trailer] clause covers practically all employees who are expected to make patentable inventions and improvements.”

Note that such clauses have the efficiency properties described here (to the extent that the content of the employer’s investment in the post-employment innovation is larger when the second innovation is in a competing area) or have anticompetitive motives.
allocate property rights in this manner\textsuperscript{32}.

We summarize the section with the following proposition:

**Proposition 4**: In the presence of multiple users or multiple innovations, the property rights may be split between the customer and the research unit. Each should get property rights on those activities for which it has a comparative advantage in creating value. This principle gives rise to shop rights, property rights based on the nature or the date of the innovation and to the "hired for" doctrine.

6 The dynamic management of innovation: short-lived vs integrated research ventures.

Nowadays, large american companies such as IBM or AT&T are involved in hundreds of research joint ventures (RJV). A joint venture is typically defined as "an association of two or more natural or juridic persons to carry on as co-owners a specific project for a limited time" (Brodley (1982)). The declared purpose of this organizational form is to promote an entrepreneurial and non-bureaucratic spirit in research and development activities. The short-lived nature of the research joint venture is to be contrasted with more durable and

\textsuperscript{32}Example: Suppose that the innovation, with value \( V_1 \), may give rise to a follow-up innovation with value \( V_2 \). The probability of the first innovation occurring is \( q_1(e_1) + r_1(E_1) \). The second innovation requires only effort by \( RU \) and has probability \( q_2(e_2) \) of occurring conditionally on the first innovation being made. Letting \( \alpha_1 \) and \( \alpha_2 \) denote \( RU \)'s share of the values, we can as in subsection 5.2 maximize the customer's payoff from the first innovation, \( (1 - \alpha_1) V_1 + p_2(e_2^2 \alpha_2 V_2)(1 - \alpha_2) V_2 \), fixing \( RU \)'s payoff from that innovation, \( \alpha_1 V_1 + [p_2(e_2^2 \alpha_2 V_2) \alpha_2 V_2 - e_2^2 \alpha_2 V_2] \), and given the constraints \( 0 \leq \alpha_1 \leq \alpha_2 \), where \( \alpha_2 = 1/2 \) or \( 1 \) depending on whether \( C \) is the user of the innovation. We will assume that \( C \) does not use the second innovation: \( \alpha_2 = 1 \). Solving this program, we obtain \( \alpha_2 \geq \alpha_1 \). Indeed, if positive incentives are given to the two parties, then either \( \alpha_2 > 0 \) and \( \alpha_1 = 0 \): \( C \) owns the first innovation and shares the benefit of the second, which may take the form of a minimal length of time over which the innovation does not belong to \( RU \). [If \( C \)'s investment content in the second innovation (which here is assumed equal to zero) declined over time, the use of such a minimal length of time would be strictly optimal.] Or \( \alpha_2 = 1 \) and \( \alpha_1 < 1 \): \( RU \) claims part of the first innovation and is residual claimant for the second.
integrated relationships created by (nontradable) direct equity participations or full vertical integration. Not surprisingly, the appropriability of (specific) knowledge is a major consideration in the choice between these various forms of collaborative ventures 33. The purpose of this section is to formalize (spell out) the basic trade-offs underlying this choice.

As before, we consider the relationship between a research unit \( RU \) and a development unit (user or manufacturer) \( C \). The research unit contributes its knowledge and the manufacturer contributes capital or other inputs to the production of a current innovation aimed at a third party 34. The transfer of the research unit’s knowledge cannot be contracted upon. The technology transfer from \( RU \) to \( C \) will thus only take place if it is incentive compatible from \( RU \)’s perspective 35.

What is the rationale for such technology transfers? The primary goal is to increase the probability of the current innovation occurring. More precisely, we assume that the probability of making the purported innovation

33 An interesting study by Pisano-Russo-Teece (1988), based on data from 974 collaborative arrangements in the U.S. telecommunications sector over the period 1982-1985, analyzes the choice of governance structure in the case of an R&D firm collaborating with a manufacturing firm (as opposed to the "horizontal" case of several R&D firms engaging in cross-licensing or in the provision of joint R&D services for the development of new products). Legal experts like Brodley (1982) often consider research joint ventures as a special case of "input joint ventures".

34 That a third party rather than \( C \) uses the innovation allows us to cleanly identify the dynamic considerations behind the choice of ownership, since from a static viewpoint incentives are entirely provided by the rule for sharing the income from this third party and ownership is irrelevant. One could clearly reintroduce the static dimension of ownership by assuming, as in sections 2-3, that \( C \) is the only user of the innovation. However, this would only restrict the set of feasible sharing rules over the first innovation without adding any insight as to the basic trade-offs governing the dynamic management of innovations. 35 For example, in the biotechnology industry, “technical and operating procedures are not well codified or even understood”. To partly circumvent the resulting difficulties for technology transfers, contracts do often provide for a high degree of contact and exchanges between the parties (e.g. by including a schedule of telephone conferences and joint meetings to aid in the transfer of information, in addition to stipulating the exchange of written documents.” (Pisano-Mang (1992)).
is:

\[
    p = \begin{cases} 
        q_0 + r(E) & \text{if } RU \text{ transfers its technology} \\
        r(E) & \text{if } RU \text{ does not transfer its technology},
    \end{cases}
\]

where \( E \) denotes the manufacturer’s investment\(^{36} \). We assume that \( E \) is noncontractible (alternatively \( E \) could be contracted upon; the “reduced incentive effect” described below may then disappear).

The innovation is sold ex post at price \( V_1 \) to a third party, and the sharing rule (\( \alpha_1 \) for \( RU \), \( 1 - \alpha_1 \) for \( C \)) over the resulting income can be fully specified in the ex ante contract between \( RU \) and \( C \)\(^{37} \). In the absence of subsequent innovation, ownership rights over the joint innovation then do not matter per se since all incentives are provided by the sharing rule. Furthermore, technological diffusion can only be beneficial to \( RU \), who realizes a net expected benefit equal to \( \alpha_1 q_0 V_1 \).

Once the possibility of future innovations based on \( RU \)'s knowledge is introduced, however, transferring this knowledge to \( C \) may dissipate future monopoly rents that would have otherwise accrued to \( RU \). In particular, suppose that making the future innovation requires \( RU \)'s technological knowledge. With this knowledge, innovating costs nothing in period 2 (but is infeasible in period 1). The second innovation has value \( V_2 \) to a third party. In a *research joint venture* (RJV), both parties have the right to make the second innovation. They therefore compete if the research unit has transferred its knowledge in period 1. In contrast, under *vertical integration with*...
C-ownership\textsuperscript{38} (VI), the research unit is bound by a trailer clause and can make and commercialize the second innovation only with the assent of the customer. [Alternatively, and almost equivalently, one could assume that innovating in period 2 requires both RU’s knowledge and the use of the current innovation. Ownership of the current innovation is then equivalent to the trailer clause when the current innovation is not needed for the second one. Not surprisingly, the analysis and the conclusions are the same in both cases. We choose to develop the first as it is notationally a bit simpler.] We take this future independence of the research unit to characterize research joint ventures.

Consider first an RJV. If no technology transfer has taken place in period 1, only RU can generate the subsequent innovation; on the other hand, if RU has transferred its knowledge to C, both parties can generate the subsequent innovation and thus compete on the same product market (assuming antitrust enforcement). Then, under Bertrand competition, RU’s second-period payoff shrinks from $V_2$ to zero if it transfers its technology to C in period 1. Overall, this technology transfer will be incentive compatible if and only if:

$$\alpha_1 g_0 V_1 \geq V_2,$$

or equivalently:

$$\alpha_1 \geq \frac{V_2}{g_0 V_1} \equiv \alpha_1^{RJV}.$$

In the integrated case where only C has the right to make and commercialize the future innovation, RU’s second-period payoff is again equal to zero if RU has transferred its technology in period 1 since C can dispense with RU’s

\textsuperscript{38}As we shall argue at the end of this section, the following analysis and results can be straightforwardly extended so as to include the possibility of vertical integration under RU-ownership.
services. On the other hand, if RU's technology has not been transferred in period 1, C cannot dispense with RU's (still) private knowledge, which in turn guarantees a second-period payoff equal to $\frac{V_2}{2}$ to RU. A technology transfer in period 1 will then be incentive compatible in the VI case iff:

$$\alpha_1 q_0 V_1 \geq \frac{V_2}{2},$$

or:

$$\alpha_1 \geq \frac{V_2}{2 q_0 V_1} \equiv \alpha_1^{VI}.$$

Hence the cost of technological diffusion in terms of C's reduced incentives to invest is lower in the integrated case than in the case of a research joint venture (reduced incentives effect). In addition, the diffusion of technological knowledge from RU to C does not induce (Bertrand) competition on the product market in the integrated case (contrary to the RJV case). In other words, technological diffusion dissipates future profits in the RJV case, but not in the integrated case (rent dissipation effect). On the other hand, both product market competition and reduced incentives for the customer can be avoided in an RJV by setting $\alpha_1 = 0$, at the cost of inducing no diffusion of knowledge from RU to C.

Overall, the total surplus generated by an RJV and an integrated structure are given by, respectively:

$$W_{RJV}^{diff} = (q_0 + r (E^* ((1 - \alpha_1^{RJV}) V_1))) V_1 + 0,$$

$$W_{VI}^{diff} = (q_0 + r (E^* ((1 - \alpha_1^{VI}) V_1))) V_1 + V_2,$$

if the technology transfer is induced, and by

$$W_{RJV}^{nodiff} = r (E^*(V_1)) V_1 + V_2 = W_{VI}^{nodiff},$$

\(^{39}\)We keep assuming alternating-offer bargaining between RU and C with no delay between two successive offers.
if no technology transfer is induced. Full vertical integration unambiguously dominates the research joint venture since $\alpha_{1}^{RJV} > \alpha_{1}^{VI}$.

So far, we have emphasized the advantages of fully integrated structures as minimizing the cost of technological diffusion between research units and development units. However, an RJV preserves the entrepreneurial spirit and generates more future innovations than the integrated structure. Suppose that by committing a noncontractible investment $c > 0$ in period 1, $RU$ can increase the value of the second innovation by an amount $\Delta$, where $\Delta > c > \frac{\Delta}{2}$. Because $RU$ is the only unit with the technological knowledge in period 1, it is natural to assume that only it can make this investment. The investment can be interpreted as a jump to the following technological generation. The second-period payoff for the research unit will then be described as in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>RJV</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>No diffusion</td>
<td>$V_2 + \Delta$</td>
<td>$\frac{V_2}{2}$</td>
</tr>
<tr>
<td>Diffusion</td>
<td>$\Delta$</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1

Under vertical integration, $RU$ never invests since it gets at most one half of the increment in the value of the innovation and $c > \frac{\Delta}{2}$. So $RU$’s payoff is unaffected by the possibility of investment. In contrast, $RU$ invests in an RJV whether it transfers the technology or not, since $\Delta > c$. In particular, its superior product allows $RU$ to make profit $\Delta$ under Bertrand competition after the diffusion of the technology.
If diffusion is to take place, the comparison between RJV and VI now trades off (the quality of) the future innovation against the probability of the current one and the prevention of rent dissipation:

\[ W_{\text{RJV}}^{\text{diff}} - W_{\text{VI}}^{\text{diff}} = \Delta - c - V_2 - \left[ r \left( E^* \left( (1 - \alpha_1^{\text{VI}}) V_1 \right) \right) \right] V_1. \]

On the other hand, vertical integration is dominated if it is not motivated by a technology transfer:

\[ W_{\text{RJV}}^{\text{nodiff}} - W_{\text{VI}}^{\text{nodiff}} = \Delta - c > 0. \]

The relative advantage of RJV over VI in terms of investments in technological progress appears to be consistent with the casual observation that large integrated firms (e.g. AT&T or IBM) are often one generation behind technologically.

Remark 1: Our analysis of the dynamic costs and benefits of vertical integration (w.r.t. short-lived research ventures) has so far been limited to the C-ownership case. Introducing the possibility of RU-ownership on all future innovations does not modify the above trade-off and conclusions, as shown in Appendix 4.

Remark 2: Our analysis so far has excluded the possibility of direct equity participations under RJVs. How would the above conclusions be modified if such equity participations were allowed? First, it is clear that the diffusion of RU's technological knowledge would be facilitated by having RU hold equity in C, since this would tend to soften second-period competition when diffusion occurs in period 1. However, a nonnegligible equity participation in C seems unrealistic in many circumstances, where the sizes of RU and C are very unequal. Conversely, suppose that C owns a fraction \((1 - \alpha)\) of RU's equity, and let us look at the outcome of the Bertrand competition between
RU and C which follows the diffusion of technological knowledge from RU to C. Let \( p = \frac{A}{\alpha} \). If RU charges \( p \), then C has no incentive to undercut RU below \( (p - \Delta) \) since by doing so C would obtain at most its residual payoff if it does not undercut RU:

\[
p - \Delta - \epsilon < (1 - \alpha)p.
\]

For \( p = \frac{A}{\alpha} \) to be an equilibrium, one must obviously have: \( p \leq V_2 + \Delta \), which in turn imposes \( \alpha \geq \frac{\Delta}{V_2 + \Delta} \). Then RU's second period payoff after diffusion is still equal to \( \Delta \), but C's payoff has increased from zero to \( \frac{1-\alpha}{\alpha} \Delta \ (= V_2 \) if \( \alpha = \frac{\Delta}{V_2 + \Delta} \). In other words, equity participation enforces some collusion in case of diffusion; it also facilitates diffusion by reducing RU's payoff in case of no diffusion. At the same time, the advantage of equity participation over full integration is the fact that it does not discourage RU's investment in technological progress.

7 Summary and directions for future research.

Managing innovation properly is one of the most important challenges faced by developed economies. This exploratory paper argues that property rights analysis offers a conceptual framework to understand the static and dynamic aspects involved in the organization of R&D activities. Let us summarize a few of our insights. First, research will be more likely to be conducted in an integrated structure if a) capital inputs are substantial relative to intellectual inputs; in contrast, when intellectual inputs dominate as for software and biotechnology, research will often be performed by independent units; b) the customer has more bargaining power ex ante, say because of intense competition among potential research teams; c) the customer has a deep pocket. Otherwise, research activities are more likely to be performed by
non-integrated research units. In that case, cofinancing by an outside investor (venture capitalist or bank) may benefit the customer of the innovation. Second, when there are multiple innovations and/or multiple customers, property rights must be split on the basis of comparative advantage in creating value. This principle gives rise to shop rights, the “hired for” doctrine, and trailer clauses. Third, [permanently] integrated structures (or direct equity participations) tend to facilitate transfers of technologies from research units to development units (customers) whenever technology transfers are noncontractible; in contrast, the temporary nature of research joint ventures tends to create a more favourable environment for speeding up or increasing the quality of future innovations, by encouraging additional specific investments by the participants to the current research venture.

Besides these testable hypotheses we obtained two “negative results”. First, predicting whether an independent research unit wants to pursue more drastic innovations than an integrated one requires detailed knowledge of the industry, and in particular of the appropriability ratio. Second, traditional Schumpeterian hypotheses fail to recognize that changes in the value of the innovation bring about changes in the governance structure that, again, are hard to predict without detailed knowledge of the industry. Furthermore, input measures often covary negatively with output measures when property rights are reallocated.

The potential of the property rights analysis for studying innovation management is broader than is suggested by the limited scope of this paper. First, we have considered cofinancing by a customer and investors, but not by several customers; that is, we have not considered “horizontal” and “unrelated” research joint ventures, where several customers competing or not in a product market join forces to finance research. Their study will raise a host of
fascinating issues concerning free riding, the allocation among customers of ownership rights as well as control rights over the research process, and antitrust policy. Second, government promotion of R&D is one of the most important areas of public policy. Analyzing the government as a customer, an investor or a benefactor (depending on the circumstances) ought to shed light on efficient ways of channelling government money into R&D. Third, we have not considered competition among research teams. It would be fruitful to merge the property rights approach of this paper and of the literature on strategic vertical integration together with the traditional patent race analysis. Last, we believe that our analysis provides some microfoundations for extending the new growth literature in several interesting directions. In particular it may help introduce financial and organizational considerations into the "neo-Schumpeterian" framework and also enrich our current views on technological innovation and diffusion within sectors and industries as major determinants of productivity growth.
References


Appendix 1: The ambiguous effect of a change in the value of innovation on the organizational form

Example 1 (an increase in $V$ makes RU ownership more desirable).

Suppose that the probability of discovery depends only on the research unit's effort: $r(E) = r_0 > 0$ for all $E$. Then $E^{RU} = E^C = 0$. Suppose further that $q(e) = 2e/V_0$ for $0 \leq e \leq 1$, and $q(e) = 2/V_0$ for $e \geq 1$. For $V < V_0$, RU chooses $e = 0$ even under pure RU ownership, since $\frac{2e}{V_0} - e < 0$ for all $e > 0$. Therefore $C$ prefers $C$ ownership to pure RU ownership since $r_0 V > r_0 V/2$, and more generally to cofinancing. For $V > V_0$, $C$ prefers RU ownership to $C$ ownership if $r_0$ is sufficiently small, since $\left(\frac{2}{V_0} + r_0\right) \frac{V}{2} > r_0 V$. Cofinancing then improves on RU ownership, but can be made as small as possible by choosing $V$ arbitrarily close to $V_0$ (any nonnegligible amount of equity taken by an investor then destroys RU's incentives). We thus conclude that at $V_0$ the organizational form jumps from $C$ ownership to RU ownership.

Example 2 (an increase in $V$ makes $C$ ownership more desirable).

Assume that the customer’s and the investor’s investments are not substitutes. Indeed, the customer’s investment is nonmonetary and noncontractible while investor’s investment is useless. We posit that $r(E) = 2\mu \sqrt{E}$ and $q(e) = 2e/V_0$ for $e \leq V_0/4$ and $q(e) = 1/2$ for $e \geq V_0/4$. We assume $V > V_0$.

Under $C$ ownership, the customer chooses $E$ so as to maximize $2\mu \sqrt{E} V - E$, yielding payoff $\mu^2 V^2$. Under pure RU’s ownership, RU chooses $e = V_0/4$. $C$ chooses $E$ so as to maximize $\left[\frac{1}{2} + 2\mu \sqrt{E}\right] \frac{V}{2} - E$, yielding payoff $\frac{V}{4} + \frac{\mu^2 V^2}{4}$. Suppose these two payoffs are equal:

$$\frac{V}{4} + \frac{\mu^2 V^2}{4} = \mu^2 V^2 \quad \iff \quad V = V^* = \frac{1}{3\mu^2}.$$
Then
\[ \frac{d}{dV} \left[ \mu^2 V^2 - \left( \frac{V}{4} + \frac{\mu^2 V^2}{4} \right) \right] \bigg|_{V=V^*} = \frac{1}{4} > 0. \]

Thus an increase in $V$ makes $C$ ownership optimal at $V = V^*$. 

Until now, we have ruled out cofinancing. As in example 1, having an investor take equity in $RU$ (and give a lump sum payment to $C$) is optimal for $C$ but cannot really be distinguished from pure $RU$ ownership if $V$ is close to $V_0$. Any nonnegligible equity of an investor in $RU$ then destroys $RU$'s incentives.

Last, note that at $V = V^*$, $p^{RU} > p^C$. Therefore an increase in $V$ at $V^*$ discontinuously reduces the probability of discovery, while discontinuously raising the measured input ($E$).

**Appendix 2: Credit constraints and the management of innovation: an example**

We consider the situation where $C$ has no cash to finance its investment $E$ and, following Townsend (1979) and Gale-Hellwig (1985), where outside investors (other than $RU$ and $C$) cannot verify the customer's profit unless they incur a verification cost $c_0 > 0$. We look for an example where, in the absence of credit-constraint (i.e. when $c_0 = 0$), $RU$-ownership is (weakly) dominated by $C$-ownership whereas the opposite holds once credit-constraints are introduced ($c_0 > 0$).

We assume the following timing. First, $C$ and $RU$ allocate property rights and specify an investment $E$ (cofinancing will turn out to be suboptimal under our assumptions). $C$ has the bargaining power at this stage. Second, $C$ and a bank $B$ secretly write a credit contract (see below) that provides $C$ with investment $E$. Third, $RU$ chooses its effort. Fourth, if the innovation occurs,
under RU ownership, each of RU and C gets to make a take-it-or-leave-it offer to the other party with probability 1/2. (C uses freely the innovation under C ownership). Fifth, C consumes the innovation (if purchased). Sixth, C announces its net income to B, who then audits if the credit contract specifies so.

A few words of explanation are in order. A credit contract specifies, as in Townsend and Gale-Hellwig, a probability of audit \( x(\tilde{\pi}) \) function of C's profit announcement \( \tilde{\pi} \), and a reimbursement \( R_0(\tilde{\pi}) \) if no audit takes place, and \( R_1(\tilde{\pi}, \pi) \) if the audit takes place and reveals true income \( \pi \). The bargaining game differs from the alternating-move bargaining game assumed elsewhere in the paper because we wish to avoid having an infinite-horizon bargaining with a finite-horizon audit. C offers a licensing fee equal to 0 when making the offer (note here that we assume secrecy of the credit contract to avoid possible commitment effects of the credit contract on RU's incentives). RU offer licensing fee \( V \) when making the offer.

We can restrict ourselves to credit contracts of the following kind \( x(V) = 0 \) and \( R_0(V) \equiv R \); \( x(0) \equiv x_0 > 0 \), \( R_0(0) = 0 \) and \( R_1(0, \pi) = \pi \) for all \( \pi \) (we can restrict attention to \( \tilde{\pi} = 0 \) or \( V \) without loss of generality). Indeed incentive compatibility when \( \pi = V \) requires that

\[
(1 - x_0)V = V - R \quad \implies \quad x_0 = R/V.
\]

Under C ownership, the bank's participation constraint is

\[
p(0, E)R - (1 - p(0, E))x_0c_0 = E.
\]

The expected auditing cost is thus strictly positive.

Consider the following example: \( p(e, E) = q(e) + r(E) \), where

\[
q(e) = \begin{cases} \frac{e}{V} & \text{for } e \leq q_0 \frac{V}{2} \\ \frac{V}{q_0} & \text{for } e \geq q_0, \end{cases}
\]
and
\[ r(E) = \begin{cases} r_0 E & \text{for } E \leq 1 \\ r_0 & \text{for } E \geq 1, \end{cases} \]
where
\[ 1/V < r_0 < 2/V \quad \text{and} \quad q_0 + r_0 \leq 1. \]

In the absence of borrowing constraint \((c_0 = 0)\), the maximum payoff \(C\) can achieve under \(C\) ownership is:
\[ \max \{ r_0 E V - E \} = r_0 V - 1 \]
(since \(RU\) does not exert any effort). Under pure \(RU\) ownership, \(C\) has no incentive to invest \((as r_0 V/2 < 1)\), and can obtain
\[ \frac{V}{q_0 \cdot 2}. \]

[Note that cofinancing destroys \(RU\)'s incentives and is thus weakly dominated by \(C\) ownership.] Suppose \(C\) is indifferent between \(RU\) ownership and \(C\) ownership in the absence of credit constraint: \( q_0 \frac{V}{2} = r_0 V - 1 \). Then introducing costly state verification implies that \(C'\) payoff under \(C\) ownership is bounded away from \(r_0 V - 1\). On the other hand, the payoff under \(RU\) ownership is unchanged because \(C\) needs no monetary investment.

**Appendix 3:** Two other derivations of appropriability ratios

**Example 2:** Process innovation in the Hotelling model: Consider the standard Hotelling model: The incumbent faces marginal cost \(c_0\) and is located at the left end of a unit segment; consumers are uniformly distributed along the segment, incur transportation cost \(t\) per unit of distance and have identical willingnesses to pay \(v\) for one unit of the product sold by the incumbent
and perhaps an entrant; the potential entrants are located at the right end of
the segment. We assume that \( v \) is sufficiently large that a monopolist covers
the market, and that \( t \) is sufficiently small that all consumers derive positive
surplus in a duopoly situation, in the relevant range of process innovations.
As in example 1, we let \( c \) denote the new marginal cost, so \( \gamma = c_0/c \). We
have:

\[
\pi_1^m(c) - \pi_0^m = (v - t - c) - (v - t - c_0) = c_0 - c
\]

\[
\pi_1(c) = \frac{1}{2t} \left[ t + \frac{c_0 - c}{3} \right]^2 \quad \text{for} \quad t \geq \frac{c_0 - c}{3} \quad \text{(the firms share the market)}
\]

\[
= c_0 - c - t \quad \text{for} \quad t < \frac{c_0 - c}{3} \quad \text{(the entrant corners the market)}.
\]

The outside option is always binding \((r > 1/2)\). Furthermore

\[
t > \frac{c_0 - c}{3} \Rightarrow r \quad \text{is increasing in} \quad c \quad \text{(that is, decreasing in} \quad \gamma)
\]

\[
t < \frac{c_0 - c}{3} \Rightarrow r \quad \text{is decreasing in} \quad c \quad \text{(that is, increasing in} \quad \gamma)
\]

In the Hotelling model, an independent research unit pursues less drastic
innovations than its integrated counterpart in the range of small innovations,
but may pursue larger innovations in the range of larger innovations. For
infinitesimal innovations, \( \pi_1(c) \) is infinitely larger than \( \pi_1^m(c) - \pi_0^m \), and the
independent research unit may want to make sure the innovation takes place,
whereas an infinitesimal innovation has little value socially and therefore
would not be pursued by the incumbent. In the case of large innovations
\((t < \frac{c_0 - c}{3})\), or equivalently when the differentiation is small relative to the
size of the innovation, competition is very strong and the research unit tries
to escape it through a drastic innovation.\(^1\)

**Example 3: Product innovation and vertical differentiation:** A similar ana-
lysis can be performed for a product innovation that raises quality from the

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\(^1\)The reader may wonder whether this result does not contradict the result in the first
eexample when \( t \) is infinitesimal. When \( t \) is close to 0, \( r = 1 - \frac{1}{c_0 - c} \) is close to 1, as it is in
example 1 when the demand is very inelastic. In example 1, the elasticity of demand makes
\( r \) increasing in \( c \). In example 2, demand is completely inelastic, and a small differentiation
makes \( r \) decreasing in \( c \).
existing level $s$ to level $\gamma s$, where $\gamma > 1$. For example, individual consumers have surplus $\theta s - p$ for one unit of quality $s$ purchased at price $p$, where $\theta$ is a taste parameter. The setup is otherwise the same as in examples 1 and 2, with Bertrand competition in case of entry. If the distribution of $\theta$ is uniform, if the monopolist covers the market for both quality levels, and if the duopoly solution gives positive market share for both firms, one can show that $r$ is constant. There is then no distortion in the choice of research line. But more generally, $r$ can be increasing or decreasing in vertically differentiated markets.

**Appendix 4: Dynamic management: RU-ownership**

Let us consider $RU$-ownership in the framework of section 6. Suppose that by committing a noncontractible investment $c > 0$, both $RU$ and $C$ can potentially increase the value of the second (future) innovation. More precisely, let us assume that with probability $1/2$ the research unit alone can increase $V_2$ by the amount $\Delta_{RU} = \Delta$, and with probability $1/2$ the customer alone increases $V_2$ by the same amount $\Delta_{C} = \Delta$ provided $RU$ does transfer its technology\(^2\). Then, assuming that $\Delta/2 > c > \Delta/4$, Table 2 gives the matrix for second-period expected payoffs.

\(^2\)The following analysis can easily be extended to the more general case where successful investments in $V_2$ by $RU$ and $C$ are not mutually exclusive, provided the two successes are not perfectly correlated.
\[ \pi_{RU} = V_2 + \frac{\Delta}{2} \]
\[ \pi_C = 0 \]

<table>
<thead>
<tr>
<th>No diffusion</th>
<th>( \pi_{RU} = V_2 + \frac{\Delta}{2} )</th>
<th>( \pi_{RU} = \frac{V_2}{2} + \frac{\Delta}{2} )</th>
<th>( \pi_{RU} = V_2 + \frac{\Delta}{2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \pi_C = 0 )</td>
<td>( \pi_C = V_2 + \frac{\Delta}{2} )</td>
<td>( \pi_C = 0 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diffusion</th>
<th>( \pi_{RU} = \frac{\Delta}{2} )</th>
<th>( \pi_{RU} = 0 )</th>
<th>( \pi_{RU} = V_2 + \frac{\Delta}{2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \pi_C = \frac{\Delta}{2} )</td>
<td>( \pi_C = V_2 + \frac{\Delta}{2} )</td>
<td>( \pi_C = 0 )</td>
</tr>
</tbody>
</table>

Table 2

* Under C-ownership (\( V_{IC} \)), \( RU \)'s expected benefits of investment are equal to \( \frac{1}{2} \cdot \frac{\Delta}{2} = \frac{\Delta}{4} \). Since \( \frac{\Delta}{4} < c \), \( RU \) will not invest in equilibrium. Similarly, under \( RU \)-ownership (\( V_{IRU} \)), \( C \) will not invest in improving the future innovation.

If diffusion is to take place, we thus obtain the same trade-off as before between (the quality of) the future innovation and both the current innovation and the prevention of rent dissipation\(^3\): Namely, the benefit of \( RU \)-ownership and \( C \)-ownership over \( RJV \) is a lower cost of technology transfers and the avoidance of ex post competition, i.e. rent dissipation over the future innovation. On the other hand, investments in the quality of the future innovation, respectively by \( RU \) and \( C \), may be discouraged under \( C \)- or \( RU \)-ownership \(^4\)

\(^3\)On the other hand, \( RU \)-ownership is equivalent to \( RJV \) if \( \Delta_{RU} = \Delta_{C} = \Delta \) and there are no technology transfers.

\(^4\)Note that \( RU \)-ownership dominates \( C \)-ownership since technology transfers are costless in the former case (\( \alpha_{V_{IRU}} = 0 < \alpha_{V_{IC}} < \alpha_{V_{RJV}} \)) \( C \)-ownership could dominate \( RU \)-ownership if quality improvements by the customer were more important than those made by the research unit.