THE MANAGEMENT OF INNOVATION*

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The paper analyzes the organization of the R&D activity in an incomplete contract framework. It provides theoretical foundations: (a) to understand how the allocation of property rights on innovations may affect both the frequency and the magnitude of these innovations; (b) to rationalize commonly observed features in research employment contracts, such as shop rights, trailer clauses, and the "hired for" doctrine; (c) to discuss the robustness of the so-called Schumpeterian hypotheses to endogenizing the organization of R&D; and (d) to provide a rationale for cofinancing arrangements in research activities.

I. INTRODUCTION

A feature common to the patent race and the endogenous growth literatures is their simplified representation of R&D activities, which are assumed to be performed by an aggregate agent playing simultaneously the roles of *financier, creator, owner,* and (often) *user* of the innovation. In practice, however, R&D takes place either within firms where employees-inventors are subject to assignment contracts with their employers or through contractual agreements between independent research units and users of their innovations or financiers. In both cases, the contractual provisions on how to finance the research activities, how to allocate control over the R&D process, how to share property rights on innovations, and on how to structure the monetary compensations to the inventors[1] are far more complex than the current aggregated view of the R&D process suggests.

Using the incomplete contract framework introduced by Grossman and Hart [1986], this paper analyzes the R&D activity from an

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1. The sharing of return streams need not covary perfectly with property rights. For example, property rights may go to the employee in universities and to the employer in aircraft manufacturers even though the sharing rules are similar (for instance, the four largest U. S. aircraft manufacturers offer their employees shares of 10 percent to 30 percent on income collected from royalties [Neumeyer 1971, Chapter 4]. Some universities give 15 percent of the royalties to their researchers). Another case in point is that customers who purchase a majority of shares in a venture may not ask for control rights [*The Economist,* August 29, 1992, pp. 53–54]. When Hoffman-Laroche bought a 60 percent stake in Genentech in 1990, it demanded only two of Genentech's thirteen board seats.

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organizational point of view. First, it studies how the allocation of property rights on innovations can affect both the frequency and the magnitude of these innovations when their exact nature cannot be contracted upon ex ante. Second, it rationalizes a number of common contracting and legal features of the organization of R&D. Third, it sheds light on the findings of the empirical R&D literature and discusses the robustness of the so-called Schumpeterian [1942] hypotheses on the effects of an increase in the scale, scope, monopoly power, or "long-purse" enjoyed by the user of an innovation on R&D inputs and outputs.

The paper is structured as follows. Section II analyzes the basic contractual relationship between a research unit and a customer. Customers are those parties who directly benefit from the innovation; namely, the manufacturers who 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 customer finances the innovation depends on the industry [von Hippel 1988], in particular on who benefits most from the innovation. For the purpose of this paper, we can content ourselves with a single aggregated customer.) The research unit, which may or may not belong to the same firm as the customer, 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 two parties cannot contract for delivery of a specific innovation. The contract (realistically) 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. In addition to this Grossman and Hart-like conclusion, the existence of a *cash constraint* on the research unit's side accounts for a possible inefficiency of the allocation of property rights when the customer ex ante has substantial bargaining power.

Is it optimal to have a single provider of funds, namely the customer? Extending further the property rights model of Grossman and Hart by allowing for equity participation by the customer as well as by third parties (investors), we show in subsection II.4 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 bank, or a parent company not in the customer's business). Furthermore, such a cofinancing 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*.

Our framework also provides a rigorous evaluation of the *Schumpeterian hypotheses* (subsection II.5). 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.

More complicated allocations of property rights commonly observed in research employment contracts include (see Neumeyer [1971]) (a) *property rights contingent on the nature of the innovation* (which, for instance, confer ownership to the customer-employer for inventions that are "related" to the employer's business or make use of the employer's facilities or data, and to the researcher-employee for inventions that pertain to other businesses); (b) *trailer clauses* (which confer ownership to the customer-employer for innovations made by a breakaway researcher-employee shortly after quitting the firm and to the researcher-employee otherwise); (c) *shop rights* (which confer ownership to the researcher-employee while at the same time allocating a nonexclusive, nonassignable, and royalty-free license to use the innovation to the employer). Shop rights, property rights contingent on the nature of the innovation, and rules governing breakaway research are instances of multiple, *split* property rights. Section III rationalizes these institutions by extending the basic framework of Section II in order to account for the possibility of multiple innovations or the existence of multiple customers for the same innovation.

Section IV analyzes the relationship between the organization of research and the *size* of the resulting innovations. In particular, it questions the validity of the common claim that independent research units have more incentives to pursue radical innovations than the research division of a customer.

Last, Section V summarizes the main insights of the paper, and discusses some directions for research.

II. The Basic Framework

II.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 are infinite so as to guarantee interior solutions (for strictly positive incentives). 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 nonseparable 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, and this is our first basic assumption, RU has no initial cash endowment, and its income cannot be negative.

Let us define the socially optimal (or first-best) effort and investment $e^*(V)$ and $E^*(V)$ by

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

or

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

II.2. Contracts

A natural way of introducing property rights considerations in the analysis of R&D activities is by postulating the incompleteness of research contracts. More specifically, and this is our second basic assumption, we posit that the exact nature of the innovation is ill defined ex ante, so that the two parties cannot contract for delivery of a specific innovation. The contract only specifies the allocation of the *property right* on any forthcoming innovation, a *sharing rule* on the verifiable revenue (license fee) obtained by the research unit, and any *verifiable* amount of *customer investment.*[2] The realized value of the innovation for the customer is noncontractible; that is, either it is a private benefit (it reduces the customer's productive effort, say), or it is a monetary benefit that cannot be recovered among the customer's many activities. (Assuming that this value is contractible would not affect the analysis in the absence of third parties.)

If property rights on the innovation are allocated to C, then C can freely use the innovation. In that case RU receives no reward for innovating.[3] This we shall refer to as *C-ownership* or *integrated case.*

If RU owns the innovation, C and RU bargain over the licensing fee once the innovation has been made. This we call

2. Allowing for announcement games between the two contracting parties after the realization of the state of nature (i.e., after the innovation has either occurred or not occurred) need not destroy the property rights interpretation developed in the paper. In particular, one can show that, in the context of this basic two-party contracting model, the optimal complete contract can be implemented by a random allocation of property rights between RU and C, provided that we allow for ex post renegotiation after the innovation has occurred. This result, however, in general is not robust to the introduction of third (cofinancing) parties, unless we preclude any net transfer from the principal to such parties in the state of nature where no innovation occurs.

3. To 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.

RU-ownership or *nonintegrated case.* (So we assume that C is the only user of the innovation and is therefore indispensable for the realization of the value of innovation. This assumption is relaxed in Sections III and IV.) For simplicity, we assume that the total pie V is then equally split ex post between the owner RU and the customer C, so that C pays a license fee equal to $V/2$.[4]

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 indispensability in the production process allows it to extract $V/2$ from RU by threatening not to produce.[5] 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. Alternatively, we could invoke RU's cash constraint to rule out its owning C.

II.3. Who Should Own the Innovation?

This subsection assumes away the possibility of C's equity holding in RU (see subsection II.4 below). Whether C or RU should own the innovation hinges on two basic considerations: (a) the *marginal efficiency* of RU's effort compared with the marginal efficiency of C's investment; (b) the *ex ante bargaining power* of the two parties (who proposes the initial contract), which reflects the extent to which the research unit is the only candidate to perform the research. The importance of ex ante bargaining assumptions follows from utility not always being ex ante transferable between RU and C. More specifically, the cash-constrained RU is unable to compensate C for a transfer of ownership to RU, even if such a transfer results in a higher total surplus ($pV - e - E$).

Consider first *C-ownership.* RU then receives no reward for innovating and therefore supplies no effort: $e = 0$. On the other

4. The equal split outcome will, for example, result from a Rubinstein [1982] bargaining process with alternative offers by the two parties and no time delay between two successive offers (also see Stahl [1972]). Focusing on the equal split case involves no loss of insights in this model where utility in the ex post bargaining game is transferable in the relevant range (where RU's income is positive). For the anecdote, the industry rule of thumb is that the innovator receives between 20 percent and 50 percent of the pie [Caves et al. 1983; Barton et al. 1988].

5. This is in the spirit of Hart and Moore [1994]. Our assumption may be weaker than the one made in Hart and Moore where parties are bound by a complete contract. Here, unlike in Hart and 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.

hand, C has appropriate incentives to invest. It maximizes $[p(0,E)V - E]$ and therefore chooses $E = E^*(V)$. Utilities are 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 $V/2$ in case of innovation. RU maximizes $[p(e,E)V/2 - e\,]$ and so chooses $e = e^*(V/2)$. If either E is noncontractible or E is contractible and C has the bargaining power ex ante,[6] C chooses its investment so as to maximize $[p(e,E)V/2 - E]$, resulting in $E = E^*(V/2)$. 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)

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

and

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

How is the property right determined? Clearly, $\tilde{U}_{RU} > U_{RU}$: RU prefers having the property right. If RU's effort is important enough that $\tilde{U}_C > U_C$, then the property right is allocated to RU. If $\tilde{U}_C < U_C$, the allocation of the property right depends on the ex ante relative bargaining strength. If RU has the bargaining power

6. 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:

$$a + E = p(e^*(V/2),E)V/2.$$

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

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

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

If $p(e^*(V/2),E^*(V))V/2 < E^*(V)$, then RU should compensate C for choosing the socially optimal investment, but cannot do so. RU then demands the highest investment consistent with C's participation, and no cash transfer.

ex ante, the allocation of the property right is efficient in that RU receives ownership if and only if $\tilde{U}_{RU} + \tilde{U}_C \geq U_{RU} + U_C$. For, if RU ownership is efficient, RU allocates the property right to itself. If C ownership is efficient, RU gives the property right to C in exchange for a cash transfer. In contrast, if C has the bargaining power (say, because there are several potential research units ex ante), C always keeps the property right as RU is cash constrained. Thus, when $\tilde{U}_{RU} + \tilde{U}_C > U_{RU} + U_C$ but at the same time $U_C > \tilde{U}_C$, since RU does not have the necessary amount of cash (namely, $U_C - \tilde{U}_C$) to compensate the customer for a transfer of the property right from C to RU, an inefficient allocation of the property right occurs in equilibrium. We have thus vindicated our earlier claim that ex ante bargaining power influences not only the distribution of the pie, but also its size.[7]

PROPOSITION 1. The allocation of the property right on an innovation between a research unit and a customer is determined by two factors.

(i) (Grossman-Hart [1986]) *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.

II.4. The Irrelevance of C's Equity in RU and the Rationale for Cofinancing

Parties who 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 cannot customers themselves provide cash to the research unit in exchange for equity shares in RU? The answer to this question turns out to be quite simple and relies on the following irrelevance argument.

7. The idea that cash constraints reduce the efficiency of bargaining processes has been used in the field of corporate finance (see Aghion and Bolton [1992]).

Suppose that C is given $(1 - \alpha)$ shares in RU. The real license fee paid by C when both parties agree on a nominal license fee l is $\bar{l} = l - (1 - \alpha)l = \alpha l$. The equilibrium level of $\bar{l}$ is, as before with l, driven by time impatience only and not by the sharing rule implied by the initial contract. Nothing is thus affected by the introduction of an equity participation of C in RU,[8] as anticipated by Hart and Moore [1990, footnote 7]. (A similar reasoning shows that RU's being given a share in C has no effect on the net license fee and is therefore irrelevant.)

This irrelevance result generalizes to nonlinear sharing rules as long as the two parties can by mutual consent tear up the initial contract and renegotiate. The initial sharing rule cannot influence the ex post bargaining game between RU and C since in contrast to some other incomplete contracts models with renegotiation,[9] the object (innovation) to be traded ex post is not ex ante contractible.

In contrast with the above irrelevance result, introducing third parties (outside investors) as co-owners of RU can help raise C's profit under RU ownership and hence may occur if C has substantial bargaining power ex ante.

Suppose therefore that C has the ex ante bargaining power. Assume further that investment is contractible (this is not crucial for the argument). C can then demand cofinancing E_I in exchange for a claim of a fraction $(1 - \alpha)$ of RU's profits. As before, RU and C bargain over the licensing fee after the innovation occurs and C must still pay an observable license fee equal to $V/2$ to RU's owners. However the researchers themselves now receive a return of $\alpha V/2$ for the innovation, whereas the outside investors receive $(1 - \alpha)V/2$. 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, to collude with

8. 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 III.3), 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 might also soften future competition between the research unit and the customer (see Aghion and Tirole [1993, section 6]).

9. For example, Hart and Moore [1988] and Aghion, Dewatripont, and Rey [1994].

the research unit.[10] Assuming ex ante competition among outside investors leads to the following free-entry condition, where E_I (respectively, E_C) denotes the outside investor(s)' (respectively, the customer's) investment:

$$E_I = p\left(e^*\left(\alpha \frac{V}{2}\right), E_I + E_C\right)(1 - \alpha)\frac{V}{2}.$$

C's profit is then

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

where $E = E_C + E_I$ is total investment. The optimal total investment for the customer is $E = E^*((1 - \alpha/2)V)$. Cofinancing thus allows the customer to give the research unit any fraction of the value of the innovation between 0 (C-ownership) and ½ (pure RU-ownership). *With contractible, perfectly substitutable investments, cofinancing transforms a discrete choice of governance structure into a continuous one.*[11]

Note that our argument relies on the license fee being verifiable. For, the customer and the research unit would have an incentive to collude against the third party by specifying a small fee and making an additional transfer on the side. In view of the

10. 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 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 toward a linear sharing rule so as to obtain congruence.

We should also point out that our analysis carries over to the situation where the investor is drawn into the bargaining process (indeed in a generalization of the alternative-move model with short periods, the research unit's payoff, $\alpha V/2$, is not affected by this possibility: see our discussion paper).

11. An alternative way of achieving the same continuum [0,½] of governance structures on the innovation would be through the random allocation of the property right between RU and C. However, there are several reasons why RU-ownership with cofinancing by a third party cannot be duplicated by a random allocation of authority between RU and C. One reason might be that C-ownership discourages RU's initiative excessively in situations where RU's current effort affects not only the occurrence of the current innovation but also the occurrence or value of future innovations. (See Aghion and Tirole [1993, section 6] for a formalization of this argument in the context of a comparison between research joint ventures and fully vertically integrated structures.) Another, more straightforward, reason is that the agent is also indispensable to the realization of V, so that any (random) allocation of ownership between RU and C would lead to the same payoffs ($V/2$,$V/2$) in the absence of a third party. There is then no substitute for cofinancing to extract the research unit's rent.

prevalence of shareholdings by outside shareholders or headquarters in the real world, we do not find the verifiability assumption unrealistic, although the collusion argument indicates one possible limit in cases where the customer and the research unit have the opportunity to make large hidden side transfers.

The choice of α is based on two considerations. First, a lower α allows cofinancing and thus reduces the customer's investment burden. Second, the dilution of *RU*'s share reduces its incentives and therefore the probability of discovery. Using *RU*'s first-order condition $(q'(e^*(\alpha V/2))\alpha V/2 = 1)$, the derivative of *C*'s profit with respect to α is equal to $[-pV/2 + [(2 - \alpha)/\alpha^2](-q'/q'')]$. 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.[12] 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 small), 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 α^* is then given by[13]

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

II.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

12. However, *C*-ownership can again become 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.

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

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. (See Aghion and Tirole [1993] for a brief discussion of this.)

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.[14]

However, these monotonicity results may not hold any longer once the organizational form or ownership structure of R&D activities is endogenized. For, as the value of innovation increases, C may *either* insist on keeping or acquiring property rights (it becomes even more important for the customer to fully capture the whole value of innovation) *or* instead want to voluntarily relinquish property rights to RU (it also becomes more important to raise the research unit's incentives through RU-ownership). The Appendix illustrates this trade-off with two simple examples, one where RU's effort contributes proportionally more to the probability of discovery than C's investment as V increases, and a (polar) example where C's investment becomes relatively more important as V increases.

Consider now a switch from C-ownership to RU-ownership. The standard R&D 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.[15] Furthermore, there is no clear relationship between either measure and the value of the innovation and therefore the Schumpeterian parameters.

14. Indeed, under C-ownership, $E = E^*(V)$, and $p = r(E^*(V))$ with $dE^*/dV > 0$ and $r' > 0$. Under RU-ownership, $e = e^*(V/2)$, $E = E^*(V/2)$, and $p = r(E^*(V/2)) + q(e^*(V/2))$ with $de^*/dV > 0$ and $q' > 0$.

15. 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.

II.6. The Long-Purse Effect

Our analysis so far has assumed away the existence of cash or credit constraints on the customer's side. Introducing such constraints into our framework has obvious implications for the optimal ownership structure.

Consider, for instance, the situation where C-ownership is optimal provided that the customer can finance $E^*(V)$ without going on the capital market and assume now that the customer has less than $E^*((V)$ and must borrow in a market that is imperfect for informational reasons.[16] External financing is then more costly than internal financing and a move from C-ownership to RU-ownership may become attractive since it reduces the customer's benchmark (monetary) investment from $E^*(V)$ to $E^*(V/2)$, and thus reduces the amount of cash C needs to borrow on the capital market. Financial constraints therefore bias the organizational form toward the use of creative inputs and away from capital expenditures. An interesting implication of this analysis is the prediction that new firms or firms which have experienced hard times will tend to farm out their research activities more than established, healthy firms. This is nothing but a refinement of the well-known "long-purse" hypothesis enunciated by Schumpeter, according to which a firm's R&D investment should be positively correlated with its assets.

III. 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 that one innovation. There is then more than one property right to allocate, and property rights can be, and often are, split.

III.1. Multiple Innovations: Contingent Property Rights and the "Hired for" Doctrine

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

16. In our working paper we modeled this credit market imperfection as a costly state verification problem. But alternative modeling choices could have been made without impacting on our basic point.

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 $T \subseteq \mathscr{R}^+$ of types of innovation. With probability x_t, with $\Sigma_{t \in T} x_t = 1$, 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). 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 known which innovation is relevant.[17] Let α_t denote RU's share of the value of the innovation of type t. Note that the nature of innovation is contractible. Because both parties never have an incentive to overinvest (their individual stakes never exceed $\Sigma_t x_t V_t$), an optimal contract must maximize the stake of either party in the innovation given the other party's stake.[18] We therefore maximize C's incentive subject to RU's incentive exceeding some level:

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

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 $\bar{\alpha}_t = 1/2$ if C consumes the innovation (recall that RU does not extract more than $V_t/2$ from C even if it owns the innovation) and $\bar{\alpha}_t = 1$ if an alternative customer uses the innovation. (We adopt the convention that an alternative customer C_t of innovation t purchases the innovation at price V_t. So, C_t competes with other firms in its industry. More generally, V_t stands for the price at which C_t purchases the innovation. For instance, if C_t is a monopsonist, V_t is

17. This is the simplest version of the model. One could alternatively assume that effort and investment are contingent on feasible types of innovation.

18. This is the case if both parties incur some (even negligible) noncontractible investment. It is only when the customer's whole investment is contractible that the customer's stake becomes irrelevant.

in the Nash bargaining solution equal to half of C_t's valuation.) We thus focus only on the allocation of incentives; the optimal $V^*_{RU}\,\alpha_t$ is determined by the same considerations (incentives, ex ante bargaining powers) as in Section II. The solution to this program satisfies for some $t_0 \in T$,

$$\begin{aligned} t > t_0 &\Rightarrow \alpha_t = 0 && (C\text{-ownership}) \\ t < t_0 &\Rightarrow \alpha_t = \bar{\alpha}_t && (\text{pure } RU\text{-ownership}) \\ t = t_0 &\Rightarrow 0 \leq \alpha_{t_0} \leq \bar{\alpha}_{t_0} && (\text{sharing}). \end{aligned}$$

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}.

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 devote excessive attention to those potential innovations with the highest α_t. Such effort allocation raises the desirability of uniform property rights.[19] (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.

III.2. Multiple Innovations: Sequential Property Rights and the Rationale for the Trailer Clause

Many employment contracts specify that an innovation made by a breakaway employee shortly after quitting the firm belongs to the former employer.[20] An efficiency rationale for this practice can

19. This reasoning is familiar from multitask models. See, e.g., Holmstrom and Milgrom [1991] for the case of agent risk aversion, Laffont and Tirole [1993, Chapters 3, 4, and 8] for the case of adverse selection, and the related literature on optimal taxation and Ramsey pricing.

20. 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 be obtained by following the lines of the previous subsection, replacing the nature of the innovation by its date.

More precisely, suppose that the effort e and the investment E produce a time sequence of innovations with present value V_t in which the customer's marginal efficiency decreases over time: $p(e,E,t) = q(e) + h(t)r(E), h'(t) < 0$. Let α_t denote RU's share of the innovation discovered at date t. Because both parties never have an incentive to overinvest,[21] an optimal contract maximizes the stake of one party (say, the customer) for a given value of the other party's stake:

$$\text{subject to } \max_{\alpha_t} \left\{ \sum_t (1 - \alpha_t) h(t) V_t \right\}$$

$$\sum_t \alpha_t V_t \geq V_{RU}.$$

The solution to this program satisfies, for some t_0,

$$t < t_0 \Rightarrow \alpha_t = 0 \quad (C\text{-ownership})$$
$$t > t_0 \Rightarrow \alpha_t = 1 \quad (RU\text{-ownership}).$$

The optimal policy is thus very similar to the trailer clauses observed in practice.

III.3. Multiple Users: 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 license 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

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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 postemployment innovation is larger when the second innovation is in a competing area) or have anticompetitive motives.

21. Individual stakes never exceed $\Sigma_t V_t$.

some noncontractible 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.

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

$$V_{RU} + V_{C_1} = V_1 + V_2 \quad \text{and} \quad V_{RU} \leq V_1/2 + V_2.$$

Let α_1 and α_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

$$0 \leq \alpha_1 \leq \tfrac{1}{2}, \qquad 0 \leq \alpha_2 \leq 1.$$

In this program α_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 affects not only 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 toward the first use. Indeed, if the optimal stake for the research unit, V^*_{RU}, does not exceed 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.[22]

We summarize Section III with the following proposition.

PROPOSITION 2. 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.

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

IV. Property Rights and the Size 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) versus incremental (nondrastic) innovations compared with the same research unit within an integrated firm?

A main motivation for analyzing this question is derived from the recent "neo-Schumpeterian" literature on endogenous technical change and the process of economic growth. This literature, and particularly the models with vertical innovations or "quality ladders," expresses the long-run rate of productivity growth as a function of both the *frequency* and the *size* of innovations.[23] Another motivation is Henderson [1991]'s tests of the hypothesis that established firms would pursue incremental rather than radical innovations (tests which yielded mixed results).

In the previous sections we concentrated our analysis on the relationship between the organizational form of research and the *frequency* of innovations. Our emphasis in this section is on the relationship between the organization of research and the *size* (or drasticity) of technological or quality improvement brought about by the innovation.

More precisely, 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 in a first step 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 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

23. See Segestrom et al. [1990], Aghion and Howitt [1992], and Grossman and Helpman [1991]. In Aghion and Howitt 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.

technology is not constrained by the competitive pressure of the incumbent. Since γ indexes the size of the innovation, $\pi_1^m(\cdot)$ and $\pi_1(\cdot)$ are both increasing.

We now compare the sizes γ_C and γ_{RU} of the innovation that obtain when C (respectively, RU) has property rights on the innovation and chooses its size.[24]

Under *C-ownership* we have

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

Note that γ_C is the efficient research line for the industry. By a revealed preference argument, the larger π_0^m, the more drastic the innovation.[25] 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.

Consider now *RU-ownership* (with or without cofinancing). Note that in the absence of potential entrants, the research unit gets a fraction of the value of 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 obtain a license fee 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 $\max((\pi_1^m(\gamma)-\pi_0^m)/2, \pi_1(\gamma))$ from C.

Suppose first that the optimal choice γ_{RU} by the research unit is such that

$$\frac{\pi_1^m(\gamma_{RU}) - \pi_0^m}{2} \geq \pi_1(\gamma_{RU}).$$

24. In the case where property rights are split from control rights and therefore C can impose the research line even though the ownership of the innovation remains with RU, one finds quite naturally that the incumbent C prefers to reduce RU's bargaining power and thus imposes a bias in the research orientation opposite to that desired by RU (see Aghion and Tirole [1993]).

25. As usual, this is a set comparison if there are several optima.

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 $\pi_1(\gamma_{RU}) > (\pi_1^m(\gamma_{RU}) - \pi_0^m)/2$, the research unit's choice γ_{RU} will generally differ from the incumbent's γ_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. To compare the customer's and the research unit's preferred research lines, note that, by definition of γ_{RU} and γ_C,

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

and

$$p(\gamma_{RU})\pi_1(\gamma_{RU}) \geq p(\gamma_C)\pi_1(\gamma_C).$$

Multiplying these two inequalities, we obtain

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

Reintroducing (ownership-contingent) inputs, the latter inequality still holds as long as the discovery function is "multiplicative," namely $p(e,E,\gamma) = g(\gamma)h(e,E)$. 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 $r(\gamma) \equiv \pi_1(\gamma)/(\pi_1^m(\gamma) - \pi_0^m)$ denote the appropriability ratio or relative willingness to pay of an entrant with respect to the incumbent for the innovation. Then, under the multiplicative discovery function, $\gamma_{RU} \geq \gamma_C$ if r is strictly increasing, and $\gamma_{RU} \leq \gamma_C$ if r 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 tends 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.[26] If r is strictly increasing over an interval

26. The patent race literature [Gilbert and Newbery 1982; Reinganum 1983] has stressed that an incumbent is more likely to innovate before an entrant when

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 $\tilde{\gamma}_{RU} > \tilde{\gamma}_C$.

Example: Process innovation in a homogeneous 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 and $p^m(c)$ denote the monopoly price for cost c, one has (abusing notation slightly)

$$\pi_1^m(c) - \pi_0^m = \int_c^{c0} D(p^m(x))\,dx$$

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

As is well-known, an entrant has more incentive to innovate than an incumbent due to the replacement effect, so $r > 1$. A fortiori, $\pi_1(c) > (\pi_1^m(c) - \pi_0^m)/2$, 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 (γ increases). *In a homogeneous good industry, an independent research unit will pursue less drastic innovations than an integrated one.* On the other hand, our working paper [1993] analyzes two other standard models of industry behavior, respectively, with horizontal and vertical product differentiation, that yield ambiguous conclusions as to the monotonicity of the appropriability ratio. There is therefore no general conclusion about the impact of the ownership structure on the size of innovations.

V. 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 organizational aspects of R&D activities and

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 willingess 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.

their implications in terms of the frequency and size of innovations. Let us summarize our main insights. First, research will more likely 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 nonintegrated 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 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, the drasticity or size of innovations is also affected by the organization of research. However, to predict 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.

The potential of the property rights analysis for studying innovation management is broader than is suggested by the limited scope of this paper.

First, except in our brief discussion of breakaway research in Section III, we have focused on the *static* management of innovation. However, the dynamic aspects of the organization of research activities are also important, and in particular they underlie the (business economics) debate on the relative merits and drawbacks of "vertical" Research Joint Ventures (RJV)[27] vis-à-vis (permanently) integrated structures (or direct equity participations). RJVs have specific objectives and are generally *limited in scope or in time*. 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

27. Such RJVs involve independent researchers (or inventors) and manufacturing firms (developers), where the former contribute their knowledge and the latter contribute capital or other productive inputs. These are to be distinguished from "horizontal" RJVs, where several customers competing or not in a product market join forces to finance research (see Brodley 1982). The study of horizontal RJVs also raises 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.

the probability of success of the joint venture, but also creates its own 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. One can show, however, that integration imperils future technological progress (see Aghion and Tirole [1993]).

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 channeling 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 to 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.

APPENDIX: 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 $(2e/V_0)(V/2) - e < 0$ for all $e > 0$. Therefore, C prefers C-ownership to pure RU-ownership since $r_0V > r_0V/2$, and more generally to cofinancing. For $V > V_0$, C prefers RU-ownership to C-ownership if r_0 is sufficiently small, since $((2/V_0) + r_0)V/2 > r_0V$. 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 $q(e) = \frac{1}{2}$ for $e \geq V_0/4$. We assume that $V > V_0$.

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

$$\frac{V}{4} + \frac{\mu^2V^2}{4} = \mu^2V^2 \Leftrightarrow V = V^* = \frac{1}{3\mu^2}.$$

Then

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

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 input E.

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REFERENCES

Aghion, P., and P. Bolton, "An Incomplete Contract Approach to Financial Contracting," *Review of Economic Studies,* LIX (1992), 473–94.

Aghion, P., and P. Howitt, "A Model of Growth through Creative Destruction," *Econometrica,* LX (1992), 323–51.

Aghion, P., and J. Tirole, "On the Management of Innovation," working paper, MIT and Nuffield College, Oxford, 1993.
Aghion, P., M. Dewatripont, and P. Rey, "Renegotiation Design with Unverifiable Information," *Econometrica,* LXII (1994), 257–82.
Arrow, K., "Economic Welfare and the Allocation of Resources for Inventions," in *The Rate and Direction of Inventive Activity,* Richard Nelson, ed. (Princeton, NJ: Princeton University Press, 1962).
Barton, J., R. Dellenbach, and P. Kuruk, "Toward a Theory of Technology Licensing," in *Stanford Journal of International Law,* "Symposium on the Law and Economics of International Technology Licensing," XXV (1988), 195–229.
Binmore, K., A. Rubinstein, and A. Wolinsky, "The Nash Bargaining Solution in Economic Modeling," *Rand Journal of Economics,* XVII (1986), 176–88.
Brodley, J., "Joint Ventures and Antitrust Policy," *Harvard Law Review,* LXXXXV (1982), 1523–90.
Caves, R., H. Crookell, and J. P. Killing, "The Imperfect Market for Technology Licenses," *Oxford Bulletin of Economics and Statistics,* XXXXV (1983), 223–48.
Fisher, F., and P. Temin, "Returns to Scale in Research and Development: What Does the Schumpeterian Hypothesis Imply?" *Journal of Political Economy,* LXXXI (1973), 56–70.
Gilbert, R., and D. Newbery, "Preemptive Patenting and the Persistence of Monopoly," *American Economic Review,* LXXII (1982), 514–26.
Grossman, G., and E. Helpman, "Quality Ladders in the Theory of Growth," *Review of Economic Studies,* LVIII (1991), 43–61.
Grossman, S., and O. Hart, "The Costs and Benefits of Ownership: A Theory of Lateral and Vertical Integration," *Journal of Political Economy,* LXXXXIV (1986), 691–719.
Hart, O., and J. Moore, "Incomplete Contracts and Renegotiation," *Econometrica,* LVI (1988), 755–86.
Hart, O., and J. Moore, "Property Rights and the Nature of the Firm," *Journal of Political Economy,* XCVIII (1990), 1119–50.
Hart, O., and J. Moore, "A Theory of Debt Based on the Inalienability of Human Capital," *Quarterly Journal of Economics,* CIX (1994), 841–79.
Henderson, R., "Underinvestment and Incompetence as Responses to Radical Innovation: Evidence from the Photolithographic Alignment Equipment Industry," mimeo, Sloan School, MIT, 1991.
Holmstrom, B., and P. Milgrom, "Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design," *Journal of Law, Economics and Organization,* VII (1991), 24–52 (special issue).
Laffont, J. J., and J. Tirole, *A Theory of Incentives in Procurement and Regulation* (Cambridge, MA: MIT Press, 1993).
Nelson, R., "The Simple Economics of Basic Scientific Research," *Journal of Political Economy,* LXVII (1959), 297–306.
Neumeyer, F., *The Employed Inventor in the United States: R&D policies, Law and Practice* (Cambridge, MA: MIT Press, 1971).
Reinganum, J., "Uncertain Innovation and the Persistence of Monopoly," *American Economic Review,* LXXIII (1983), 741–48.
Rodriguez, D., "The Growth and Diffusion of Knowledge and the Theory of the Firm," mimeo, MIT, 1992.
Rubinstein, A., "Perfect Equilibrium in a Bargaining Model," *Econometrica,* L (1982), 97–110.
Schumpeter, J., *Capitalism, Socialism and Democracy* (New York: Harper, 1942).
Segestrom, P., T. Anant, and E. Dinopoulos, "A Schumpeterian Model of the Product Life Cycle," *American Economic Review,* LXXX (1990), 1077–92.
Ståhl, I., *Bargaining Theory* (Stockholm: Stockholm School of Economics, 1972).
von Hippel, E., *The Sources of Innovation* (Oxford: Oxford University Press, 1988).