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ASSET SPECIFICITY, R&D FINANCING, AND THE SIGNALLING PROPERTIES OF THE FIRM'S FINANCIAL STRUCTURE

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Equity financing is the optimal strategy for innovating firms, which can use their financial structure as a signalling device to attract outside investors. This situation is likely to arise when the firm undertakes a specific purpose R&D project aimed at developing a certain product innovation. Typically, innovations of this kind draw on the firm's cumulative, idiosyncratic knowledge base and, accordingly, the innovation process involves a high degree of asset specificity. Under such circumstances, the terms of debt financing will be adjusted adversely, and equity financing will represent the most economically efficient solution.

These arguments are developed in standard static principal-agent models dealing with New Technology Based Firms and publicly held large firms undertaking an aggressive R&D strategy. In the case of NTBFs, two kinds of optimal venture capital contracts are considered, which render the sharing rules independent (a) of the agent's action and (b) of both the agent's action and the specific assets involved in the transaction. Regarding innovating large firms, it is argued that in this case, too, equity represents the optimal financing strategy, and that top executives use their equity share to signal the firm's expected return stream and value to outside investors.

KEY WORDS: R&D Financing, High-Tech Industries, Asset Specificity, Efficient Contracting, Agency Theory, Signalling.

1. INTRODUCTION

This paper attempts to shed light on the influence that the types of investments undertaken by a firm exert on its financial structure. In particular, the paper addresses the financing of specific R&D projects and presents a theoretical description of the signalling properties of the innovating firm's financial structure. An innovating firm is assumed to be one engaging in a (set of) specific action(s) in order to *create* a new, patentable invention. The innovative process is therefore taken to be the result of an *aggressive* R&D strategy aimed at developing this and only this specific innovation. Innovations of this type are likely to draw on a firm's cumulative, idiosyncratic knowledge base and result from a "D oriented" R&D activity.

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Under the above assumptions, the innovating firm possesses better information than the *market* concerning the possible return stream generated by its specific R&D project, and it is thus able to use its finance structure as a signalling device to attract investors (Spence, 1973; Riley, 1975; Leland and Pyle, 1977).

The theory developed by the paper stands at the intersection of organizational economics, finance, and the economics of technological change. It draws on Transaction Costs Economics (henceforth TCE) and Agency Theory (henceforth AT), approaches which offer many useful insights in the modelling of the relation between financial structure, internal organization, and innovation at the firm level. In fact, both TCE and AT use an "efficient contracting" framework, and both are interested in the study of managerial discretion (cf. Williamson, 1988b). Among the differences between the two theories, the most significant for the purposes of this paper are that TCE takes the *transaction* as its elementary unit of analysis while AT uses the *individual agent*, and that TCE focuses on *ex post*, and AT on *ex ante* contractual relations (with respect to the production process). Thus a combination of the two approaches allows one to study the behaviour of some *specific* agents when they are engaged in equally *specific* transactions.

I accept the assumption by TCE that there is a sharp distinction between firms which commit themselves to specific purpose, nonredeployable investments, such as the particular type of R&D considered here, and firms committed to general purpose investments. Thus, since a specific R&D project involves asset specificity (as defined by Williamson (1981)), on the basis of Williamson's (1988b) arguments I assume that in this case equity financing is the most efficient type of financing.

Likewise, I employ AT for analysis of the behaviour of individual agents in the contractual relation of the equity type which is likely to arise in the financing of specific R&D activities when the agent has private information about the firm's R&D which the principal does not (cf. Myers and Majiluf, 1984; Hart, 1988). In particular, I consider the case of start-up enterprises, for instance New Technology Based Firms (henceforth NTBFs), and Previously Established Publicly Held High Technology Firms (henceforth PEPHHTFs¹). In fact, in the situation considered here, informational asymmetries arise between those who are in control of the R&D process and potential financiers (whether these are venture capitalists or shareholders), and AT is a powerful tool of analysis when dealing with imperfect or incomplete information (cf. Arrow, 1985).

The above assumptions drawn from TCE and AT provide the basis for the paper's principal arguments: that the Modigliani-Miller Irrelevance Theorem does *not* apply to the case of innovating firms, since the R&D process that these undertake gives rise to informational asymmetries;² that the firm's financial structure is a crucial variable in the presence of *special purpose* investments entailing *asset specificity*, such as the R&D expenditures considered here (Williamson, 1985, 1988a, 1988b); that in this situation the firm's financial structure displays important signalling properties; and that this firm enters into financing contracts of the equity type which can be analysed as standard principal-agent problems.

Section 2 uses the example of the biotechnology industry to provide empirical motivation and justification for the theoretical arguments presented in the paper.

¹Where "Previously" refers to the R&D project.

²As already known, one of the crucial assumptions in the Modigliani-Miller Theorem is that the information structure is complete and perfect.

Section 3.1 reviews some features of the incomplete contract literature; section 3.2 develops a standard principal-agent model of the relationship between a venture capitalist and an R&D-performing NTBF run by an entrepreneur wishing to undertake a specific purpose investment. Section 4 outlines a model of the relationship between aggressive R&D strategies and the issuing of new equity in PEPHHTFs. Section 5 makes some concluding remarks.

2. SOME FACTS ABOUT R&D FINANCING IN THE BIOTECHNOLOGY INDUSTRY

Many high-tech start-ups occurring in locational clusters of the Silicon Valley type are mostly self-financed. In such cases, entrepreneurs/technologists rely on money put up by themselves or by relatives and friends to implement R&D projects that they confidently expect to succeed.

However, when this capacity to create internal funds is lacking,¹ it is more likely that financing of the venture capital type will be sought than bank loans or any other kind of pure debt-financing (cf. Dean and Giglierano, 1990; Sahlman, 1990). The main advantage of contracts of the venture capital type is that they are set over a very long period (at least five years), and that by signing such contracts the entrepreneurs share the risk of the investment with outsiders. In fact, the projects involved in such transactions are characterised by very high risk and their speculative nature. Thus, by looking for long-term commitment the entrepreneur/technologist signals to potential outside financiers the presence of asset specificity and nonredeployability in the project and his/her confidence that, when the R&D investment reaches maturity, the NTBF's return stream will be significantly high.

Conversely, in the case of pure debt contracts, even though they may be set over an equally long period, (a) stipulated interest payments must be made at regular intervals, (b) principal and interest must be paid at the loan expiration date, and (c) in the event of default the outside financier will realize differential recovery in the degree to which the assets involved in the project are redeployable (cf. Williamson, 1991). The first point implies that the NTBF will be subject to liquidity constraints even before the project is fully implemented, and the second that a failure to make payments on schedule will result in liquidation, even if the firm is economically viable.² As to the third point, a deepening in the degree of asset specificity determines a decline in the value of pre-emptive claims, as a consequence of which the terms of debt financing will be adjusted adversely.

Recourse to venture capital is particularly widespread in the US in development of NTBFs in all those circumstances where they are not able to rely upon the entrepreneur's own funds. Often the invention-development effort is undertaken by university researchers, who need financial backing to support their project and, eventually, to commercialize its results (cf. Smilor, Gibson and Dietrich, 1990). For example, Genentech Inc. of South San Francisco, one of the most successful US biotechnology companies, started its business in this way when, in 1976, it began

¹Or when it is sufficient only for initial financing, and external funds are needed for subsequent financing.

²This is a typical case of involuntary default, which in the situation considered here is likely to occur if the *initial* market performance of the new product is poorer than expected.

research on what would eventually become its first commercial product: the human growth hormone produced by recombinant DNA technology.¹

In the field of biotechnology, it takes seven to ten years on average to develop new prescription drugs and it costs about \$200 million, while the innovation process takes place through exploration of new natural trajectories of technology (as defined by Nelson and Winter, 1977). The broad field of biotechnologies therefore represents a technological regime in the sense of Nelson and Winter, whereas recombinant DNA technology is one of the most pervasive natural trajectories set in motion by this regime.

Genentech has undertaken R&D projects within the boundaries of such a natural trajectory, alternatively focusing on project innovations like synthetic growth hormones, tissue plasminogen activators (t-PA), and gamma interferons. The innovation process of this and similar firms therefore consists of the search for a specific new drug and entails a significant level of physical, human, and even site asset specificity (Williamson, 1981). In fact, each project employs instruments designed for a specific experiment, and human capital specially trained for that particular field of application.² Moreover, such firms tend to cluster in a single excellence region as a consequence not only of historical accidents, but also of agglomeration economies and network externalities³ (cf. Arthur, 1990).

After the first product has been developed, the second step taken by successful high-technology venture capital funded start-ups is to become publicly held companies. In fact, if the company does not go public or sell out to a large company, it is difficult for the venture capitalist to recover his/her investment. Thus the greater the amount the venture capitalist has invested, the more equity he/she will have in the newly formed company. Genentech has followed this procedure, and soon became a publicly held company. As far as this event is concerned, it is worth noting that the price per share, fixed at \$0.72 when the first round of financing from venture capitalists began in April 1976, skyrocketed to \$35.00 when shares were first offered to the public in October 1980 (cf. Shalman, 1990).

After Genentech went public, in 1980, it experienced high rates of growth combined with high profitability. During the transition from the NTBF to the PEPHHTF form, almost one hundred per cent of Genentech employees became shareholders, and stock options were introduced into the executives' compensation scheme.

Established companies displaying these features invest up to 40% of their total revenues in new drug development, but the amount of money set aside for specific purpose R&D investment is not always enough to cover all their expenses, since general purpose expenditures which cannot be deferred are also incurred. Thus the issue of new equity is a financing decision superior in efficiency to any kind of debt financing when the company undertakes an R&D investment entailing nonredeployability and specificity of assets. As Williamson (1988b, p. 580) states, "confronted

¹The information on Genentech used in this paper is based on an interview with the company's co-founder and Chairman of the Board Mr. Robert Swanson, conducted on January 14, 1991, and on the company's annual reports.

²For example, Genentech employed for its first product custom equipment made for that purpose by the Swedish company Alfa-Laval.

As far as human asset specificity is concerned, when starting a new project Genentech usually hires young scientists just out of post-doctoral programs who are specially trained in that field.

³In the case of Genentech and other smaller biotechnology companies located in the San Francisco Bay Area all of these locational factors seem to have played a role.

with the prospect that specialized investments will be financed on adverse terms, the firm might respond by sacrificing some of the specialized investment features in favour of great redeployability. But this entails tradeoffs: production costs may increase or quality decrease as a result." The alternative financial instrument available to firms seeking to avoid the tradeoffs entailed by debt financing is equity. This allows more managerial discretion than debt and is thus reserved for projects uncertain in nature and characterised by high asset specificity. In fact, pure market exchange, to which debt is more akin, becomes more complicated when asset specificity is involved and some credible commitments are required to support the transaction (Williamson, 1975).

Genentech faced a similar situation in 1989, when it decided to resort to equity financing in order to raise the financial resources needed to implement its R&D projects. The new equity was wholly acquired by the Swiss pharmaceutical company Hoffman-La Roche. Hoffman-La Roche thus holds 60% of Genentech, which in turn has raised \$500 million to accelerate the pace of its ongoing research activity and undertake new special purpose R&D projects. The agreement with Hoffman-La Roche does not entail any shift in control: Genentech will continue its activity as an autonomous publicly held company seeking to expand basic knowledge in the field of recombinant DNA technology and to develop new health care products.

The case of the agreement between Genentech and Hoffman-La Roche is of course a somewhat peculiar one in that the newly issued equity was subscribed by only one major investor. Nonetheless it is representative of a very general tendency in the biotechnology industry to fund special purpose R&D by issuing new equity. For example, Genentech itself has invested \$15 million worth of equity in Glycomed Inc. for a research project to develop a carbohydrate-based drug. The rationale for this widespread resort to equity financing in biotechnologies seems again to be risk-sharing combined with the consideration that, given the specificity of the assets involved in most of the R&D projects, a pure debt transaction would not be supported by credible commitments of any kind. Of course, similar considerations apply also to the cross holdings and the equity links which characterise many cooperation agreements in this industry, where there has been a recent tendency towards bilateral relationships involving two or more firms committed to the development of a specific new product (cf. Orsenigo, 1989; Pisano and Teece, 1989; Teece, 1989).

3. A PRINCIPAL-AGENT MODEL OF THE FINANCIAL STRUCTURE OF THE NEW TECHNOLOGY BASED FIRM

3.1. *Incomplete contracts and firm financial structure*

The special case of R&D programs considered in this section is one in which innovating NTBFs can enter into long-term financing contracts of the venture capital type only in order to fund their R&D blueprints. In fact, (a) they cannot make use of retentions, because the project requires an investment of funds that exceeds their resources (this problem has been treated extensively by Stiglitz, 1974); (b) they cannot resort to short-term finance,¹ since this enables only routine investments, which reach maturity earlier than investments in innovation-oriented R&D strategies; (c) long-term debt is not worthwhile, because in the presence of asset specificity its terms are adjusted adversely for the NTBF.

¹I.e. to a contract providing finance only over the foreseeable future.

NTBFs are influenced in the choice of an optimal financial structure by their requirement to enter into a financial contract that specifies the terms of future finance. The only contract fully displaying these features is an equity type one, which "bears a residual-claimant status to the firm in both earnings and asset-liquidation respects [and] contracts for the duration of the life of the firm" (Williamson, 1988b, p. 580). Otherwise, if the innovative investment project has not reached maturity by the time a debt contract expires, problems will arise for both the firm and the outside investor. The former will be in an unfavourable bargaining position when renegotiating further loans, and the latter will run the risk of losing at least in part his or her funds should the firm fail to pay stipulated interest payments or go bankrupt (on bankruptcy threat, cf. Aghion and Bolton, 1988). This may provoke conflict between entrepreneur and outside financier as circumstances change to the advantage or detriment of one or other party to the contract. A suboptimal solution to such conflict may be found by writing long-term contingent incomplete contracts (for a survey, cf. Hart and Holmström, 1986) of the venture capital type, which involve at least three different kinds of benefit.

Firstly, they provide a saving on transaction costs by establishing in advance what action is required of each party at different stages of the contractual relationship. The parties therefore do not have to negotiate further short-term contracts and they thus avoid the problems outlined above.

Secondly, long-term contracts enable the parties to avoid problems connected with further informational asymmetries arising during their relationship which may affect their bargaining efficiency. This property is particularly significant in the situation considered in the present paper, where further informational asymmetries are likely to arise during the execution of the contract.

Thirdly, a long-term contract also performs a screening function: it may attract the venture capitalist by offering high future equity interest if the R&D program is successful. In this case, the venture capitalist and the entrepreneur/technologist sign a contract prescribing future shareholding involvement by the former in all those circumstances which give rise to a tangible outcome from research activity. For example, if the venture capitalist puts up 70% of the capital, he/she might require a 40% equity interest.

3.2. *The model*

According to the description of high-tech start-ups presented in section 2, and under the above considerations, let us consider an entrepreneur-technologist (or scientist) who, although he/she has access to a specific R&D program, needs long-term finance in order to implement his/her investment project (Arrow, 1962; Mayer, 1988). This situation is likely to give rise to an R&D partnership where two parties – a limited partnership and a sponsoring company – enter into a contingent incomplete contract under which the sponsoring company performs R&D on a best effort basis¹ and the limited partnership provides the funds that are necessary for early stage financing.²

¹That is, without guaranteeing any results.

²In the language of venture capitalists this includes: *seed financing* (used to prove a scientific or a technological concept); *start-up financing* (necessary for product development, as in the case here); *first-stage investing* (used when the prototype has been already developed and the company begins manufacturing).

The venture capitalist-limited partnership is assumed to be risk-neutral, and to seek all those investment opportunities offering the highest profitability. For the sake of simplicity, it is also assumed that expected profitability is positively correlated with the degree of innovativeness.

The above is a typical case where there are gains to specialization; it is therefore one where agency relationships between a risk-neutral venture capitalist and the innovating firm are likely to arise (Stoneman, 1987, Chapter XIII; Holmström, 1989).¹ In fact, the contract which both parties agree to sign specifies in advance how the payoff is to be shared between the principal (venture capitalist) and the agent (entrepreneur/technologist), i.e. it states what the equity interest for each party will be.

Let a denote a generic element among a given set of actions A (e.g. alternative ways to implement the R & D project) available to the agent. Let x then denote a verifiable outcome or a monetary payoff $x = x(a, \sigma \in \theta)$, resulting from the agent's choice of some action a and from the specific tangible and intangible assets σ involved in the project. In the case of a venture capital contract, outcome x is represented by the value of the NTBFs total equity when the project has reached maturity, the resulting new product has been introduced in the market, and the initial public offering is made. In practice, σ is the idiosyncratic knowledge base on which x depends, and it represents a portion of the natural trajectory of technology θ , which contains a series of assets $\sigma_1, \dots, \sigma_n$ (with $\theta = \{\sigma\}$). Thus, outcome x depends not only on the agent's action, but also on some specific assets, and is obtained from a production process in which Ω is the subset of $A \cap \theta$, such that

$$A \cap \theta = \{x | x \in \Omega \subseteq A\} \text{ and } x \in \Omega \subseteq \theta \tag{1}$$

where

$$A \cap \theta = \begin{cases} (\emptyset) & \text{with probability } p \\ \Omega & \text{with probability } 1 - p \end{cases}$$

since the R&D process can either be unsuccessful (\emptyset) or successful (Ω). In practice, any possible value of x reflects an action a in the set of A and some specific assets $\sigma \in \theta$. Thus, the following notation

$$\Omega = \{x | P(x) \text{ is true}\} \tag{2}$$

denotes that Ω is the set of outcomes x to which a certain property P applies - i.e. those outcomes that can be achieved by undertaking an action $a \in A$ which makes it possible to exploit the potentialities of some specific assets $\sigma \in \theta$.

The problem now is to determine how outcome x can be shared optimally between the agent and the principal in a contractual relation where the principal puts up an amount of money y enabling the agent to develop his or her R&D project from which a payoff x is expected.

Let y denote the amount of capital set aside by the principal and beneficial to the agent. The agent's utility function is $H(y, a)$ with $H_y \geq 0$, $H_a \leq 0$, and the principal's $U(x - y)$. The principal's utility function depends on the outcome of the

¹It is worth noting, however, that the sources of the agency problem differ from those usually considered in standard principal-agent literature. In fact, in the situation that concerns us here, the agency problem is created by the risk-taking incentives implicit in the contract, whereas in standard principal-agent literature the agency problem arises because the principal has to induce a risk-adverse agent to undertake a certain level of action.

inventive activity and the size of the payment y made to the agent to allow the undertaking of the R&D investment. It also depends on $\sigma \in \theta$ and a , and is such that $U' > 0$ and $U'' < 0$, since the principal is risk neutral and his or her utility function can be represented as a linear one.

Venture capitalists – even if they are specialized in that given industry and have had personal training and/or experience in it – generally perform most of the analysis and investigation before investing their money. They gain access to the sponsoring company and make the investment only when they have obtained the information they want.¹ The empirical evidence on high-tech start-ups provided by MacMillan, Kulow and Khoylian (1990) indicates that venture capitalists are involved most in the financial aspects of the venture, at least compared to the entrepreneur/technologist. In particular, the lowest degree of involvement seems to be in those activities which concern ongoing research operations. In fact, venture capitalists usually possess the base technological knowledge necessary to ascertain whether by exploring a given natural trajectory commercially successful products might be developed, but they lack the specific knowledge needed to implement a specific project. Their assessment of a specific R&D project depends on their perceptions of the normal rates of innovation in that industry, i.e. of the leading natural trajectories.² Hence, in venture capital contracts of the kind considered here, the knowledge required to deal with the tangible and intangible assets involved in the transaction is specific to the agent.

Assuming that the principal does not exert any monitoring, but reviews only the achievement of intermediate goals, we can demonstrate the existence of an optimal financing contract in which the sharing rules are functions of x alone. Following standard agency theory, the hypothesis of imperfect information concerns states of nature in which the agent's action a is chosen when the specific assets involved in the transaction are not known to the principal. In practice, imperfect information arises because the agent possesses a significant degree of knowledge concerning the non-redeployable assets $\sigma \in \theta$, whereas although the principal has sufficient knowledge of the natural trajectory θ , he/she has only limited knowledge (if any) of the specific assets which are involved in the transaction.

As in Holmström (1979), let $s(x)$ denote the agent's (NTBF's) share of x , and let $r(x) = x - s(x)$ denote the principal's (venture capitalist's) share. Pareto-optimal sharing rules to the agent, $s(x)$, are generated by solving the following program:

$$\max_{s(x), a} \sum_{i=0}^n U(x_i - s(x_i)) \quad \text{where } x = x(a, \sigma \in \theta) \quad (3)$$

which explains the variation of the discrete variable x . Accordingly, notation (3) can be substituted by notation (4), in which E denotes the expectational operator conditional on available information

$$\max_{s(x), a} E\{U(x - s(x))\} \quad (4)$$

¹For informational reasons, venture capitalists have at least one member on the board of directors of the firm they are funding, since they do not invest for short-term interest or dividends, but maintain a long-term capital gain orientation towards their activities.

²Otherwise, should the principal possess the same knowledge as the agent concerning $\sigma \in \theta$, he/she will implement the R&D project directly, developing his/her sponsoring company in order to share costs and risks with other outside investors.

subject to

$$E\{H(s(x), a)\} \geq \bar{H} \tag{5}$$

where \bar{H} denotes the minimum level of the agent's expected utility, and

$$a \in \operatorname{argmax}_{a^* \in A} E\{H(s(x), a^*)\} \tag{6}$$

where "argmax" denotes the set of arguments which maximize the principal's objective function. Solution (4), subject to (5) and (6), is a second best solution, where notation (4) denotes that the agent is guaranteed the minimum expected utility, and the agent's objective function (6) takes account of the fact that the principal can only observe the outcome x but not the action a , since he or she does not monitor the agent's action. On the basis of the assumption that $x = x(a, \sigma \in \theta)$, the program may be solved by taking the expectations in (4) and (5) relative to the distribution of $\sigma \in \theta$ (see Harris and Raviv, 1979).

In this model, the only persisting informational asymmetries are those relating to the specific assets $\sigma \in \theta$ involved in the transaction. These allow adverse selection or, put in terms of the TCE approach, opportunistic behaviour on the agent side. To forestall the problems arising from adverse selection, the contract may be replaced by another one, independent of the agent's action a . The analytical procedure for dealing with this different contract has been introduced by Harris and Raviv (1979). This makes it possible to overcome the problems connected with opportunistic behaviour on the agent side, even if the efficiency superior contracts that it entails allow fewer degrees of liberty.

Let us begin by considering two different contracts S_1 and S_2 . The former is the standard contract as described above, where the sharing rules are a function of the agent's action a , a particular outcome x , and some specific assets $\sigma \in \theta$; the latter is a contract where the agent's action does not affect the sharing rules. Thus, the problems of adverse selection are reduced, in the sense that they only depend on the informational asymmetries represented by the differing knowledge possessed by the agent and the principal of the specific assets $\sigma \in \theta$. In contract S_2 the signalling argument is more clear cut than in contract S_1 , since the outside investor has the guarantee that the NTBF will choose the action which, consistently with θ , enables achievement of outcome x .

PROPOSITION 1. *Assuming $(S_1; x, a, \sigma \in \theta)$ to be the general form of the contract between the NTBF and the outside financier considered here, there is a contract $(S_2; x, \sigma \in \theta)$ such that any contract which depends on x, a , and $\sigma \in \theta$ can be dominated by one depending on x and $\sigma \in \theta$ only.*

Proof. As in Harris and Raviv (1979), let $a_1 = a(S_1)$, and $x \in \Omega$, with $\Omega^*(\sigma \in \theta) = \Omega(a_1, \sigma \in \theta)$

and then define the contract independent of action a as

$$S_2(x, \sigma \in \theta) = S_1(\Omega^*(\sigma \in \theta), a, \sigma \in \theta) - \Omega^*(\sigma \in \theta) + x \tag{7}$$

Hence, with V^A denoting the agent's choice of the action maximizing his/her utility, and with $a_2 = a(S_2)$, we obtain

$$\begin{aligned} V^A(S_2, a_2) &\geq V^A(S_2, a_1) \text{ by definition of } a_2 \\ &= V^A(S_1, a_1) \text{ by construction of } S_2 \end{aligned}$$

In this case it is also true that

$$\begin{aligned} & \Omega(a_2, \sigma \in \theta) - S_2(\Omega(a_2, \sigma \in \theta), \sigma \in \theta) \\ = & \Omega(a_2, \sigma \in \theta) - S_1(\Omega^*(\sigma \in \theta), a_1, \sigma \in \theta) + \Omega^*(\sigma \in \theta) - \Omega(a_2, \sigma \in \theta) \\ = & \Omega(a_1, \sigma \in \theta) - S_1(\Omega(a_1, \sigma \in \theta), a_1, \sigma \in \theta) \end{aligned}$$

Taking V^P to be the action maximizing the principal's utility, we obtain

$$V^P(S_2, a_2) = V^P(S_1, a_1)$$

In this case, since the realizations of $\sigma \in \theta$ and x are observable, a is inferrable *ex post*. The existence of such a contract has been proved by Harris and Raviv (1979).

If one wishes to solve all the problems arising from adverse selection, the importance of the specific assets $\sigma \in \theta$ in establishing the sharing rules should decrease even further, thus also reducing the degree of technological determinism implicit in the contract.¹ The problem arising over informational asymmetries relates to the role of $\sigma \in \theta$ in the establishing of sharing rules and compensation schemes for the agent. It can be solved in the manner set out by Harris and Raviv (1979), thus enabling us to consider a contract S_3 dominated by x alone, which is superior to S_1 and S_2 in terms of signalling properties. In fact, by signing such a contract the NTBF guarantees that, although it possesses superior information, it will also act in the outside financier's interest.

PROPOSITION 2. *In the particular case where the NTBF is risk-neutral and the outside financier does not monitor the agent because of his/her limited knowledge of the technical features of the agent's action, any contract which depends on x , a , and $\sigma \in \theta$ will be dominated by a contract which depends only on x .*

Proof. As in the proof of proposition 1, let $(S_1; x, a, \sigma \in \theta)$ be a generic contract with $a_1 = a(S_1)$, $x \in \Omega$, and $\Omega^*(\sigma \in \theta) = \Omega(a_1, \sigma \in \theta)$, and define

$$c = E_{\sigma \in \theta} \{ \Omega(a, \sigma \in \theta) - S_1[\Omega(a_1, \sigma \in \theta), a_1, \sigma \in \theta] \},$$

and let S_3 be a contract such that

$$S_3(x) = x - c \tag{8}$$

The principal is indifferent as to the choice between S_1 and S_3 . Hence the action maximizing his/her utility may be defined as

$$\begin{aligned} V^P(S_3, a_3) &= E_{\sigma \in \theta} U[\Omega(a_3, \sigma \in \theta) - S_3(\Omega(a_3, \sigma \in \theta))] \\ &= E_{\sigma \in \theta} U(c) \quad \text{with } S_3(x) = x - c \\ &= U[E_{\sigma \in \theta} \{ \Omega(a_1, \sigma \in \theta) - S_1[\Omega(a_1, \sigma \in \theta), a_1, \sigma \in \theta] \}] \\ &= E_{\sigma \in \theta} U[\Omega(a_1, \sigma \in \theta) - S_1\{\Omega(a_1, \sigma \in \theta), a_1, \sigma \in \theta\}] \\ &= V^P(S_1, a_1). \end{aligned}$$

In his/her turn, the agent solves the following problem to maximize his/her utility:

$$\begin{aligned} V^A(S_3, a_3) &\geq V^A(S_3, a_1) \text{ by definition of } a_3 \\ &= E_{\sigma \in \theta} U^A[\Omega(a_1, \sigma \in \theta) - c, a_1] \end{aligned}$$

¹Since it is the nature of the assets that determines the features and the outcome of the contractual relation.

$$\begin{aligned}
 &= U^A[E_{\sigma \in \theta}(\Omega(a_1, \sigma \in \theta) - c), a_1] \text{ by risk neutrality} \\
 &= U^A[E_{\sigma \in \theta}S_1(\Omega(a_1, \sigma \in \theta), a_1, \sigma \in \theta), a_1] \\
 &= V^A(S_1, a_1) \text{ by risk neutrality.}
 \end{aligned}$$

In this case the optimal contract, which is a second-best solution, is written when the sharing rules are such that the principal's share is independent of $\sigma \in \theta$, ignoring incentive problems. This equilibrium solution handles the problems connected with informational asymmetries between principal and agent, and the principal's lack of knowledge of the specific assets $\sigma \in \theta$. The existence of this contract has been proved by Harris and Raviv (1979).

4. A MODEL OF THE OPTIMAL FINANCIAL STRUCTURE IN THE CASE OF THE ESTABLISHED HIGH TECHNOLOGY FIRM

On the basis of the premises set out in section 2, this section considers (a) the financial strategy of a large PEPHHTF when it decides to implement an aggressive R&D project aimed at developing a specific product innovation, and (b) the signalling mechanism set in motion by its top executives in order to raise the necessary funds. As was the case with NTBFs, a key element in analysis is the private information processed by the agents (in this case represented by the top executives of the firm) concerning the R&D project.

In modern finance theory, the R&D costs faced by firms of the type considered in this section are those resulting from planned search, the expected future return stream of which is discounted at a cost of capital which is conditional on the social risk inherited in that stream. Within this framework, individual portfolios or capital constraints do not present any problems. However, in the real economy PEPHHTFs allocate a limited amount of money every year to different projects, and the internal demand for funding is thus likely to exceed the amount set aside for R&D purposes in any particular year (cf. Holmström, 1989). Thus issuing new equity is a type of activity able to supply fresh funds to the company and to allow the undertaking of long-term, special purpose R&D projects. This form of financing avoids the problem connected with debt financing in the presence of asset specificity (cf. section 2), and enables equity holders to act as risk sharers in the expectation of future rewards, represented either by high dividends or by an increase in the total value of the firm.¹

Theoretical models in which capital structure is determined by agency costs belong to a tradition begun by Fama and Miller (1972) and developed in the classic papers by Myers (1977) and Jensen and Meckling (1976). According to Jensen and Meckling, when one hundred per cent of equity is held by those not controlling the firm, its executives tend to slack. This tendency diminishes, however, when executives hold a share of total equity, because the greater their claim on the firm, the stronger their incentive to reduce slack. In this case, performance by top executives is therefore closely related to their firm's performance, and stock options – which can be taken to

¹Of course, in the case of equity joint ventures and cross holdings the reward might also take the form of rights to develop the new product further or to market it in a particular geographical area.

represent the range of pecuniary and non-pecuniary benefits referred to by Jensen and Meckling – indirectly benefit the firm by improving its top executives' performance.¹

In fact, there is empirical evidence to show that the relationship in managerial firms between executives' shareholdings and a firm's performance is usually positive and significant. For example, Lewellen (1969) found that by the early 1960s the pay of top executives in large US corporations depended in a significant manner on the performance of their stockholdings. According to Lewellen's study, the ratio of the sum of after tax stock-based remuneration, after tax income and absolute after tax capital gains to the after tax fixed dollar remuneration of top executives rose sharply from 0.86 in 1940 to 6.9 in 1963. Similar results have been obtained by Lawriwski (1984) in a study conducted on a sample of Australian companies.² More recently, Gibbons and Murphy (1990) have shown that the revision of the pay schedule for Chief Executive Officers and the probability that they will remain so the following year are positively and significantly correlated to firm performance.

For analytical simplicity – since this section of the paper focuses on the agency relationship between top executives and equity holders – we assume that top executives' decisions are fully accepted and implemented by R&D managers, i.e., that no agency relationship exists between the central R&D function and the top executives.

Consider now a publicly held company belonging to a science-based industry with the objective function of maximizing its total sales and profits. Assume that its top executives hold m per cent of the company's shares and are willing to undertake an aggressive R&D project (I_{RD}) in the belief that it may give the company competitive edge and increase its market share, thus enabling them to obtain additional stock options. The top executives can sell a fraction of the firm represented by newly issued equities to outside investors or to incumbent equity holders in order to collect the funds necessary to start the R & D project.³

This problem can be handled using a two period model where decisions taken in the first period affect the second period return-stream. Let us assume that the amount of the equities issued by the PEPHHTF is the sum of the equities m issued at different times m_1, \dots, m_n and that

$$\sum_{i=1}^n m_i = M_n \quad (9)$$

is the total amount of equities at time n . On starting its I_{RD} , at time $n + 1$ the PEPHHTF issues new equities. The amount of total equities therefore raises from M_n to M_{n+1} and may be represented by the following sum

$$\sum_{i=1}^{n+1} m_i = M_{n+1} \quad (10)$$

Hence, if things go as planned the top executives receive (as in Ross, 1977) the

¹ Recent extensions of this approach have focused mainly on the problem of overinvestment (Jensen, 1986; Stulz, 1990) and failure to liquidate (Harris and Raviv, 1991).

² Even if the relationship between top managers' shareholdings and firm's performance is proved to be curvilinear.

³ The underlying assumption is again that when top executives hold a significant shareholding in the firm, they improve their performance (see Morck, Shleifer and Vishny, 1988).

following remuneration in period 2 (in terms of stock options F)

$$F = (1 + r)\gamma_1 V_1 + \gamma_2 \begin{cases} V_2 & \text{if } V_2 \geq M_{n+1} \\ V_2 - L & \text{if } V_2 < M_{n+1} \end{cases} \quad (11)$$

where V_1 and V_2 denote, respectively, firm value in period 1 and period 2; L stands for the penalty to top executives if the firm goes bankrupt in period 2, after carrying out I_{RD} ; r is the rate of interest; γ_1 and γ_2 are non-negative constants. The values of these constants differ from period 1 to period 2. In fact, this model deals with logical time, and from this perspective the distance between period 1 and period 2 may be assumed to be long enough to determine a change in the constants.

Top executives maximize their objective function, as represented by the level of stock options F . Their main goal is therefore to implement I_{RD} and maximize - by maximizing the firm's total sales and profits¹ - the amount of their stock options. Accordingly, notation (11) represents a signalling device, in the sense that M_{n+1} signals the firm type to outsiders and to incumbent equity holders. In practice, the greater the difference between M_n and M_{n+1} in period 2, the clearer the perception by outside investors and equity holders that the firm is undertaking an innovative investment able to improve the firm's future return stream and value.

Let A^* and B^* represent two different PEPHHTFs, with the former engaged in aggressive R&D programs and the latter pursuing adaptive and imitative investment strategies, and let a and b denote the respective total return. Assuming M^* as the critical level of financing, taking F^* as the level of top executives' stock options when they own one hundred per cent of the equity and F as the actual level, the result will be $b \leq F^* < a$ if $F > F^*$ - in which case the market will perceive the PEPHHTF to be a type A^* firm - and $F \leq F^*$ if the market perceives the PEPHHTF to be a type B^* firm. Corporation A^* will sell its newly issued equities at a face value such that $F^A \leq a$ and consequently firm value in period 1 will be

$$V_1 = V_1(F^A) = a/1 + r \quad (12)$$

with r denoting the interest rate. Firm B^* will choose a face value such that $F^B \leq b$, and hence

$$V_1 = V_1(F^B) = b/1 + r \quad (13)$$

At this point, the stock options F of firm A^* 's top executives are

$$F^A(M_{n+1}^A) = \begin{cases} (\gamma_1 + \gamma_2) & \text{if } F^* < F^A \leq a \\ \text{and} & \\ \gamma_1 b + \gamma_2 a & \text{if } F^A \leq F^* \end{cases} \quad (14)$$

while those of firm B^* are

$$F^B(M_{n+1}^B) = \begin{cases} \gamma_1 a + \gamma_2(b - L) & \text{if } F^B > F^* \\ \text{and} & \\ \gamma_1 b + \gamma_2 b & \text{if } F^B \leq b \leq F^* \end{cases} \quad (15)$$

The top executives may resort to a particular strategy in order to spread confidence

¹The commercial exploitation of the new invention should in fact determine extra-profits to the firm.

in the market concerning expected returns on I_{RD} : they attract investors by increasing their total equity holdings, in this way signalling their confidence in the R&D project which is about to be undertaken.

Let m_{n+1} be the additional equity issued when the firm is planning to undertake an R&D project. Only an amount i of the new equity m_{n+1} such that $0 < i < m_{n+1}$ will be sold to incumbent and/or new shareholders, while an amount $(m_{n+1} - i)$ will be bought by its top executives. This is a typical game of reputation (cf. Friedman, 1986), where a *closed loop* strategy is available to the participants. In fact, the top executives decide to buy an amount $(m_{n+1} - i)$ of equity when they discover that the potential outside investors are not interested in the new equity, whereas the outside investors decide to buy the amount i of new equity on the basis of information which has become available after the beginning of the game, i.e. when the top executives have bought back an amount $(m_{n+1} - i)$ of the new equities. The equilibrium solution referred to in the game is a Nash equilibrium.

PROPOSITION 3. *Incumbent and potential equity holders lack confidence that the undertaking of an aggressive R&D strategy will be beneficial to the firm. In this case top executives increase their equity share to spread confidence among equity holders over the firm's investment strategy.*

Proof. Let V^* be the face value of the firm's equity and

$$\sum_{i=1}^{n+1} m_i = (M_{n+1})V^* \quad (16)$$

the total value of the firm's equity. If the issue of new equity is linked with an innovation-oriented R&D project, by buying a significant amount of new equity, the equity-holding top executives signal to outsiders their confidence in the results of the new project. This will enable them to change their level of stock options in period 2, when extraordinary profits are achieved. The outsider and/or the incumbent shareholder will now be willing to pay the amount $(m_{n+1} - \lambda)V^*$ to buy the fraction of new equity $(m_{n+1} - \lambda)$.

In period 2, an increase in firm value takes place which brings direct benefit to the equity-holding top executives. This compensates them for the additional expenditures they have been forced to make in order to attract incumbent shareholders and/or outside investors to the new project.

5. CONCLUSIONS

This paper has employed standard static agency models to analyze the financial structure of firms engaged in aggressive R&D strategies aimed at developing specific product innovations. R&D investment has been treated as a typical case of asset specificity *à la* Williamson, one able to affect the firm's choice of its financial structure. It has thus been possible to use formal models to describe the financial strategies of both innovating small firms (NTBFs) and large corporations (PEPHHTFs). Such models provide a better understanding of the behaviour of Schumpeterian entrepreneurs and corporate top executives, and they also enable the analyst to employ qualitative data from the firm when investigating the set of processes and decisions involved in the undertaking of R&D projects. Regarding the financing of aggressive R&D carried out by NTBFs, the paper's major conclusions relate to two kinds of optimal contract: those which allow R&D financing contracts to be developed where

the sharing rules are independent of the agent's action; and those where the sharing rules are independent of both the agent's action and the specific assets involved in the transaction. Regarding PEPHHTFs undertaking aggressive R&D, the paper has pointed out that in this case too equity represents the optimal financing strategy, and that top executives increase their equity share as a signalling device to attract new and incumbent shareholders.

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