THE WILLIAM DAVIDSON INSTITUTE
AT THE UNIVERSITY OF MICHIGAN BUSINESS SCHOOL

Financing Mechanisms and R&D Investment

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Working Paper Number 180
July 1998

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Presented at the International Workshop in Transition Economics
A CEPR/WDI Workshop Hosted by CERGE-EI
Prague, 9/12 July 1998

Financing Mechanisms and R&D Investment [1]

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Abstract

This paper analyzes how financial institutions affect efficiency in R&D investments by providing a new contractual foundation for soft budget constraints. We show that inefficient elements (informational asymmetries and conflicts of interest among co-investors) in multi-investor financing can be used as a commitment device to stop bad projects which are discovered ex post. In the case of single investor financing (such as internal financing), however, the commitment device does not exist. Our theory predicts that optimally many investors should finance a R&D project if there are high uncertainties. Otherwise, internal financing is preferable. In addition, an institutional cost affects firm decisions and efficiency in R&D investments.

[1] We thank Masahiko Aoki. Patrick Bolton. Charles Goodhart. Oliver Hart. John Moore. Mark Schankerman. and John Sutton for helpful discussions: Jian Tong for research assistant: and especially Nancy Hearst for editorial help. In particular. we thank Eric Maskin for numerous invaluable comments and advice on this project. All remaining errors are our own.

INTRODUCTION

It has long been observed that economic institutions play important roles in technological progress and economic growth (e.g. Schumpeter, 1934, 1950). A closely related observation is that "idea-rich small firms originate a disproportionate share of innovations" (Scherer, 1992).[2] Numerous anecdotes suggest that small bio-tech companies do better than their large counterparts in R&D.[3] A similar picture can also be found in the computer, tele-communication, and other high-tech industries.[4] However, theoretical analysis of the impact of economic institutions on technological change is lacking.

One of the key factors affecting the efficiency of large and small firm R&D is financing. Early on, Schumpeter emphasized small firms' advantages in originating innovations (Schumpeter, 1934); while later he argued that large corporations are

[2]In the U.S., firms with 500 employees or less accounted for about 40 percent of all technical innovations in manufacturing in 1982 (Acs and Audretsch, 1988). A majority of the 100 most important innovations during the 1900-1950 period were intoduced by small firms (Jewkes, Sawer and Stillerman, 1969). Among 21 recent types of major software, 18 originated with small start-up firms, although the best-selling software was marketed by large established firms (Prusa and Schmitz, 1991).

[3]In 1994, 1995, and 1996, Merck, the best performing large pharmaceutical company (in terms of Dow performance) in the U.S. spent $1.2 billion, $1.3 billion, and $1.5 billion respectively for R&D; and respectively developed 10, 8, and 8 new drugs (in late-stage clinical trials). In contrast, small firms developed more drugs than Merck, but spent far less. In those years, 130 publicly traded small bio-tech companies in the U.S. spent $3.1 billion, $3.4 billion, and $3.9 billion; and respectively developed 60, 100, and 220 new drugs (Fortune, No. 6, Mar. 31, 1997).

[4]An overwhelmingly large majority of today's major computer companies, such as Intel, Microsoft, Apple Computer, Digital Equipment, Compaq Computer, Lotus Development, and Sun Microsystems were all small firms and were financed by outside investors (e.g., venture capitalists) in the period of 1970s and 1980s. Now Intel and Microsoft are larger than IBM. However, the amount of investment involved in all of these small firms together is less than that in one large firm. For example, in 1988 IBM's investment for R&D and capital expenditures was about $9 billion, while in the same year the total investment for R&D and capital expenditures from U.S. professional venture capitalists to small firms in all industries, including computer and bio-tech industries, was only about $3 billion (Sahlman, 1990). The spinning-off of Bell Laboratories, the largest and one of the most successful research groups in industry, from AT&T in the mid-1990s may be another example of the limitations of large corporations in R&D.

able to do better than small firms in terms of innovation by providing internal funds (Schumpeter. 1950). As a matter of fact. large firms generally are not (or are less) constrained by wealth to finance R&D projects and indeed their R&D projects are mostly internally financed.[5] In comparison. a typical small high-tech firm is financed externally by many investors. such as large companies, venture capitalists, and others.[6]

However. the above noted observations are puzzling. This is because it has been well argued that the informational asymmetries between a firm and its investor(s) will make external financing more costly due to moral hazard and adverse selection problems (Arrow. 1962; Stiglitz and Weiss. 1981; Myers and Majluf, 1984; and Kemien and Schwartz, 1978). Particularly, when there are more investors. the problem will be exacerbated. Moreover. given that a R&D project involves a large sunk cost (low liquidation value). with multi-investor external financing the moral hazard and adverse selection problems are more severe (Bernanke and Gertler. 1989; Calomiris and Hubbard. 1990; Hubbard and Kashyap. 1990).

In this paper we provide a theory to attempt to explain this contradiction. With high uncertainties and high sunk costs in R&D activities. the efficiency of R&D in-

[5] Several independent investigations find that for large firms. such as Fortune 500 firms. there is no correlation between internally financed investments and R&D (Scherer. 1965; Mueller. 1967; Elliot. 1971). or there is a very low correlation (Hall. 1992). Consistent with these results. more recent work finds that the larger the firm. the lower the correlation (Himmelberg and Petersen. 1994).

[6] It has been documented that a typical venture-capital-backed firm is financed externally by multi-investors. For example. all 433 venture-capital-backed firms which had initial public offerings between 1978 and 1987 in the U.S. (according to Barry et al. (1990) this is an exhaustive data set for this category) had many investors. including venture capitalists (VC). large firms. and other funds. The VC shares averaged 34.3 percent for each firm's equity holdings; moreover. a typical firm in this data set involved more than one VC: each firm averaged three venture capital investors. Moreover. on average. two of the VCs sat on the board of a typical small high-tech firm (an average of one-third of all seats) (Barry et al.. 1990). A survey of venture capital in New England (one of the two areas in the U.S. with the highest VC concentration). shows the average number of investors for each high-tech start-up firm (more than one-half of which were in bio-tech) was close to four. and only approximately one-eighth of the surveyed firms were financed by one investor (*Boston Globe*. September 19. 1993). Schilit reported that most venture capital firms coinvest or syndicate with one another. and that between 70% and 90% of the venture capital backed projects had multi-investors (Schilit. 1991. pp.76-77).

vestment is affected by the way that the R&D projects are selected. Because the uncertainties associated with R&D projects can only be reduced when a project is carried out, ex post selection is more effective than ex ante selection. However, an ex post screening mechanism requires a commitment that a bad project will be stopped even when refinancing of a bad project is ex post profitable (which means that the earlier sunk costs of the project are not taken into consideration in an ex-post decision) (Qian and Xu, 1998). We argue that multi-investor financing[7] can be deployed as a commitment device to reject bad projects when they are discovered ex post. However, in single investor financing (internal financing is a special case of single investor financing) the commitment device, i.e. the ex post screening mechanism, does not exist.

In our model there are numerous entrepreneurs and large corporations. While the entrepreneurs have innovative ideas, they lack necessary the wealth to finance them; the large corporations are wealthy enough to finance at least one innovation internally (or externally jointly with other investors of their choice). We consider that all projects can be either of a bad type, which requires three-periods of investment and is ex ante unprofitable, or of a good type, which only requires two-periods of investment and is ex ante profitable. When a R&D project is financed by multi-investors, there is an informational asymmetry and conflicts of interest between the investors. Informational asymmetries and conflicts of interest between the co-investors increase the ex post cost of refinancing a bad project.[8] This ex post cost can help the investors commit to terminating a bad project (Proposition 1). Moreover, such a commitment can deter entrepreneurs from continuing a bad project after they privately learn whether it is good or bad. Thus the commitment can effectively solve the informational asymmetry between the entrepreneur and the investors and thus can deter bad projects in a timely fashion (Proposition 2). In contrast, if a project

[7] Obviously, multi-investor financing implies external financing; moreover, in reality, in most cases of external financing there are multi-investors (e.g., Barry et al., 1990; Schilit, 1991).

[8] It is documented that information problems and conflicts of interest between investors destroy values when a firm is under re-organization (e.g., Weiss and Wruck, 1998; for a court case of converting a reorganization into liquidation due to conflicts of interest between investors see U.S. Bankruptcy Court, 1997).

is financed by a single investor (e.g. internal financing within a large firm). the commitment device does not exist (Proposition 3). Thus. a large firm does not have an effective ex post screening mechanism if its R&D projects are financed alone (that is. internally).

The trade-off between the costs and benefits of multi-investor financing and that of single investor financing (e.g. internal financing) in our model allows us to analyze optimal R&D project selection and financing. Our theory predicts that if a R&D project has high uncertainties and requires high investments at later stages (such as in a typical high-tech project). co-financing by multi-investors is optimal. Otherwise (such as in the case of engineering perfection). financing R&D projects internally within a large corporation is optimal (Proposition 5). Moreover. in an economy where the institutional costs of external financing are high. R&D investment is efficient only in projects of low uncertainty. such as those of imitation or engineering perfection (Proposition 6).

Our theory is built upon the concept of soft budget constraints (Kornai. 1980). due to an economic system's lack of commitment to terminate an unprofitable project ex post (Dewatripont and Maskin. 1995). This paper attempts to provide a new contractual foundation for "soft budget constraints." which allows us to expand the soft budget constraint paradigm to many other important issues. such as financing decisions of large corporations. We show that ex post inefficiency caused by informational asymmetries and conflicts of interest between investors can be used as a commitment device. However. in a centralized economy. either due to the fact that there is only one investor — the state bank — or due to high institutional costs of external financing outside of the state bank. a soft budget constraint prevails.

Following Dewatripont and Maskin (1995). we emphasize the role of ex post inefficiency as a commitment device. A key difference of our model is that investors are not constrained by liquidity of wealth to finance a project alone if they so choose.[9] In the spirit of Hart and Moore (1995) and Bolton and Scharfstein (1996). we con-

[9]Moreover. in Dewatripont and Maskin's model the multi-investors are involved sequentially and thus the asymmetric information between investors is generated sequentially: while in our model multi-investors are involved simultaneously and thus the asymmetric information is generated simultaneously.

sider the conflicts of interest between the multi-investors. However, we focus on the commitment problem and endogenize a renegotiation-proof institution.

The rest of the paper is organized as follows. In Section 2 we set up the model. In Section 3 we analyze the model, and more specifically we endogenize hard (soft) budget constraints and analyze their ex ante effect on the entrepreneurs' incentives. Section 4 compares the efficiencies of internal and external co-financing. Finally, Section 5 discusses the conceptual implications of our results, particularly on economic growth, and presents some concluding remarks.

MODEL

We consider an economy where there are numerous entrepreneurs and investors.[10] Each entrepreneur has a new idea for an invention or an innovation, which can be taken as a R&D project, but he has no wealth to finance it. There is no wealth constraint on the investor side to finance R&D projects. When an entrepreneur proposes a project to an investor, the investor can either finance the project alone (in the case that the investor is a large firm, the firm can buy the project and hire the entrepreneur as an employee), or the investor can co-finance the project with other investors (we model the case of two investors but it can be easily extended to the case of more than two investors). We refer to the former as a case of single investor financing, and to the later as a case of multi-investor co-financing.

We suppose that among all the projects proposed by entrepreneurs, $1-\lambda$ percentage of the projects are of the good type and λ percentage of the projects are of the bad type. A good project takes two periods to finish and requires a total investment of $I_1 + I_2$, where I_t is the required investment in period t and I_1 and I_2 are sunk.[11] A bad project takes three periods for completion and requires a total investment of

[10] In this paper we do not distinguish between investors and large firms which have a lot of wealth to finance R&D projects. In fact, large corporations often run venture capital subsidiaries which are a major source of venture capital (e.g. Schilit (1991, p.68)). Moreover, the venture capital subsidiaries of large firms have "deep pockets" and have access to additional sources of capital from the parent company if attractive opportunities develop.

[11] We can regard zero as a normalized liquidation value. However, if we allow I_1 and I_2 to be sunk only partially and the liquidation value to be positive, our results will not be altered.

$I_1 - I_2 + I_3$. For each project, there are two signals, $\tilde{s}_A$ and $\tilde{s}_B$, on different aspects of the project that can be observed by the investors in the first two periods. If the two signals $\tilde{s}_A$ and $\tilde{s}_B$ are observed by the investors, they will receive a positive profit from a good project, i.e., $\hat{V} > I_1 - I_2$.[12]

We assume that investors A and B specialize in technologies A and B respectively. With their specialties, investor A can observe $\tilde{s}_A$ with no costs, but has to pay a cost c_A to observe signal $\tilde{s}_B$; and investor B can observe $\tilde{s}_B$ with no costs, but has to pay a cost c_B to observe signal $\tilde{s}_A$. Therefore, in the case that investors A and B co-finance a project, they can collect $\tilde{s}_A$ and $\tilde{s}_B$ without incurring costs. In the case of single investor financing, investor J will collect signal $\tilde{s}_J$ and pay cost c_J to collect information $\tilde{s}_{\bar{J}}$, where $J, \bar{J} = A, B$, and $J \neq \bar{J}$.[13]

If a project is a good one, it will be completed at date 2 no matter whether it is financed by one investor alone or it is co-financed by two investors. That is, from the perspective of the financing decision there is no difference between these two financing options. In the rest of the paper, we will focus on the case of bad projects.

We suppose that the returns from a completed bad project under the best possible reorganization strategy, V, generated at date 3, are greater than those of the last period investment; but lower than the sum of the last two periods' investment, i.e.,

[12] There are many reasons why information collected by investors affects the value of a project: in the case that the investors are large firms and intend to use the technology developed by the project, the information may have a direct value; in the case that the investors are venture capitalists, the information may affect the value of the project when it goes public.

[13] The assumptions on signal $\tilde{s}_J$ are not critical to the model. Without these assumptions there needs to be an item in the contract (or some other reason) to prevent the co-investors from sharing information. We believe that our assumptions are realistic, and numerous illustrative examples can be provided. For instance, IBM and Kodak may have interests to co-finance a R&D project for a new type of memory chip since it could have a great impact on the development of computers and digital cameras (similarly, several large pharmaceutical companies may have various interests in co-financing a new bio-tech project which may have a revolutionary impact on the development of a variety drugs to treat diabetes or cancers, etc.). Due to their idiosyncratic interests and specialties, IBM and Kodak may derive different information from the same project. Similar illustrations may also be provided for the co-financing of specialized financial institutions, such as co-financing provided by different venture capital firms specializing in various technologies; or co-financing provided by large firms or mutual funds, etc.

$I_3 < V < I_2 + I_3$. Obviously, it is not efficient to undertake a bad project ex ante, but it is efficient to refinance it ex post. Therefore, at date 2 a decision has to be made by the investor(s) regarding a bad project: either to refinance it or to liquidate it. To focus on this point, we suppose that ex ante all projects are worthy of being financed, and we assume that the discount rate is zero.

With respect to information, we assume that ex ante the distribution of the types of all projects is common knowledge, but neither the investors nor the entrepreneurs know precisely the type of each project. At date 1, after working on a project for one period the entrepreneur discovers the type of the project, but the investor(s) still do not know its type. That is, there is an information asymmetry between the entrepreneur and the investor(s) at date 1 as long as the entrepreneur does not reveal the truth.[14]

We assume that an entrepreneur gets a private benefit b_t from working on a project, where t denotes the date when the project is either completed or terminated at $t = 1, 2, 3$. Specifically, if the entrepreneur quits the project at date 1, he gets a low private benefit, $b_1 > 0$. At date 2, a completed good project generates a private benefit, $b_{2g} > b_1$, to the entrepreneur. A bad project will be liquidated or reorganized at date 2. If it is liquidated, the entrepreneur gets a still lower private benefit b_{2b}, where $0 \leq b_{2b} < b_1$. If a bad project is refinanced, it will be completed at date 3 and it will generate a private benefit b_3 to the entrepreneur and $b_{2g} > b_3 > b_1 > b_{2b} \geq 0$.

We assume that there are two strategies to reorganize a bad project during the third period, but only one of them can generate a profit ex post. The right decision on the selection of strategies depends on signals s_A and s_B, where $s_J \in [\underline{s}, \overline{s}]$, $\underline{s} < \overline{s}$ and $J = A, B$. Here, we suppose that signal s_J can only be observed by the investor who has observed $\overline{s}_J$ earlier, after I_3 is invested.[15]

We assume that strategy b makes the project ex post profitable if signal s_A is higher

[14] This is a realistic assumption even in cases where the project is financed internally within a large corporation or by one venture capitalist who monitors closely, because finance experts may not be equipped to make judgments on the nature of a project at an early stage.

[15] The assumption that s_J can only be observed after I_3 is invested is not essential in the model. Its role is to rule out mixed strategies which will complicate the model without providing more insight, since it is rare to observe mixed strategies in financial decisions. Therefore, this assumption is realistic.

than s_B, i.e., $s_A > s_B$, and strategy a makes the project ex post profitable if signal s_A is lower than s_B, i.e., $s_A < s_B$. Formally,

$$\begin{cases} V^b(s_A, s_B) - I_3 > 0 > V^a(s_A, s_B) - I_3, \text{ when } s_A > s_B; \\ V^b(s_A, s_B) - I_3 = V^a(s_A, s_B) - I_3 = 0, \text{ when } s_A = s_B; \\ V^a(s_A, s_B) - I_3 > 0 > V^b(s_A, s_B) - I_3, \text{ when } s_A < s_B. \end{cases} \quad \text{(A-1.1)}$$

where $V^j(s_A, s_B)$ is the total payoff of the project reorganized by strategy j. In the case of co-financing, we denote the payoff under strategy j to investor J by $V_J^j(s_A, s_B)$, and $V^j(s_A, s_B) = V_A^j(s_A, s_B) + V_B^j(s_A, s_B)$, where $j = a$ or b and $J = A$ or B.

Moreover, we assume that the outcome of a wrong strategy is bad enough that the expected net payoff of randomizing between the two strategies is worse than liquidation, i.e.,

$$qV^b(s_A, s_B) - (1-q)V^a(s_A, s_B) - I_3 < 0 \qquad \text{(A-1.2)}$$

where $q = \Pr(s_A > s_B)$.[16]

Finally, we suppose that a higher s_J is more beneficial to investor J if the project is reorganized under strategy j than under another strategy. That is, for any $s^h > s^l$,

$$V_A^a(s_A^h, s_B) - V_A^a(s_A^l, s_B) > V_A^b(s_A^h, s_B) - V_A^b(s_A^l, s_B) > 0, \qquad \text{(A-2.1)}$$

$$V_B^b(s_A, s_B^h) - V_B^b(s_A, s_B^l) > V_B^a(s_A, s_B^h) - V_B^a(s_A, s_B^l) > 0. \qquad \text{(A-2.2)}$$

In the case of multi-investor co-financing, ex post the co-investors might share their private information as long as they decide to reorganize a bad project. This is equivalent of saying that B buys s_A from A, or A buys s_B from B. Without a loss of generality, however, investor B will buy the private information s_A from investor A only when the price that B has to pay, $T(s_A, s_B)$, is not too high.

Now we summarize the timing of the game as follows:

- Date 0: All parties know the distribution of the projects but none know which project is good and which is bad. The investor(s) offer a take-it-or-leave-it contract to the entrepreneur. If the contract is signed the investor(s) will invest I_1 units of money into the project during period 1, and the investor(s) will start to observe $\tilde{s}_A$ and $\tilde{s}_B$.

[16] Any randomization based on $\tilde{q} \in [0, 1]$ and $\tilde{q} = q$ cannot get a better result than (A-1.2).

- Date 1: By working on the project, the entrepreneur becomes aware of the type of the project, but the investor(s) still do not know its type. If the entrepreneur stops the project he gets a private benefit $b_1 > 0$: otherwise, if the project is to be continued, I_2 units of investment are required from the investor(s).

- Date 2: The type of project becomes public knowledge:

  - If the project is a good type, it will be completed on date 2 and will generate a return of $\widehat{V}$ to the investors after they observe $\bar{s}_A$ and $\bar{s}_B$: and a private benefit of $b_{2g} > b_1$ to the entrepreneur;

  - if it is a bad project, a decision whether to liquidate or to reorganize has to be made.

    * If the project is liquidated the investor(s) get zero and the entrepreneur gets $b_{2b} < b_1$; otherwise,

    * if the project is reorganized, I_3 units of investment are required.

- After investing I_3, signals s_A and s_B are observed by the investor(s) and a reorganization strategy is chosen based on the signals.

- Date 3: A bad project is completed and generates a return of V to the investor(s) and a return of $b_1 < b_3 < b_{2g}$ to the entrepreneur.

In the following we present a concrete example to illustrate how our model relates to reality.

Example 1 : *Suppose AVC, a venture capital fund, and BMI, a large computer company, are interested in financing an entrepreneurial start-up firm called 'Super-Chip.' We refer to 'Super-Chip' as SC, AVC as investor A, and BMI as investor B. A's interest is to make the project go public and A is able to observe signals related to SC's IPO value, $\bar{s}_A$, without incurring an extra cost (an extra cost means some cost more than the investments committed to the project): while B's interest is to share the technology developed by SC and it is able to observe relevant signals of SC's technological advance, $\bar{s}_B$, without incurring an extra cost. Investor B needs $\bar{s}_B$ to decide how to use the new products and investor A needs $\bar{s}_A$ to promote SC* *in the IPO. If the project is financed by A or B alone, then the investor has to pay an additional cost to acquire all information, including that about which she has no expertise to observe (e.g. a consultant may need to be hired to observe the signal). But if the project is financed by A and B together, then A and B will take care of the relevant signals, based on their expertise, without having to pay anything. In the case that the SC project is a bad one (for example, the technology does not work unless some more work is done), there are two possible strategies a and b to reorganize the project: strategy a will forego exploring the technologies which are most useful to BMI but will make the IPO value and the refinancing cost of SC break even, which will improve AVC's reputation as a venture capitalist: and strategy b will forego the plan to sell SC equities to the public but will make SC technology useful to BMI. That is, strategy a benefits AVC but hurts BMI: and strategy b benefits BMI but hurts AVE.*

INVESTMENT DECISIONS

In our model, because the earlier investments are sunk, refinancing a (bad) project after date 2 is ex ante inefficient although it can be ex post efficient (by (A-1.1)). Therefore, only those institutions that are able to commit to stopping bad projects are efficient in dealing with highly uncertain innovative projects. In this section, we show that multi-investor co-financing provides a commitment device to stop bad projects but single investor financing does not.

Multi-investor Co-financing

In analyzing the investment decision with regard to multi-investor co-financing, we start with the refinancing decision at date 2 and then consider the entrepreneur's investment decision at date 1. At date 2, when the two investors discover that the project is a bad one, they should decide either to liquidate or to reorganize (i.e. to assign a probability of p[17]). If they decide to reorganize the project, they will invest I_3. Then signals s_A and s_B are observed by the two investors respectively and they need to decide what reorganization strategy should be selected (i.e., the investors assign probabilities of $1 - q(s_A, s_B)$ and $q(s_A, s_B)$ to select reorganization strategy

[17] For example, if their decision is definitely to liquidate the project, they assign $p = 1$.

a and b respectively).

We now show that the asymmetric information between the two investors will make refinancing ex post inefficient, thus they will terminate bad projects at date two.

Proposition 1 *Under assumptions (A-1) and (A-2), all bad projects with multi-investor co-financing will be liquidated at date 2.*

Proof. We show that if each investor J is able to observe only s_J ($J = A$ or B) after I_3 is invested, under (A-1) and (A-2) there is no efficient incentive-compatible scheme $q(s_A, s_B)$ and $T(s_A, s_B)$ which can induce investor J to tell the true value of s_J; thus there is no efficient scheme to reorganize the project. As a result, the investors choose to liquidate the bad project.

In the following proof, we first analyze investor A's incentive problem. For this purpose, we fix s_B at an arbitrary value $s^* \in (0, 1)$ and s_A can be $s_A^h > s^*$ or $s_B^h < s^*$.

Given compensation scheme $T(s_A, s_B)$ and strategy $q(s_A, s_B)$, investor A should tell the truth only if the expected payoff of doing so is not worse than false reporting. That is, the incentive compatibility (IC) condition is:

$$\begin{aligned} & q(s_A, s_B)V_A^b(s_A, s_B) + (1 - q(s_A, s_B))\, V_A^a(s_A, s_B) - T(s_A, s_B) \\ \geq\ & q(\hat{s}_A, s_B)V_A^b(s_A, s_B) + (1 - q(\hat{s}_A, s_B))\, V_A^a(s_A, s_B) - T(\hat{s}_A, s_B), \end{aligned}$$

where $\hat{s}_A$ is the false reporting of the signal.

In the case that the information $s_A = s_A^h > s^*$, the IC is

$$\begin{aligned} & q(s_A^h, s_B)V_A^b(s_A^h, s_B) + \left(1 - q(s_A^h, s_B)\right) V_A^a(s_A^h, s_B) - T(s_A^h, s_B) \\ \geq\ & q(s_A^l, s_B)V_A^b(s_A^h, s_B) + \left(1 - q(s_A^l, s_B)\right) V_A^a(s_A^h, s_B) - T(s_A^l, s_B), \end{aligned}$$

that is,

$$\begin{aligned} T(s_A^h, s_B) - T(s_A^l, s_B) \ \geq\ & \left(q(s_A^l, s_B) - q(s_A^h, s_B)\right) V_A^b(s_A^h, s_B) - \\ & \left(q(s_A^h, s_B) - q(s_A^l, s_B)\right) V_A^a(s_A^h, s_B). \qquad (1) \end{aligned}$$

The IC for A's information $s_A = s_A^l < s^*$ is:

$$\begin{aligned} & q(s_A^l, s_B)V_A^b(s_A^l, s_B) + \left(1 - q(s_A^l, s_B)\right) V_A^a(s_A^l, s_B) - T(s_A^l, s_B) \\ \geq\ & q(s_A^h, s_B)V_A^b(s_A^l, s_B) + \left(1 - q(s_A^h, s_B)\right) V_A^a(s_A^l, s_B) - T(s_A^h, s_B). \end{aligned}$$

that is,

$$\left(q(s_A^l, s_B) - q(s_A^h, s_B)\right) V_A^b(s_A^l, s_B) + \left(q(s_A^h, s_B) - q(s_A^l, s_B)\right) V_A^a(s_A^l, s_B)$$
$$\geq \; T(s_A^h, s_B) - T(s_A^l, s_B). \qquad (2)$$

The IC conditions (1) and (2) imply

$$\left(q(s_A^l, s_B) - q(s_A^h, s_B)\right) V_A^b(s_A^l, s_B) - \left(q(s_A^h, s_B) - q(s_A^l, s_B)\right) V_A^a(s_A^l, s_B)$$
$$\geq \; \left(q(s_A^l, s_B) - q(s_A^h, s_B)\right) V_A^b(s_A^h, s_B) + \left(q(s_A^h, s_B) - q(s_A^l, s_B)\right) V_A^a(s_A^h, s_B).$$

or,

$$\left(q(s_A^h, s_B) - q(s_A^l, s_B)\right)\left(V_A^a(s_A^h, s_B) - V_A^a(s_A^l, s_B)\right)$$
$$\leq \; \left(q(s_A^h, s_B) - q(s_A^l, s_B)\right)\left(V_A^b(s_A^h, s_B) - V_A^b(s_A^l, s_B)\right).$$

According to (A-2.1), $V_A^a(s_A^h, s_B) - V_A^a(s_A^l, s_B) > V_A^b(s_A^h, s_B) - V_A^b(s_A^l, s_B) > 0$. Thus, the incentive compatibility implies $q(s_A^h, s_B) \leq q(s_A^l, s_B)$, i.e., $q(s_A^l, s_B)$ should be non-increasing in s_A.

However, by (A-1), for any given s_B when s_A increases from $s_A < s_B$ to $s_A > s_B$, for any $q(s_A, s_B) = \bar{q}$, where $\bar{q} \in [0, 1)$ is a constant, the efficiency can be improved by increasing $\bar{q}$, i.e. by $\bar{q} + \varepsilon$, where $\varepsilon > 0$. Thus, efficiency requires $q(s_A, s_B)$ to be non-decreasing in s_A.

Therefore, the only possible scheme of $q(s_A, s_B)$ which may satisfy both IC and the efficiency requirement is to keep $q(s_A, s_B)$ constant, i.e. $q(s_A, s_B) = \bar{q}$. It is obvious that for any $\bar{q} \in [0, 1]$, reorganization based on any $\bar{q} \neq q = \Pr(s_A > s_B)$ is worse than q. However, by (A-1.2), a reorganization decision based on q is worse than liquidation.

The case of investor B can be proved by symmetry.

Given the above results, any randomization between liquidation and reorganization at date 2 will be worse than liquidation. Thus, the probability of liquidation is $1 - p = 1$. ■

This proposition says that when a bad project is revealed to the co-investors at date 2, there exists no efficient reorganization scheme which can be agreed upon by both investors. That is, as a result of the informational asymmetry and conflicts of interest between the two investors, multi-investor financing can serve as an ex post commitment device to stop bad projects.[18] This commitment to liquidate bad projects has a deterrent effect on entrepreneurs who are involved in bad projects. Afraid of further losses by hiding bad news, an entrepreneur with a bad project will choose to quit once he discovers it is a bad project because the losses incurred by quitting at date 1 are smaller than those at date 2, i.e. $b_{2b} < b_1$. Therefore we have the following result:

Proposition 2 *Under multi-investor financing, entrepreneurs will stop bad projects at date 1 'voluntarily.'*

Single Investor Financing

We again begin our analysis with the refinancing decision at date 2 and then consider the entrepreneur's investment decision at date 1. Note that under single investor financing, the investor will have all information s_A and s_B and will be able to use this information to choose an ex post efficient strategy to reorganize the project such that payoff $V^*(s_A, s_B)$ is greater than the ex post cost of refinancing, I_3. Therefore, the investor is not able to commit to terminating a bad project ex post.

Moreover, the fact that the investor cannot commit to terminating a bad project affects the entrepreneur's ex ante incentives to reveal information. When the entrepreneur at date 1 discovers that his project is a bad one, he expects that the project will always be continued and refinanced by the investor at date 2. Consequently, if he decides to quit the project, he gets private benefit b_1; if he decides to continue the project, the bad project will always be refinanced by the investor and will generate a private benefit $b_3 > b_1$ for the entrepreneur. Therefore, the entrepreneur will always choose to continue a bad project after he privately discovers its type. We record these results as the following proposition.

Proposition 3 *Under assumption (A-1), all single investor-financed bad projects will be refinanced, ex post.*

[18] Our theory of an ex post commitment device is in the spirit of Maskin (1992) which shows that information asymmetry between two parties can make auctions inefficient.

An interesting insight from this result reveals that without conflicts of interest and informational asymmetries on the investor side. single investor financing is not able to solve the asymmetric information problem between the investor and the entrepreneur due to the lack of a commitment to liquidate bad projects.[19]

In addition. our theory has an important implication for centralized economies. In a centralized economy. the state bank (or the government) finances all projects and collects all information. According to our theory. the state bank as the sole investor in R&D projects is not able to commit to terminating bad projects ex post. Therefore, there is a soft budget constraint in a centralized economy (Kornai. 1980; Dewatripont and Maskin. 1995).

EFFICIENCIES IN SINGLE INVESTOR AND MULTI-INVESTOR FINANCING

The above section shows the benefits associated with multi-investor financing. However. it is well known that relative to internal financing (a special case of single investor financing), external financing (multi-investor financing is often observed in external financing) may incur an additional cost. Finance literature provides many reasons for the additional cost of external financing. The most prevalent reason is that due to the asymmetric information between a firm and its investors in the case of external financing, there exist both moral hazard and adverse selection problems. As a result. external financing is more costly than internal financing and hence it is less efficient (Arrow. 1962: Stiglitz and Weiss. 1981: and Myers and Majluf. 1984; LaPorta. Lopez de-Silanes. Shleifer. and Vishny. 1997). Particularly, since a typical R&D project involves a large sunk cost (low liquidation value). with external financing the moral hazard and adverse selection problems in R&D projects are more severe (Bernanke and Gertler, 1989: Calomiris and Hubbard. 1990: Hubbard and Kashyap. 1990).

[19] This result is similar to that of Dewatripont and Maskin (1995). The major difference between their result and ours is that there is no wealth constraint on the investors in our model: moreover. in our model the two investors are involved simultaneously. while in their model the investors are involved sequentially.

In this section, by establishing the trade-offs between the benefits and costs associated with multi-investor financing, we analyze an optimal strategy for firms. To keep our model simple and to focus on our major contribution, we call the costs incurred by external financing an institutional cost. We denote the institutional cost of external financing as c and the cost of collecting signals in the case of internal financing (or single investor financing) as c^s. We assume that both c and c^s are exogenously given, and $c > c^s$.

According to Proposition 2, in the case of multi-investor financing in equilibrium, all bad projects will be dropped by the entrepreneur at date 1. Moreover, for any project proposed randomly from the project pool, with probability $1 - \lambda$ a project is a good one, generates an expected return $\widehat{V}$, and requires investments $I_1 + c - I_2 + c$; with probability λ a project is a bad one, generates an expected return V, and requires investment $I_1 - c$ only. Thus, the expected profits from multi-investor financing π^o are.

$$
\begin{aligned}
\pi^o &= (1-\lambda)(\widehat{V} - I_1 - I_2 - 2c) - \lambda(-I_1 - c) \\
&= -I_1 - (1-\lambda)(\widehat{V} - I_2) - (2-\lambda)c.
\end{aligned}
$$

Using Proposition 3, in the case of single investor financing, a bad project will definitely be refinanced. Given that with probability $(1 - \lambda)$ a project is a good one, generates an expected return $\widehat{V}$, and requires investments $I_1 - I_2$; and with probability λ a project is a bad one, generates an expected return V, and requires investments $I_1 - I_2 - I_3$, the expected profits from single investor financing are:

$$\pi^i = -I_1 - c^s - (1-\lambda)(\widehat{V} - I_2) + \lambda(V - I_2 - I_3).$$

The difference between the profits from single investor financing and the profits from outside co-financing is

$$\pi^i - \pi^o = -\lambda(I_2 - I_3 - V) - (2-\lambda)c - c^s.$$

In comparison, it is easy to see that if liquidation did not deter an entrepreneur from continuing a bad project at date 1, the expected payoff in multi-investor financing would be $\pi^o = (1-\lambda)(\widehat{V} - I_1 - I_2 - 2c)$. In such a case, liquidation would not be efficient. This is because

$$\pi^i - \pi^o = 2c - c^s - \lambda(V - I_3) > 0.$$

To summarize the result, we have the following:

Proposition 4 *Without a deterrent effect, liquidation alone is less efficient than reorganization. However, with a deterrent effect, the institution which commits to liquidation can be more efficient.*

Similar to the literature on bankruptcy (e.g., Aghion, Hart, and Moore, 1995), we show that liquidation per se can be less efficient than reorganization. But unlike the above, we emphasize ex ante expectational effects of different 'bankruptcy procedures.' We demonstrate that a commitment to liquidate bad projects plays a fundamental role in deterring entrepreneurs from hiding private information. Therefore, an institution which commits to liquidate bad projects may be more efficient.

However, even with a deterrent effect, multi-investor financing may still be less efficient than single investor financing. This is because the difference in the net benefits between single investor financing and multi-investor co-financing depends on the extra cost of multi-investor financing, c;[20] the uncertainties of the projects, λ; the required investment in the second and third periods, I_2 and I_3; and the realized value of a bad project when it is completed, V. In the following we conduct a comparative static analysis of the difference between π^i and π^o.

The equation $\pi^i - \pi^o = -\lambda(I_2 - I_3 - V) - (2 - \lambda)c - c^s$ shows the trade-off between single investor and multi-investor co-financing. On the one hand, there is a savings of investment in a bad project under multi-investor financing, $\lambda(I_2 - I_3 - V)$. On the other hand, there is an extra cost under multi-investor financing, $c(2 - \lambda)$. From this trade-off, we solve for a threshold level λ^* which makes $\pi^i = \pi^o$. Then we have

$$\lambda^* = \begin{cases} \frac{2c - c^s}{c - I_2 - I_3 - V}, & \text{if } c < I_2 - I_3 - V - c^s; \\ 1, & \text{if } c \geq I_2 - I_3 - V - c^s. \end{cases}$$

[20] The institutional cost of external multi-investor financing varies depending on the financial institution (examples can be find in LaPorta, Lopez de-Silanes, Shleifer, and Vishny, 1997).

such that if λ, the probability that a project is bad, is greater than λ^*, multi-investor co-financing is more efficient than single investor financing, and vice versa. Investigating λ^* leads to the following lemma.

Lemma 1 *If $c - c^s = 0$, multi-investor financing is always more efficient: if $c - c^s \geq I_2 - I_3 - V$, single investor financing is always more efficient: if $0 < c - c^s < I_2 + I_3 - V$, the more efficient financing mechanism depends on λ.*

This lemma shows extreme cases where the efficiency of financing is independent from the uncertainty of the project.

Against the threshold level λ^*, it follows:

$$\begin{cases} \pi^i > \pi^o, & \text{if } \lambda < \lambda^*, \\ \pi^i \leq \pi^o, & \text{if } \lambda \geq \lambda^*. \end{cases}$$

It is also easy to see that $\frac{\partial}{\partial \lambda}\{\pi^i - \pi^o\} < 0$. That is, if the budget constraint is hard, the advantage of multi-investor financing vis-a-vis that of single investor financing increases with the uncertainty of the project type. Therefore, we can summarize the following results regarding the optimal strategies for R&D project financing when a firm faces different degrees of uncertainties.

Proposition 5 *If $0 < c - c^s < I_2 + I_3 - V$, there is a critical level of uncertainty of the project, $\lambda^* = \frac{2c - c^s}{c + I_2 + I_3 - V}$, such that*

1. *if uncertainty is low, that is, $\lambda < \lambda^*$, single investor financing is more efficient than multi-investor co-financing;*
2. *if uncertainty is high, that is, $\lambda > \lambda^*$, multi-investor financing is more efficient;*
3. *the advantage of multi-investor co-financing over single investor financing increases in λ.*

Moreover, a comparative static analysis of the difference between π^i and π^o leads to:

Proposition 6 *If $0 < c - c^s < I_2 - I_3 - V$, the advantage of multi-investor financing over single investor financing increases as*

1. *the institutional cost of multi-investor financing, c, decreases;*

2. *the uncertainty of the project, λ, increases;*

3. *the costs of required investment at the second and third periods, I_2 and I_3 respectively, increase; and*

4. *the final return of a bad project, V, decreases.*

The above proposition sheds some light on the relationship between financing institutions and technical changes. The creation and development of modern financial intermediaries, motivated by a demand to reduce the costs of external financing, have led to a steady increase in the share of multi-investor financing in developed economies. Venture capital financing may be an example. Moreover, most high-tech projects, in such fields as computers, software, bio-tech, etc., are characterized by high uncertainties. Thus, the concentration of venture capital financing in high-tech industries matches our results well.

Furthermore, when the uncertainty of a project is lower, and/or the costs of required incremental investments decrease, and/or the final return from a bad project increases, our results indicate that single investor financing is more efficient. These predictions are consistent with the observation that large corporations tend to purchase innovative projects at later stages when uncertainties are much lower and the final returns from bad projects are not too low. Our results thus can also explain why cash-rich large corporations devote more attention to perfection-related or cost-reduction-related innovation and less attention to new-product-related innovation (Scherer, 1991, 1992), and why corporate executives tend to restrict their R&D activities in less uncertain and less novel projects (Jewkes et al., 1969; Nelson et al., 1967).

If cash-rich large corporations are interested in investing in R&D, then our theory shows out that it is in their interest to co-finance such projects externally. This may shed some light on why in the 1970s IBM contracted out its first generation PC CPU chips to Intel and its operating system to Microsoft; why AT&T did not choose to keep Bell Laboratories for its R&D; and why Merck did not take over one-third of the publicly traded small bio-tech companies which produced almost ten times more new drugs, though spending approximately the same amount of money for R&D.

CONCLUDING REMARKS

In this paper we argue that the inefficient elements in multi-investor co-financing, such as informational asymmetries and conflicts of interest among co-investors, can be strategically employed to prevent renegotiation, and thus can help co-investors commit themselves to terminating bad projects which can only be discovered ex post. With such a credible threat, multi-investor co-financing deters bad projects at an early stage. In contrast, if a R&D project is internally financed and there are no informational asymmetries or conflicts of interest on the investor side, the commitment device does not exist. A disadvantage of multi-investor financing compared with single investor financing is an extra cost caused by moral hazard and adverse selection problems, which measures the cost of external capital markets; this is viewed as an institutional cost. Based on the trade-off between the costs and benefits of multi-investor financing vs. single investor financing, our theory explains optimal R&D project selection and financing.

Our theory sheds light on the stylized fact that large companies usually finance R&D projects internally and they tend to finance safer projects. Our theory explains how the very attractive feature of a large company – that is, no binding financial constraints for R&D and, no serious conflicts of interest in financial decisions – prevents them from committing to an efficient ex post selection of projects. The lack of an effective ex post screening mechanism in large corporations makes them tend to choose safer innovative projects. Indeed, this insight is consistent with empirical studies which show that large corporations tend to maintain the stability of their R&D organization; moreover, their R&D budgeting is usually not based on individual projects, which implies a smoothing of revenue across projects (Mansfield, 1968, p.62, and Reeves, 1958).

Our theory has implications for economic growth. The central role of technological change on economic growth has been recognized since Schumpeter (1934). In the classical Solow growth model, R&D has been viewed as a power engine for economic growth. In new growth theory, the role of R&D on growth is endogenized through inputs to technological change while institutions are exogenously given (Romer, 1990; Grossman and Helpman, 1991). Nevertheless, we observe institutions playing important roles that affect the efficiency of R&D and growth. Despite its early success in R&D, the former Soviet Union did poorly in high-tech areas and in growth, despite having the world's highest percentage of GNP allocated to R&D from the mid 1970s to the late 1980s. Moreover, from a different perspective the 'East Asia miracle' may also show that institutions play important roles in R&D, thus in growth. Recent developments in growth theory try to incorporate institutions into the picture (Aghion and Howitt, 1992; Aghion and Tirole, 1996; Young, 1992). In this paper, we focus on financial institutions without modeling growth.

For firms in catching-up economies, imitating or perfecting existing technologies are the best strategies. With the low-uncertainty of imitation, our theory implies that single investor financing is more efficient for work on catching-up projects. Thus, financial institutions which make R&D internal financing easier can greatly accelerate the catching-up process, such as Japan in the 1960s to the early 1980s, and South Korea and other East Asian economies in the 1980s and the 1990s. However, high-tech firms in the most advanced economies face frontiers of technological innovations which are associated with high uncertainties. Our theory predicts that multi-investor financing should be more efficient, but a low institutional cost for multi-investor financing is critical. Venture capital institutions may reduce this cost. In contrast, those financial institutions which are efficient to finance catching up (imitation or perfection) projects may not be efficient to finance highly uncertain projects. This may shed some light on the reasons for the early success and the recent troubles experienced by the Japanese and the "East Asian miracle" economies.

Our results also have important implications for centralized economies. In those industries where R&D projects are less uncertain, such as machine building, chemicals, steel, and other heavy industries, the optimal financing strategy is internal. R&D projects are always financed internally in centralized economies. Thus our model predicts that there is no difference in efficiency between a decentralized economy and a centralized economy. In reality, centralized economies perform reasonably well in

R&D for heavy industries.

However, in high-tech industries, such as computers, electronics, or bio-tech, where R&D projects can be very uncertain,[21] multi-investor financing will be more efficient. With no other investors in a centralized economy, the option to co-finance a project externally is not available (or the cost is too high). This implies serious inefficiencies for R&D projects in these areas due to the lack of an ex post screening mechanism in a centralized economy. In fact, the most striking and devastating examples to support this point are the serious efforts but failure on the part of the Soviet Union to catch up with the West in computers and electronics, despite their strategic and military importance.

Finally, some remarks on our approach are in order. In order to focus our analysis on financing mechanisms and their effects on R&D investment, we have chosen to use a reduced form of some parameters in our model, such as the institutional cost of multi-investor financing and the private benefits of entrepreneurs. The institutional cost of multi-investor financing is a measurement of the imperfection of multi-investor capital markets. It is related to another dimension of the informational asymmetry between the investors and the entrepreneur which may result in moral hazard and adverse selection problems for the entrepreneur. Depending on capital market development and other institutional settings, such as that of the legal system, the institutional cost may vary across countries and over time (LaPorta, et al. 1997). There also exists extensive economic and finance literature which provides the rationale for such institutional costs (e.g., Arrow, 1962; Stiglitz and Weiss, 1981; and Myers and Majluf, 1984).

Regarding our reduced form treatment of the entrepreneurs' private benefits, it should be pointed out that this can be replaced by endogenized compensations to the entrepreneur and none the above results will be changed qualitatively.[22]

[21] Most of the basic scientific principles for computers, integrated circuits, and bio-tech were developed parallel to R&D projects in the respective fields. This made the uncertainty of such projects very high.

[22] See our companion paper which focuses on financing mechanisms and optimal managerial contracts (Huang and Xu, 1997).

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