JOURNAL OF FINANCIAL INTERMEDIATION 4, 328–357 (1995)

Proprietary Information, Financial Intermediation, and Research Incentives

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Received April 21, 1995

We contrast equilibria in loan markets with bilateral bank–borrower ties, in which proprietary technological knowledge of borrowers is not revealed to product market competitors, with equilibria under multilateral financing in which such knowledge may be shared among competing borrowing firms. Using each of these two institutional arrangements, we examine the conditions for existence of equilibrium, its ex ante optimality, and borrowing firms' incentives to engage in private costly research. Also explored is the potential for lending banks to coordinate postinvention collusion in product markets by multiple inventing firms. *Journal of Economic Literature* Classification Numbers: 310, 312, 314.

1. INTRODUCTION

In their examination of corporate financial policy, Bhattacharya and Ritter (1983) introduced an equilibrium model of proprietary information

* Bhattacharya gratefully acknowledges research support, past and present, from the Institut d'Analisi Economica, Barcelona and IRES, Université Catholique de Louvain. Both authors acknowledge financial and/or research support from the Innocenzo Gasparini Institute for Economic Research at Milan, including a Senior Fellowship for the first author over the 1992–1993 academic year. Gabriella Chiesa acknowledges support from CNR and MURST. We thank Guy Laroque, a referee and the editors for their helpful comments on content and exposition.

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1042-9573/95 $12.00

and its disclosure in financial markets. In equilibrium, a firm with superior private knowledge, having a higher Poisson intensity of invention in a research and development (R&D) race, is induced to disclose part of its knowledge as a signal. The benefit of the signal is that the financing for the R&D can be obtained at lower cost. The cost of the signal arises from the fact that the information disclosed benefits the firm's product market competitors.

In this paper, we consider a scenario in which technological knowledge revealed to a firm's financier(s) need not also flow to its R&D and product market competitors. Thus, while proprietary knowledge exists, whether it is revealed to other competing firms is determined endogenously by self-interested financiers. Whether this information is revealed at the interim stage of an R&D contest depends on the financing process; we consider two possibilities: bilateral bank–borrower ties and multilateral (multifirm and multibank) lending relationships. At the outset of the R&D contest, competing firms may find it efficient ex ante to share their knowledge at the interim stage of the contest. However, since at the interim stage firms will be in different positions in the race to the finish, knowledge sharing may be impossible to enforce unless done by financiers acting in their own interest. Of course, firms will anticipate whether interim-stage knowledge sharing will occur, and this will affect their ex ante incentives to invest in R&D. We analyze the implications of these tradeoffs, vis-à-vis interim knowledge spillover and ex ante research incentives, for the ex ante equilibrium choice between bilateral and multilateral financing mechanisms.

Our model is articulated in three stages: (i) ex ante financing choice with monitorable investment and privately observed research expenditures by firms, (ii) interim knowledge acquisition and its possible disclosure across firms, and (iii) postinvention payoffs for firms and lenders. We allow lenders to offer either long-term debt contracts or short-term debt, which must be refinanced at the interim (knowledge acquisition) stage. We do so because firms' incentives to make privately observed R&D investments are often superior under such short-term financing. In addition, we show that a multilateral lender may also help coordinate product market collusion across its borrowers in the event of multiple cost-reducing inventions by these firms.[1] If such postinvention collusion is coordinated in favor of the firm with the best research knowledge at the interim stage, then firms' ex ante incentives for R&D investments will also improve.[2]

[1] Hence, multilateral financing may also serve as a partial substitute for knowledge licensing contracts as in Bhattacharya, *et al.* (1992).

[2] Thus, our approach provides the foundations for a theory of comparative financial systems based on bilateral financing without knowledge sharing or postinvention collusion, public financing with knowledge sharing but no product market collusion, and strategic multilateral institutional financing with *both*.

Our model contributes to two areas of research. The first is the literature on bank monitoring and information acquisition in long-term bank–borrower relationships. Diamond (1984) examined the prudential monitoring of ex post cash flow and diversification of risk across borrowers by financial intermediaries. Since then, others have examined how banks acquire borrower-specific information through time and the implications of this for equilibrium loan contracts, rent-extraction from borrowers by banks, and the nature and optimality of borrowers' investment decisions (see Dewatripont and Maskin, 1995; Garella, 1995; Pagano and Japelli, 1993; Rajan, 1992; Sharpe, 1990; and von Thadden, 1995). Our work extends this research to proprietary information environments in which the private value of research knowledge to a firm is reduced by the revelation of this knowledge to the firm's competitors.

A complementary approach to the choice of financing in these environments is pursued in Yosha (1995), who models firms' choices between bilateral and multilateral (public information) financing at the interim stage following their acquisition of proprietary knowledge. The informed firm's preference for bilateral versus multilateral financing depends on the perception its competitors have about its type since these perceptions shape the competitors' actions and their impact on the informed firm's profit. The analysis exploits the tension between an exogenous cost of disclosing information to a large number of lenders in a public financial market and an endogenous cost faced with bilateral financing because its competitors may believe that the firm's choice of bilateral financing means that it has something to conceal, and hence react accordingly. In equilibrium, the higher quality firms (those with more to lose with disclosure) choose bilateral financing. The cost differential between bilateral and multilateral financing prevents competitors from unambiguously inferring that these firms are hiding information.

The second line of research pertinent to our paper is that on knowledge-licensing contracts in the context of R&D races or contests. The work of Bhattacharya *et al.* (1992), for example, assumes that the courts can verify knowledge voluntarily disclosed by a successful leading firm to its competitors in an R&D contest. Hence, such interim knowledge can be licensed for a fee. By contrast, we assume that licensing fees are infeasible, owing to information nonverifiability problems. Thus multilateral financing may serve as a precommitment mechanism for knowledge sharing among competing firms, when such sharing is ex ante efficient but not interim incentive-compatible for the competing firms.

Our model should be viewed as primarily normative, suggesting that knowledge sharing among competing firms may be predicated on the manner in which these firms are financed. However, there is some empirical support for our thesis that lenders or other stakeholders may help borrowers cooperate in sharing information. Hellwig (1991) cites evidence that German and Austrian banks in an earlier era facilitated product market collusion among their multiple borrowing firms through the coordination of production and investment decisions. Our model suggests an analogous role for lenders under multilateral financing from the ex ante perspective of borrowers, even though disclosure of one borrower's proprietary knowledge to another by a lender might be viewed (if proven) as a violation of the lenders' fiduciary duty.

More recently, Sako's (1995) research on suppliers' associations in the Japanese automobile industry provides evidence that these affiliate suppliers value interfirm learning about technology or knowledge spillover among themselves (rather than from the coordinating large assembler firm which often owns some of their equity) as the main advantage of association membership. She also finds that suppliers outside these associate relationships, in which the large assembler firms rarely hold an equity stake, invest relatively more in duplicative R&D. The latter finding is also consistent with our result regarding firms' R&D incentives under bilateral financing of different firms by different lenders.[3]

Our model also provides an alternative framework for studying comparative financial systems. Dewatripont and Maskin (1995) have emphasized the differential ability of centralized lenders such as large banks versus decentralized financial markets with multiple smaller investors to gather information about their borrowers. They analyze the implications for "short-termism" on investment decisions in decentralized credit markets, versus "soft-budget constraints" regarding further interim investment under centralized institutional financing. In contrast, Allen (1993) has suggested that information about firms' prospects is better analyzed and aggregated in decentralized stock markets containing many informed investors and having a publicly observable price mechanism.

Our approach sidesteps these debates about the a priori advantage of one institutional mechanism for financing over another in the processing of information about firms. We suggest instead that the financiers' incentives for information disclosure, and hence interfirm knowledge spillover, would differ according to the institutional arrangements for financing. These differences will have implications for the incentives of borrowers to invest in R&D.

The paper is organized as follows. The basic model is outlined in Section II. Tradeoffs vis-à-vis knowledge disclosure and research incentives, under

[3] Firms in suppliers' associations typically have several different equity owners other than the assembler firm whose "club" they belong to. Hence, the role of the assembler firm in coordinating interim knowledge disclosure among its suppliers is more complex than in our model here.

bilateral and multilateral financing with long-term debt, are analyzed in Section III. Section IV extends the analysis to include short-term debt and interim refinancing. In Section V we discuss other extensions, such as interim investments and postinvention collusion among the borrower firms. Section VI concludes.

II. THE MODEL

A. *The Setting*

We consider an economy in which two banks compete to provide risky loans[4] to firms engaged in an R&D contest for cost-reducing inventions in the product market. For simplicity, we assume that there are only two such rivals in each of many industries. Each bank monitors the investments of its borrowers who obtain financing at the ex ante stage, and in the process banks are assumed to acquire the knowledge generated by their borrowers' research at the interim stage. These banks also diversify across borrowers in many industries to guarantee an almost certain rate of return to their depositors who thus need not monitor.

We consider two alternative institutional arrangements as equilibrium outcomes for financing with qualitatively different bank–borrower linkages. Under bilateral financing, each bank in equilibrium finances only one of the rivals in each industry. Under multilateral financing, the ex ante equilibrium is such that each bank takes its symmetric (half) share in the financing of both the rivals; this may also be thought of as a metaphor for a public financial market.[5] The two banks are assumed to be contract-setting (price and quantity) competitors in the loan market, each facing an infinitely elastic deposit supply curve at a rate of interest $d = 0$.[6]

The R&D investment opportunity faced by each of the two borrowing firms requires an observable investment of capital I, and an externally unobservable expenditure C, at date $t = 0$, where C is a privately observed effort choice by the firm's manager. The R&D project delivers a payoff at the final date, $t = 2$, which is either 0 or $V > 0$. The firms are Bertrand

[4] Given the dichotomous payoffs of an R&D contest, with the lower outcome being zero, conventional distinctions between debt and equity financing are irrelevant for the model we develop below.

[5] With multiple (countably infinite number of) industries, an alternative multilateral financing equilibrium would have each bank lending to both borrowers in different industries, such as the first bank in odd-numbered industries and the second in even-numbered ones. This outcome results in the same knowledge disclosure decisions as in our multilateral financing equilibrium.

[6] See Bhattacharya (1982), Yanelle (1989), and Matutes and Vives (1992) for issues that arise when banks compete strategically for finitely elastic deposit supplies.

competitors in the product market, so that the R&D payoff is V if and only if there is one invention only, in which case the inventor earns the rent V, limit pricing at its rival's cost. In the event of no invention as well as of inventions by both firms, the private payoff to a firm from R&D is zero, since product market competition is unrestrained by knowledge-licensing contracts.[7]

The R&D project consists of two stages. In the first stage, firm i, $i = 1, 2$, undertaking the projects, invests cash, I, at date $t = 0$. The R&D project delivers an interim result, r, at the end of the first stage, date $t = 1$. Firm i's interim result, r_i, can be either $r_i = k$, in which interim knowledge relevant to the R&D project is produced, or $r_i = 0$, in which no interim knowledge is produced by firm i. The probability of $r_i = k$ is S if firm i also expends the effort cost C at date $t = 0$, and is zero if firm i chooses not to expend C, where $0 < S \leq 1$. At the second stage, firm i uses the interim research knowledge it has acquired (and not necessarily produced) as an input in its R&D process for a patentable invention at $t = 2$. This interim knowledge input, $\underline{r}_i$, can be either k or 0. If $\underline{r}_i = k$, then firm i faces probability P of inventing at the final date $t = 2$. If $\underline{r}_i = 0$, then firm i's probability of inventing at the second stage is Q, satisfying $0 \leq Q < P \leq 1$.

In principle, firm i's input at the second stage, $\underline{r}_i$, can equal k in two possible ways. Because firm i has been successful at the first stage, or alternatively because firm i has obtained knowledge k by having its competitor's result, $r_j = k, j \neq i$, disclosed. Clearly, at date $t = 1$ a firm j whose interim result is $r_j = k$ will not wish to disclose its knowledge to its competitor whose result is $r_i = 0, j \neq i$, since by so doing firm j reduces its probability of sole invention from $P(1 - Q)$ to $P(1 - P)$, and $P > Q$. Nevertheless, both firms may wish to precommit at date $t = 0$ to knowledge sharing at date $t = 1$. The potential benefit to firm j, $j = 1, 2$, of precommitting at the outset arises from the possible occurrence of the state in which firm j fails at the first stage of R&D and firm i succeeds. Then the probability that firm j is the sole inventor at the final stage under no knowledge sharing is $Q(1 - P)$, whereas given knowledge sharing, it increases to $P(1 - P)$. We prove below that in a first-best world firms would precommit to knowledge sharing when $P \leq \frac{1}{2}$, even when they cannot restrain their product market competition if both firms invent at the final stage.

B. *The First-Best Outcome*

Consider a first-best (full-information) world where firms can precommit at date $t = 0$, to (i) invest effort cost C, and (ii) have a disclosure rule for date $t = 1$. Because of ex ante competition between the two banks in the

[7] See Bhattacharya *et al.* (1992) for an analysis of the case where knowledge-licensing contracts across firms are feasible.

lending market, it would be in both firms' interest to choose the disclosure rule that maximizes the aggregated ex ante expected values of their R&D projects.

Under a regime of no information disclosure, the interim knowledge available to firm i, $i = 1, 2$, at the second stage of the R&D project is $\underline{r}_i = r_i \in \{0, k\}$, the interim knowledge that firm i has produced at the first stage of the R&D. Therefore, V_{ND}, the ex ante expected present value of each R&D project with no knowledge disclosure is given by

$$\begin{aligned} V_{\text{ND}} = {} & S[P(1-P)S + P(1-Q)(1-S)]V \\ & + (1-S)\{Q(1-P)S + Q(1-Q)(1-S)\}V. \end{aligned} \tag{1}$$

The expression in the square brackets in Eq. (1) is the probability of sole invention by a firm conditional upon having produced interim knowledge at the first stage, and the expression in the curly brackets is the corresponding conditional probability when the firm has not succeeded in acquiring interim knowledge.

Under a regime of information disclosure or knowledge sharing, the interim knowledge available at the second stage of the R&D project to firm 1 and firm 2 is $\underline{r}_1 = \underline{r}_2 = \max(r_1, r_2)$, where the $\max(r_1, r_2) = 0$ if and only if both the firms have failed at the first stage of research. Hence, the ex ante expected value of the R&D project under interim knowledge disclosure, V_{D}, is given by:

$$\begin{aligned} V_{\text{D}} = {} & S[P(1-P)(1-S) + P(1-P)S]V \\ & + (1-S)\{Q(1-Q)(1-S) + P(1-P)S\}V. \end{aligned} \tag{2}$$

The expression in square brackets in (2) is the probability of sole invention by either firm conditional upon its success at the first stage of R&D, given that its knowledge will be disclosed to its competitor. The expression in curly brackets in (2) is the probability of sole invention by each firm conditional upon its failure at the first stage of R&D, and the possible receipt of knowledge from its successful competitor. Lemma 1 characterizes the circumstances in which a policy of interim knowledge disclosure across rivalrous firms maximizes both firms' ex ante probability of sole invention in their R&D contest.

LEMMA 1. *If $P \leq \frac{1}{2}$, then knowledge disclosure across rivals at the interim stage is optimal ex ante. The expected present values of both R&D projects are maximized by having the firm that has produced interim knowledge disclose it to its competitor, and having the competitor reciprocate when the situation is reversed.*

Proof. Information disclosure is optimal if and only if

$$V_{\mathrm{D}} \geq V_{\mathrm{ND}},$$

which is true, using Eqs. (1) and (2), if

$$S(1 - S)[2P(1 - P) - P(1 - Q) - Q(1 - P)] \geq 0$$

or,

$$(P - Q) \geq 2P(P - Q),$$

which is equivalent to the condition

$$P \leq \tfrac{1}{2}. \qquad \text{Q.E.D.}$$

C. *Feasible Contracts*

In our model, the set of contracts that can be enforced is restricted because (i) the entrepreneurs' effort choices, C or 0, are not monitorable by outsiders, and (ii) disclosure of interim knowledge cannot be committed to or licensed. In this informationally constrained environment, we seek an optimal financing arrangement that maximizes the ex ante expected values of the R&D projects of borrowers. We shall consider two possible financing arrangements arising in ex ante equilibrium: bilateral financing, BF, and multilateral financing, MF. With BF, each firm borrows only from its private bank; under MF, each firm borrows from both of the banks. Within each regime, financing is with debt contracts for which the maturity can be either the final date $t = 2$ (long-term debt), or the interim date $t = 1$ (short-term debt) which is followed by (possible) refinancing up to $t = 2$. These financing arrangements differ in the incentives they provide lenders for interim knowledge sharing across borrowers, as well as the ex ante incentives they provide borrowers to incur privately observed costs for research. For tractability, we specialize the problem by making the following assumptions:

(i) The interim expected value of the R&D project of a firm without interim knowledge, $\underline{r} = 0$, is negative in net present value:

$$V[Q(1 - Q)] < I. \tag{A1}$$

(ii) Provided a firm invests C at date $t = 0$, its R&D project has positive ex ante net present value with or without interim sharing of knowledge, when interfirm knowledge disclosure is value maximizing, $P \leq \frac{1}{2}$, and without interim sharing of knowledge otherwise, when $\frac{1}{2} < P \leq 1$:

$$\min[V_D, V_{ND}] = V_{ND} \geq (I + C), \qquad \text{when } 0 \leq P \leq \tfrac{1}{2} \tag{A2}$$

and

$$\max[V_D, V_{ND}] = V_{ND} \geq (I + C), \qquad \text{when } \tfrac{1}{2} < P \leq 1. \tag{A2'}$$

(iii) For a knowledgeable firm at the interim stage to have a probability of invention P, the entrepreneur of the firm must remain in charge until $t = 2$. (A3)

(iv) Interim knowledge obtained by a bank can be disclosed to a firm if and only if the recipient had borrowed from the bank during the first stage of its R&D project, at $t = 0$. (A4)

Assumption (A3) implies that enforcing bankruptcy of borrowers at the interim stage is costly for their banks. Assumption (A4) implies that bank j cannot disclose the interim knowledge produced by its borrower to that of another bank i, $i \neq j$, at date $t = 1$. In particular, (A4) prevents the bank from threatening to force its successful borrower to disclose his knowledge to a product-market competitor. Hence, the refinancing game at the interim stage only involves the one-sided threat of a bank's successful borrower obtaining refinancing from the other bank at the cost of knowledge disclosure to his competitor. With long-term debt contracts, a bank could only benefit from selling its borrower's knowledge to the borrower of another bank, and this is infeasible.

We now characterize the circumstances in which bilateral or multilateral financing arrangements arise as the preferred ex ante equilibrium in the game between banks and borrowers involving loan contract offers by banks and accept/reject choices by borrowers. We do so by initially allowing only long-term debt contracts in Section III, and then consider short-term debt, and its interim refinancing, in Section IV.

III. LONG-TERM DEBT CONTRACTS

In the first subsection we prove that multilateral financing with long-term debt implements the first-best disclosure rule and hence, absent entrepreneurs' incentive problems, it maximizes the expected present value of the R&D projects for both the borrowing firms. We then focus on each borrower's incentive to incur C, which is privately observed and noncontractible.

A. *Multilateral Financing*

Under multilateral financing, both banks bid to finance parts of the investment requirement of each borrower. To simplify, we assume that each bank finances half of the required cash outlay, I. Competition implies that both banks offer the same financing terms and earn zero profit. Let $(\frac{1}{2})R$ be the contractual repayment due at date $t = 2$ to a bank, where $R < V$ given assumption (A2) and ex ante interbank competition. The probability that an entrepreneur will repay his debt maturing at $t = 2$ equals the probability that he will be the sole inventor at $t = 2$. Suppose a borrower has been successful at the first stage, whereas his competitor has failed. Given knowledge disclosure to its failed rival, the probability that a successful firm i, $i = 1, 2$, is the sole inventor and hence is solvent is $P(1 - P)$. Consequently, the expected payoff to a bank under information disclosure, π_D, when at least one of its borrowers has succeeded, is given by:

$$\pi_D = 2[P(1 - P)(R/2)]. \tag{3}$$

With no information disclosure from a successful to an unsuccessful borrower at the interim stage, the successful borrower repays his debt at $t = 2$ when he is the sole inventor, an event with probability $P(1 - Q)$, whereas the unsuccessful borrower is solvent with probability $Q(1 - P)$. The expected payoff to both the banks under no information disclosure, from a successful and unsuccessful borrower combination, π_{ND}, is therefore

$$\pi_{ND} = [P(1 - Q) + Q(1 - P)](R/2). \tag{4}$$

Thus, each bank finds it optimal to share interim ($t = 1$) knowledge across its borrowers if and only if

$$\pi_D \geq \pi_{ND},$$

or, using Eqs. (3) and (4),

$$2P(1 - P) \geq P(1 - Q) + Q(1 - P),$$

which is true if and only if

$$P \leq \tfrac{1}{2}.$$

Hence, under multilateral financing with long-term debt, the lenders' interim criterion for knowledge sharing across borrowers coincides with the first-best disclosure rule, derived in Lemma 1 above. Consequently, the expected present value of the R&D projects is the max (V_D, V_{ND}).

Since the credit market is competitive, if $P \leq \frac{1}{2}$, information will be disclosed at date $t = 1$, and the gross repayment due at $t = 2$, R, will satisfy

$$R[SP(1 - P) + (1 - S)[P(1 - P)S + Q(1 - Q)(1 - S)]] = I. \quad (5)$$

Because in equilibrium banks obtain zero ex ante expected profit, the ex ante expected payoff to the borrower, Z_0(MFL), is

$$Z_0(\text{MFL}) = V_D - I. \quad (6)$$

The borrower's interim expected payoff conditional upon success at the first stage of R&D, $Z(S)$, is

$$Z(\text{S}) = (V - R)\, P\, (1 - P), \quad (7)$$

and the borrower's interim expected payoff conditional upon failure, Z(F), is

$$Z(\text{F}) = (V - R)[P(1 - P)S + Q(1 - Q)(1 - S)], \quad (8)$$

where R is given by Eq. (5).

The difference between the borrower's conditional expected payoffs in (7) and (8) is crucial in providing the borrowing firms incentives to invest C. We label this difference the Reward to Research Effort. These expressions are summarized in Table I below. The expression for $[Z(\text{S}) - Z(\text{F})]_{\text{MFL}}$ has been obtained by substituting from Eq. (5) into (7) and (8), and noting that

$$\begin{aligned}[Z(\text{S}) - Z(\text{F})]_{\text{MFL}} &= (1/S)[V_D - I - Z(F)] \\ &= (V_D - I)[K/(L + SK)],\end{aligned} \quad (9)$$

where K and L are as in Table I (Eqs. (15a) and (15b)).

If $P > \frac{1}{2}$, and we replace Assumption (A2) by

$$\max(V_D, V_{ND}) = V_{ND} \geq (I + C), \quad \text{(A2')}$$

then the borrowers' interim knowledge will not be shared at $t = 1$. The expected value of each R&D project therefore equals $V_{ND} = \max(V_D, V_{ND})$, and the promised repayment R that provides the banks zero ex ante expected profit solves

$$R[S[P(1-P)+(1-S)P(1-Q)]+(1-S)[Q(1-P)S+Q(1-Q)(1-S)]]=I, \tag{10}$$

where $R < V$, by (A2′). The ex-ante expected payoff to the borrower, Z_0(MFL), is then

$$Z_0(\mathrm{MFL}) = V_{\mathrm{ND}} - I. \tag{11}$$

The borrower's expected profits conditional upon success and failure, respectively, are

$$Z(\mathrm{S}) = (V-R)[P(1-Q)(1-S)+P(1-P)S] \tag{12}$$

$$Z(\mathrm{F}) = (V-R)[Q(1-P)S+Q(1-Q)(1-S)], \tag{13}$$

where R is given by (10). The difference between the conditional expected payoffs to the successful and failed borrowers under multilateral financing with long-term debt, when $P > \frac{1}{2}$; can thus be written, using Eqs. (10), (12), and (13) as

$$[Z(S) - Z(F)]_{\mathrm{MFL}} = (V_{\mathrm{ND}} - I)[A/(B + SA)], \tag{14}$$

where A and B are defined in Table I (Eqs. (16a) and (16b)).

B. *Bilateral Financing*

Under bilateral financing with long-term debt, there is no value of P for which a bank or a borrower has an incentive to disclose the outcome. Consequently, regardless of P, the ex ante expected value of each R&D project equals V_{ND}. The ex ante expected payoff to the borrower, Z_0(BFL), and the Reward to Research Effort, $[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{BFL}}$, are summarized in Table I. These are the same expressions as the ones derived above for the multilateral financing regime when banks do not share interim research knowledge across their common borrowers (when $P > \frac{1}{2}$), but these formulas are now valid for all $P \in (0, 1)$.

We now turn to the question of incentives for borrowers to incur C. In the process, we shall show that the equilibrium choice of financing regimes, in ex ante competition among banks for borrowers, crucially depends on the importance of such incentives at the initial stage.

TABLE I
BORROWERS' EX ANTE SURPLUS AND REWARD TO RESEARCH EFFORT WITH LONG-TERM DEBT

Financing	Multilateral		Bilateral
	$0 \leq P \leq \frac{1}{2}$	$1 \geq P > \frac{1}{2}$	All P
Ex ante surplus	Z_0 (MFL)		Z_0 (BFL)
	$V_D - I$	$V_{ND} - I$	$V_{ND} - I$
Reward to Research Effort	$[Z(S) - Z(F)]_{MFL}$		$[Z(S) - Z(F)]_{BFL}$
	$\dfrac{(V_D - I)K}{(L + SK)}$	$\dfrac{(V_{ND} - I)A}{(B + SA)}$	$\dfrac{(V_{ND} - I)A}{(B + SA)}$,

where

$$K \equiv (1 - S)[P(1 - P) - Q(1 - Q)] \quad (15a)$$
$$L \equiv [P(1 - P)S + Q(1 - Q)(1 - S)] \quad (15b)$$
$$A \equiv (P - Q)[S(1 - P) + (1 - S)(1 - Q)] \quad (16a)$$
$$B \equiv Q[S(1 - P) + (1 - S)(1 - Q)] \quad (16b)$$

C. *Research Incentives and Choice of Financing Regimes*

Table I, including Eqs. (15a), (15b), (16a), and (16b), indicates the crucial differences between the bilateral and multilateral financing regimes when $P \leq \frac{1}{2}$. When interim disclosure of R&D knowledge across borrowers is ex ante optimal, multilateral (bilateral) financing does (not) lead to such disclosure, resulting in higher (lower) ex ante surplus for borrowers. However, the incentives to incur C can be lower for borrowers under multilateral financing. This is the case, for example, as the probability of success in first-stage research, S, tends to unity for any $(P - Q)$ difference. Equation (15a) reveals that $K \rightarrow 0$ as $S \rightarrow 1$, but (16a) shows that $A \neq 0$ when $S = 1$, so that Reward to Research Effort tends to zero under multilateral financing as $S \rightarrow 1$, but not under bilateral financing. The intuition is that, with the interim knowledge disclosure anticipated from its rival under the multilateral financing regime, each firm is induced to free ride on its rival's R&D, in contrast to bilateral financing, which has no interim knowledge sharing. However, a situation in which only one of the two firms incurs C is incompatible with equilibrium multilateral financing. A borrower that incurs C in this case would be lured away by a competitive zero-profit bilateral financing offer from either bank because it could then incur C without having to share the resulting knowledge. We make the following additional assumption:

(v) Sufficient incentives to incur C always exist under bilateral financing with no knowledge sharing, so that

$$S[Z(S) - Z(\mathrm{F})]_{\mathrm{BFL}} = \left[\frac{(V_{\mathrm{ND}} - I)SA}{(B + SA)}\right] \geq C. \tag{A5}$$

We can now state the key result of this section on long-term debt financing.

PROPOSITION 1.

(a) *When $P > \frac{1}{2}$, bilateral and multilateral long-term debt are equivalent; both regimes lead to no interim disclosure of knowledge across rival borrowing firms, and provide borrowers incentives to incur C.*

(b) *When $P \leq \frac{1}{2}$, multilateral financing leads to disclosure of interim research knowledge across borrowers, but bilateral financing does not result in such disclosure, even though it is ex ante optimal (as is no disclosure when $P > \frac{1}{2}$).*

(c) *When $P \leq \frac{1}{2}$, there exists $S^* \in (0, 1)$ such that for $S > S^*$ only bilateral financing provides adequate incentives for R&D effort. Hence, for $S > S^*$, the bilateral financing regime arises as the ex ante equilibrium choice of the institutional arrangement for financing.*

Proof. Parts (a) and (b) have already been proved in the text above, as summarized in Table I. To prove part (c), note first that each borrowing firm would incur C under multilateral financing if and only if:

$$S[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{MFL}} = \left[\frac{(V_{\mathrm{D}} - I)SK}{(L + SK)}\right] \geq C > 0.$$

But using (15a) and (15b) in Table I, there exists $0 < S^* < 1$ such that the inequality above cannot be satisfied for $S > S^*$. Hence, using assumption (A5), the proposition is proved. Q.E.D.

Proposition 1 summarizes the key tradeoffs in the equilibrium choice of financing arrangement. When interim knowledge disclosure across rivals in an R&D contest improves their ex ante probability of sole invention, and free riding problems related to these rivals' incentives to make privately observed investments in R&D are not too severe, multilateral financing arrangements would arise in equilibrium. Otherwise, bilateral financing with no interim disclosure of R&D knowledge arises in equilibrium.[8]

[8] A purely public financing mechanism may lead to interim knowledge disclosure across rivals even when that is not ex ante optimal, i.e., when $P > \frac{1}{2}$, if the privacy of knowledge gathered by many financiers simply cannot be protected. Then, for $P > \frac{1}{2}$ bilateral financing would be chosen in equilibrium.

IV. SHORT-TERM DEBT CONTRACTS

If there are incentive (moral hazard) problems present when $C > 0$, there is scope for shortening debt maturity. Debt that matures at $t = 1$ implies recontracting at the date when the outcomes of the first stage of research are realized. It is possible that firms' expected payoffs conditional upon first-stage success and failure, and hence the Reward to Research Effort, may be enhanced by the use of short-term debt. In this section we characterize loan market equilibria when banks can offer short-term debt contracts at $t = 0$, which must be refinanced, if possible, at $t = 1$.

A. *Multilateral Financing*

At the initial date, $t = 0$, each bank lends (by symmetry) amounts equalling at least $I/2$ to either firm as short-term debt, in return for repayments due of $R_1/2$ at the interim date, $t = 1$. We refer to a borrower who has succeeded (failed) at the first-stage of R&D as an S-type (F-type) borrower. The game at $t = 1$, when the repayment of the first period loan, R_1, is due, proceeds as follows:

(i) Bank 1 offers an S-type (F-type) borrower a refinancing contract—a loan of size R_1—with repayment τ_S (τ_F) due at $t = 2$. Bank 2 offers analogous refinancing contracts with repayments due of τ_S' and τ_F', respectively.

(ii) If the min $(\tau_S, \tau_S') > V$, then the S-type borrower defaults. If $\tau_S \neq \tau_S'$, and if the min $(\tau_S, \tau_S') \leq V$, then the S-type accepts the loan offer with the lower repayment demand. If $\tau_S = \tau_S' \leq V$, then the S-type borrower refinances $(\frac{1}{2})R_1$ from each of the two banks. The F-type borrower makes a similar choice, and in calculating his payoff he anticipates whether the interim knowledge of the other borrower will or will not be disclosed to him (depending upon the state of the other borrower).

(iii) Given the contracts offered by the banks i, $i = 1, 2$, and given the borrowers' choices of refinancing offers, each bank i chooses whether or not to disclose the interim knowledge produced by a successful borrower to a failed borrower.

We characterize below the first-period debt contract, i.e., the size of the loan granted at $t = 0$ and the repayment due at $t = 1$, R_1, so that (a) in the equilibrium of the game above interim research knowledge is shared across borrowers if and only if $P \leq \frac{1}{2}$, and (b) banks earn zero expected profit ex ante.

Consider first an equilibrium of the refinancing game outlined above when $0 \leq P \leq \frac{1}{2}$, in which R_1 satisfies:

$$VQ(1 - Q) < I < R_1 < VP(1 - P). \tag{17}$$

We shall prove that, given the outcome of the refinancing game at $t = 1$, the R_1 that gives banks zero expected profit ex ante satisfies (17). Let the interim state realization be (S, F) at date $t = 1$; one borrower has succeeded at the first stage of R&D and the other has failed. Let banks offer the refinancing contract $\tau'_F = \tau_F = \tau'_S = \tau_S = \tau$, satisfying

$$P(1 - P)\tau = R_1, \tag{18}$$

where $\tau < V$, given the inequality in (17) above. Then both firms borrow $(\frac{1}{2}) R_1$ from each bank, and a bank chooses to disclose the interim knowledge of one borrower to the other if and only if:

$$(\tfrac{1}{2})P(1 - P)\tau + (\tfrac{1}{2})P(1 - P)\tau \geq (\tfrac{1}{2})P(1 - Q)\tau + (\tfrac{1}{2})Q(1 - P)\tau. \tag{19}$$

The left-hand side of (19) is the bank's expected payoff under disclosure when each borrower is the sole inventor at $t = 2$ (the probability of each borrower being the sole inventor is $P(1 - P)$); the right-hand side of (19) is the bank's expected payoff conditional upon no knowledge disclosure, so that the successful borrower is the sole inventor at $t = 2$ and hence is solvent with probability $P(1 - Q)$, and the failed borrower is the sole inventor and hence repays τ with probability $Q(1 - P)$.

By Lemma 1, when $P \leq \frac{1}{2}$ inequality (19) is satisfied, so that knowledge sharing is the banks' optimal choice given the loan offers defined by (18) and given the entrepreneurs' choices of borrowing. Analogous reasoning in the cases where the realized (knowledge) state of the two borrowers at $t = 1$ is either (S, S), or (F, F), leads us to the following result.

LEMMA 2. *Let $P \leq \frac{1}{2}$ and assume* (A1), (A2), *and* (A3), *as given in Section II. Then, in the short-term debt refinancing game at $t = 1$, the unique (subgame perfect Nash) equilibrium outcome is as follows:*

(a) *If the interim knowledge state is* (S, S), *i.e., both borrowers have succeeded in their first-stage research, then $\tau_S = \tau'_S = \tau < V$, where τ satisfies* (18).

(b) *If the interim knowledge state is* (F, F), *i.e., both borrowers have failed in their first-stage research, then $\tau_F = \tau'_F > V$, and both borrowers default on their first-period loan.*

(c) *If the interim knowledge state across the two borrowers is* (S, F) *or* (F, S), *i.e., only one of the two borrowers has succeeded in first-stage research, then knowledge is shared across the two borrowers, who are refinanced with $\tau_S = \tau'_S = \tau_F = \tau'_F = \tau < V$, where τ satisfies* (18).

(d) *Furthermore, in the ex ante contract-setting (Bertrand) competition* *between the two banks, the (Nash) equilibrium repayment amount on the first-period loan, R_1, satisfies* (17).

Proof. Part (a) is obvious given interim ($t = 1$) interbank competition. To prove part (b), notice that a first-period repayment of $R_1 < I$ cannot provide the lending bank with nonnegative expected profit ex ante, and (A1) implies that a repayment $R_1 \geq I$, cannot be refinanced from either bank when the interim knowledge state is (F, F).

To prove part (c), first note that the contract given above is the only subgame perfect equilibrium with interim interbank competition if the banks' optimal policy in stage (iii) of the refinancing game is to share the knowledge of the S-type borrower with the F-type borrower. To establish that this is the only possible outcome, we must show that a subgame perfect Nash equilibrium without knowledge sharing by the banks at stage (iii) of the refinancing game cannot arise. This is accomplished in Appendix A.

Finally, to establish part (d), note that R_1 must yield banks zero ex ante expected profit, i.e., given parts (a), (b), and (c) above,

$$R_1[1 - (1 - S)^2] + V[(1 - S)^2Q(1 - Q)] = I, \tag{20}$$

so that, given (A1) and (A2), R_1 satisfies (17). Q.E.D.

Lemma 2 has important implications for the relative performance of multilateral financing with short-term debt versus that with long-term debt, with respect to borrowers' Reward to Research Effort. The reason is that with short-term debt when the interim knowledge state is (F, F), both borrowers are bankrupt and hence obtain zero payoffs, whereas they would have earned positive expected payoffs with long-term debt financing (the option value). Correspondingly given R_1, the short-term debt repayment, and τ, the repayment of refinanced short-term debt, S-type borrowers obtain strictly higher conditional expected payoffs with short-term debt financing. Before summarizing these results, we consider the case when $P > \frac{1}{2}$, so that interim knowledge disclosure across borrowers is not first-best, and examine the refinancing game at $t = 1$ across the banks and their borrowers. Assuming $Q < \frac{1}{2}$, so that the probability of sole invention is not maximized by having two F-type borrowers, we have the following result.

LEMMA 3. *Let $P > \frac{1}{2} > Q$, and assume* (A1), (A2′), *and* (A3) *are satisfied. Then R_1 will satisfy:*

$$V[P(1 - Q)] > R_1 \geq max\{V[2P(1 - P) - Q(1 - P)], V[Q(1 - Q)]\}. \tag{21}$$

As a result, in the refinancing game at $t = 1$, the unique set of subgame perfect equilibrium outcomes is as follows:

(a) *If the interim knowledge state is* (F, F), *i.e., both borrowers have failed in their first-stage research, then* $\tau_F = \tau'_F > V$ *and the failed borrowers are forced to default on their first-period loans.*

(b) *If the interim knowledge state is* (S, F) *or* (F, S), *i.e., only one of the two borrowers has succeeded in first-stage research, then* (i) *interim research knowledge is not shared across the borrowers,* (ii) $\tau_F = \tau'_F > V$ *so that the failed* F*-type borrower defaults, and* (iii) *the* S*-type borrower is refinanced with promised repayment* $\tau_S = \tau'_S = \tau < V$ *at* $t = 2$, *satisfying*

$$P(1 - Q)\tau = R_1 \tag{22}$$

and each bank lends $R_1/2$ *to each borrower at* $t = 1$.

(c) *If the interim knowledge state is* (S, S), *so that both the borrowers have succeeded in their first-stage research, only one of the two borrowers is declared in default, and the banks set* τ *for refinancing the other borrower to satisfy*

$$P(1 - Q)\tau = R_1 \tag{22}$$

under interim competition.[9]

(d) *Given parts* (a), (b), *and* (c) *above, the ex ante expected net profit of each bank is set equal to zero when each bank lends to each borrower the amount* $I'/2$, *where* I' *satisfies the equation*

$$\begin{aligned} I \leq I' = S\left[(1 - S)R_1 + \frac{S}{2}\{R_1 + Q(1 - P)V\}\right] \\ + (1 - S)[SVQ(1 - P) + (1 - S)VQ(1 - Q)], \end{aligned} \tag{23}$$

in accordance with the equilibrium characterized in parts (a), (b), *and* (c) *above. A solution to* (23) *satisfying* (21) *exists, and the excess lending* $(I' - I)$ *if any is assumed to be consumed by the borrowers ex ante, at* $t = 0$.

Outline of Proof. The complete proof of Lemma 3 is lengthy and tedious, and hence it is relegated to Appendix B which is available from the authors on request. Here we sketch the proof.

The crucial problem the bank lenders now face is that of avoiding opportunistic disclosure of an S-type borrower's interim research knowledge to an F-type borrower by one of them, at $t = 1$ when the short-term debt

[9] The repayment demanded of the borrower put into default is $\tau_S = \tau'_S > V$, since $VP(1 - P) < R_1$, and the defaulted borrower's success probability drops to Q by (A3). The renegotiation is at least weakly Pareto-improving for banks and borrowers.

must be refinanced. Such knowledge revelation is undesirable from the (first-best) perspective of ex ante surplus maximization, since $P > \frac{1}{2}$, by Lemma 1. To preclude such disclosure, R_1 must be set sufficiently high, so that

$$(\tfrac{1}{2})[R_1 + VQ(1 - P)] \geq VP(1 - P). \tag{21a}$$

The left-hand side of (21a) represents a bank's payoff from the equilibrium strategies, as spelled out above. The right-hand side of (21a) represents a bank's payoff from deviating by repaying the first-period loan of the F-type borrower from the other bank of amount $\frac{1}{2}R_1$, using the repayment of its first-period loan to the S-type, and then transferring the S-type borrower's interim research knowledge to the captured F-type at stage (iii) of the refinancing game, in return for promised repayment of V at $t = 2$, which is subgame perfect given the deviation.

The proof of part (a) of the lemma is obvious, and analogous to that of part (b) of Lemma 2. Given the argument following inequality (21a) above, which makes use of Assumption (A3), part (b) of Lemma 3 follows from interim competion for the successful S-type borrower between the two banks, given the first inequality in (21).

The proof of part (c) of Lemma 3 involves the observation that, for the short-term debt contract, the required repayment R_1 (satisfying (21)) exceeds $VP(1 - P)$, so that at least one of the knowledgeable borrowers would be declared bankrupt. Declaring only one to be bankrupt is optimal, given assumption (A3), since it improves the probability of sole invention by the two borrowers taken together. Thus, one of the two S-type borrowers, chosen randomly, is declared bankrupt, and the other is refinanced competitively.

Finally the proof of part (d) of the Lemma and the inequality in (23), follow from ex ante (Bertrand) competition between the two bank lenders.

Given Lemmas 2 and 3 above, the ex ante expected net surpluses of the borrowers under multilateral short-term debt financing are

$$Z_0(\mathrm{MFS}) = [V_\mathrm{D} - I], \qquad \text{when } P \leq \tfrac{1}{2} \tag{24}$$

and

$$Z_0(\mathrm{MFS}) = [V_\mathrm{ND} - I] + \frac{S^2}{2}[P(1 - Q) + Q(1 - P) - 2P(1 - P)]V, \qquad \text{when } P > \tfrac{1}{2}. \tag{25}$$

Analogously, the expressions for Reward to Research Effort, $[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{MFS}}$, are now given by

$$[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{MFS}} = \left[\frac{(V_{\mathrm{D}} - I)(1 - S)}{(2S - S^2)}\right] \tag{26}$$

when $P \leq \frac{1}{2}$, and when $P > \frac{1}{2}$ by

$$\begin{aligned}[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{MFS}} &= Z(\mathrm{S}) \\ &= \left[\left(1 - S + \frac{S}{2}\right) P(1 - Q)(V - \tau)\right],\end{aligned} \tag{27}$$

where τ satisfies (22), and R_1 satisfies (23) and (21) as well.

Equation (26) has been obtained by using Lemma 2, which implies that

$$[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{MFS}} = [(V - \tau)P(1 - P)](1 - S),$$

where τ satisfies Eq. (18) and R_1 satisfies (20), and V_{D} is given by (2). Notice that (26) implies that Reward to Research Effort under multilateral financing is greater with short-term than with long-term debt, for $P \leq \frac{1}{2}$, since

$$[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{MFS}} = (V_{\mathrm{D}} - I)\Big/\left[S + \frac{S}{(1 - S)}\right] \tag{26'}$$

and $[S/(1 - S)]$ is strictly less than the corresponding term L/K of Eqs. (15a) and (15b) in Table I, for long-term debt.

However, when $P > \frac{1}{2}$, multilateral financing need not provide greater Reward to Research Effort for borrowers with short-term debt than with long-term debt, since the equilibrium loan contract in Lemma 3 implies that some successful borrowers in the (S, S) state, as well as failed F-type borrowers, obtain zero expected payoffs.[10] We can examine this issue further, using (27), (22), (23), and (21). Under some conditions, derived in Appendix B, (23) is satisfied with $I' = I$ whereas (21) is a strict inequality and hence, using (22) and (27) also, we have[11]

$$\begin{aligned}[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{MFS}} = \frac{1}{S}\{V_{\mathrm{ND}} - I\} + \frac{S}{2}[&P(1 - Q) + Q(1 - P) \\ &- 2P(1 - P)]V.\end{aligned} \tag{27'}$$

[10] The resulting expected surplus for lenders is remitted to borrowers in the form of the excess lending $(I' - I)$, over and above that required for the initial investment I.

[11] Sufficient conditions for (27') to hold, derived in Appendix B, are that either (i) $Q \geq 2(1 - P)$, which implies that $VQ(1 - Q)$ drives the R_1 solution satisfying (21), or (ii) $Q < 2(1 - P)$ and $[S(1 - S)(2P - 1)(P - Q]V \geq [V_{\mathrm{ND}} - 1]$, which imply that inequality (21) is strict, and (23) is satisfied with $I' = I$. Condition (ii) requires that the net surplus from R&D is not too high, and it may not hold for P in a neighborhood of $P = \frac{1}{2}$.

The curly-bracketed term in (27′) reflects the fact that, with short-term debt financing, all F-type borrowers at the first stage are forced into bankruptcy. The square-bracketed term further reflects the fact that, with optimal refinancing of the multilateral short-term debt contract, in the state (S, S) at $t = 1$ when both borrowers have succeeded in their first-stage research, only one of the two borrowers is allowed to continue, which is optimal when $P > \frac{1}{2}$. The expression for Reward to Research Effort in (27′) clearly exceeds that for multilateral financing with long-term debt, given in Table I including (16a) and (16b). Hence, short-term debt financing again improves borrowers' incentives to incur the cost C.[12]

B. *Bilateral Financing*

As with multilateral financing, for each borrower the short-term debt from his original lender matures at $t = 1$ with R_1 due, but only the unique lender of each borrower is now aware of his interim knowledge. Hence, the refinancing game among the two borrowers and the two banks at $t = 1$ is now one of incomplete information; a new lender is convinced of the knowledge of the erstwhile borrower of another bank if and only if the latter reveals it. Furthermore, given (A3), the probability of invention in the event of success at the first stage of R&D is P if and only if the entrepreneur is kept in control at the second stage.

Suppose that $R_1 > VQ(1 - Q)$. Then, conditional on failure of the first stage of R&D, the borrower has no outside option, i.e., he cannot get refinancing from a bank other than the one from which he borrowed in the first period. Since the probability of invention of a nonknowledgeable firm is Q no matter who is in control, a failed F-type borrower of either bank is always forced into a zero expected payoff situation at $t = 1$, so that $Z(\mathrm{F}) = 0$.

The payoff to the borrower in the event of success at the first stage of R&D is the outcome of bilateral bargaining at $t = 1$ with the bank he borrowed from in the first period, with an outside option for the borrower. The bilateral bargaining element comes from the fact that, as noted above, the entrepreneur being in control is crucial for the probability of invention to be $P > Q$ (by Assumption (A3)), and this implies that a surplus can be generated by having the entreprenuer in control at the second stage of R&D relative to the entreprenuer being removed (declared bankrupt). The value of this surplus is given by:

[12] As we noted earlier in footnote 8, our analysis is predicated on a strategic view of financiers' behavior under multilateral financing. If one thinks of multilateral financing instead as simply being decentralized public financing, then interim knowledge disclosure across borrowers may take place even when $P > \frac{1}{2}$, and that is likely to reduce the Reward for Research Effort under such financing.

$$\begin{aligned} ES &= [VP(1-Q)(1-S) + VP(1-P)S] \\ &\quad - [VQ(1-Q)(1-S) + VQ(1-P)S] \\ &= V(P-Q)[(1-Q)(1-S) + S(1-P)]. \end{aligned} \tag{28}$$

The outside option feature derives from the fact that a successful borrower can seek refinancing of R_1 at $t = 1$ from the other bank. Due to the infeasibility of knowledge licensing, contracting can only take place after a successful borrower seeking refinancing from the other bank reveals his success at the first stage of R&D. Moreover, once such information has been disclosed, the other bank will find it optimal to inform its failed borrower, since it can always refuse to refinance the knowledgeable erstwhile borrower of its competing bank. Consequently, the expected value of the R&D project of a successful borrower seeking refinancing from the other bank is $VP(1-P)$, independent of whether his competitor succeeded or failed at the first stage of R&D. Hence, the S-type borrower succeeds in refinancing from the other bank if and only if:

$$VP(1-P) \geq R_1. \tag{29}$$

The value of the outside option of the successful S-type borrower is then the $\max[VP(1-P) - R_1, 0]$, and therefore the $t = 1$ expected payoff to the successful S-type borrower, $Z(\mathrm{S})$, is given by

$$Z(\mathrm{S}) = \max[\mu ES, \max[VP(1-P) - R_1, 0]], \tag{30a}$$

where $0 \leq \mu \leq 1$ is the fraction of the surplus ES (see (28)) accruing to the borrower. Assume that the bank has all the bargaining power, i.e., $\mu = 0$. Then the $t = 1$ expected payoff to the successful borrower equals the value of his outside option, i.e.,

$$Z(\mathrm{S}) = \max[VP(1-P) - R_1, 0]. \tag{30b}$$

Ex ante Bertrand competition among banks implies that R_1 must satisfy, for the equilibrium loan amount I', at date $t = 0$,

$$\begin{aligned} &(1-S)[VQ(1-P)S + VQ(1-Q)(1-S)] \\ &\quad + S[[VP(1-P)S + VP(1-Q)(1-S)] - Z(\mathrm{S})] = I' \geq I, \end{aligned} \tag{31}$$

which can be expressed, when $I' = I$, as

$$[V_{\mathrm{ND}} - I] = SZ(\mathrm{S}), \tag{31'}$$

where $Z(\mathrm{S})$ satisfies (30b) and $VP\,(1 - P) > R_1$.

Let $P \leq \frac{1}{2}$; then $[V_{\mathrm{ND}} - \mathrm{I}] > 0$ by (A2), and an R_1 that solves (31′) exists and satisfies $VQ\,(1 - Q) < R_1 < VP\,(1 - P)$ if $[V_{\mathrm{ND}} - \mathrm{I}]$ is not too large, i.e., if $[V_{\mathrm{ND}} - I] < S[VP(1 - P) - VQ(1 - Q)]$, where $P(1 - P) > Q(1 - Q)$, because $Q < P \leq \frac{1}{2}$. The value of the outside option of the S-type borrower is then indeed positive, whereas the value of the outside option of the F-type borrower is zero. The borrower's ex ante surplus is therefore given by

$$Z_0\,(\mathrm{BFS}) = (V_{\mathrm{ND}} - I) \tag{32}$$

and the Reward to Research Effort is given by

$$\begin{aligned}[Z(\mathrm{S}) - Z(\mathrm{F})]_{\mathrm{BFS}} &= VP(1 - P) - R_1 \\ &= \frac{1}{S}[V_{\mathrm{ND}} - I].\end{aligned} \tag{33}$$

On comparing (32) and (33) with the corresponding quantities in Table I for bilateral financing with long-term debt, we see that while short-term debt financing leaves the ex ante surplus of borrowers unchanged, it improves the Reward to Research Effort.

If $P > \frac{1}{2}$, then there are two ranges of values of P that are relevant. If P is sufficiently close to $\frac{1}{2}$, then the same conclusion as above applies. If P is sufficiently higher than $\frac{1}{2}$, i.e., $VP(1 - P)$ is sufficiently small, then the value of the outside option of the S-type borrower, and hence his expected interim payoff, is zero. This in turn implies that $I' > I$ in (31), and research incentives are destroyed. In essence, when $P > \frac{1}{2}$and short-term debt is used, the possibility of disclosure of the knowledge of the successful borrower of Bank 1 to the failed borrower of Bank 2 erodes the desirable incentive properties of bilateral financing. The derivations in the two subsections above are summarized in Table II.

C. *Comparison of Financing Regimes and Equilibrium Choices*

On comparing Tables I and II, and taking into account the results summarized in Proposition 1 above, we can now state the full result for our comparison of alternative institutional arrangements for the financing of R&D intensive firms. These comparisons take into account multilateral and bilateral financing, as well as optimal security design between long-term and short-term debt, the latter with refinancing and renegotiation at $t = 1$.

TABLE II
BORROWERS' EX ANTE SURPLUS AND REWARD TO RESEARCH EFFORT WITH SHORT-TERM DEBT

Financing	Multilateral		Bilateral
	$0 \leq P \leq \frac{1}{2}$	$1 \geq P > \frac{1}{2}$	All P
Ex ante surplus		Z_0 (MFS)	Z_0 (BFS)
	$V_D - I$	$\left[V_{ND} - I + \frac{S^2}{2}\left\{\begin{matrix} P(1-Q) + \\ Q(1-P) - 2P(1-P)\end{matrix}\right\}V\right]$	$V_{ND} - I$
Reward to Research Effort		$[Z(S) - Z(F)]_{MFS}$	$[Z(S) - Z(F)]_{BFS}$
	$\left[\frac{(V_D - I)(1-S)}{(2S - S^2)}\right]$	$\left[\frac{1}{S}(V_{ND} - I) + \frac{S}{2}\left\{\begin{matrix} P(1-Q) + Q(1-P) \\ -2P(1-P)\end{matrix}\right\}V\right]^a$	$\frac{1}{S}(V_{ND} - I)$, or zero[b]

[a] Under conditions described in footnote 11 and derived in Appendix B.
[b] See discussion in Section IV.B in text.

PROPOSITION 2. *Assume* (A1), (A2), (A2′), (A3), (A4), *and* (A5) *as above are satisfied. Then the ex ante equilibrium choice of financing regimes is as follows:*

(i) *If* $P \leq \frac{1}{2}$, *and* $0 < S \leq S^*$, *then the equilibrium choice is multilateral financing, with long-or short-term debt, where* S^* *is characterized in the proof of Proposition* 1.

(ii) If $P \leq \frac{1}{2}$, *and* $S^* < S \leq S^{**}$, *where* S^{**} *satisfies*

$$\left[\frac{S^{**}(V_D - I)(1 - S^{**})}{(2S^{**} - S^{**2}}\right] = C, \tag{34}$$

where C is the privately chosen (effort) cost of first-stage research, then multilateral financing with short-term debt prevails in ex ante equilibrium.

(iii) *If $P \leq \frac{1}{2}$, and $S^{**} < S \leq 1$, then bilateral financing with long- or short-term debt prevails in ex ante equilibrium.*[13]

(iv) *If $P > \frac{1}{2}$, and the assumptions behind (27′) are met, as detailed in footnote* 11 *and Appendix B, then multilateral financing with short-term debt prevails in ex ante equilibrium.*[14]

Proof. Straightforward, on comparing Tables I and II. Q.E.D.

The major difference between Propositions 1 and 2 lies in the fact that multilateral financing with short-term debt increases ex ante surplus and Reward-to-Research-Effort, particularly when $P > \frac{1}{2}$. This arises from the strategic use made of short-term debt contracts by multilateral lenders to increase ex ante surplus and Reward to Research Effort. These strategies go beyond implementing optimal nondisclosure of interim research knowledge across a successful and a failed borrower at the interim stage, when $P > \frac{1}{2}$. They further involve eliminating one of two knowledgeable firms at the interim stage from carrying out further R&D with its knowledge. Such a collusive role (from an ex ante point of view) for multilateral bank lenders distinguishes multilateral financing in our model from straightforward public (debt) financing with either no information acquisition about borrowers over time, and/or no strategic refinancing renegotiations at the interim stage, at date $t = 1$. In the following section, we consider the idea that multilateral lenders can facilitate collusion in the postinvention product market among two borrowers who are R&D rivals and are both successful in the second stage of their R&D projects.

V. EXTENSIONS

We have thus far assumed that the R&D project requires capital only at the initial stage, and also that the new technology requires no investment in order to be implemented. In this section we discuss the implications of relaxing these assumptions.

If further investment is required to complete the project and the efficient continuation decision is contingent upon the R&D outcomes of the two firms, then the basic tradeoff determining the equilibrium choice between

[13] If Assumption (A5), on the viability of bilateral financing with long-term debt, is not satisfied for S sufficiently close to 1, bilateral financing with short-term debt may still provide borrowers with adequate incentives to incur the first-stage research cost C, since (by Table II) it provides greater incentives for costly research.

[14] If the characterization of borrowers' research incentives in Eq. (27′) does not hold, and research incentives under multilateral short-term financing are inadequate, then multilateral or bilateral financing with long-term debt will prevail.

the two financing regimes will be reinforced. To see this, suppose a second cash outlay, I_2, is required at $t = 1$. Further, a firm that is successful in first-stage R&D should always invest I_2 and complete the project, but a firm that is unsuccessful should do so only if the competitor has also failed, i.e.,

$$I_2 < VQ(1 - Q). \tag{35}$$

We assume that I_2 should not be invested if the competitor's R&D outcome is not known, i.e.,

$$I_2 > V[SQ(1 - P) + (1 - S)Q(1 - Q)], \tag{36}$$

given no knowledge sharing across the borrowing firms. With knowledge sharing in multilateral finance, both projects will be continued when either firm has succeeded and $P \leq \frac{1}{2}$. But with an absence of knowledge sharing in bilateral finance, only the successful firm(s) at the first stage will invest I_2. Moreover, when both firms fail in the first stage of R&D, projects will be continued under multilateral financing (with complete information at the interim stage) but not under bilateral financing. The reason is that truthfully revealing their borrowers' R&D outcomes cannot be an equilibrium for banks. If bank i truthfully reveals that its borrower has failed, bank j is better off announcing that its borrower has succeeded, since by so doing it maximizes the probability of its borrower being the sole inventor. As a result, under bilateral financing the ex ante surplus will further decline below that under multilateral financing. But under bilateral financing the borrower who failed at the first stage gets nothing since he will discontinue the project. Consequently, the result that bilateral financing provides better incentives to engage in first-stage research (when $P \leq \frac{1}{2}$) is reinforced.

Finally, consider the possibility that an invention at $t = 2$ requires some capital, I_3, to introduce it to the product market. Now, with inventions by both firms, the product-market rent V can be captured if and only if one of the two inventors invests I_3. In a world of complete contracts, firms would maximize expected profits by signing an agreement whereby: (a) in case of joint invention only one firm invests I_3 and enters the market, and (b) the firm that acquires acknowledge at the interim stage discloses its knowledge to its competitor. Since collusion prevents rent dissipation in the postinvention product market, information disclosure is now first-best optimal (since $P > Q$) regardless of P, in contrast to Lemma 1. In such a world, the firms' incentives to invest in first-stage research could be further enhanced by ensuring that, in the case of interim knowledge disclosure, the interim knowledge provider is chosen to be the one that enjoys the postinvention rent.

Because of contract incompleteness, such an agreement is unenforceable. However, multilateral finance provides a mechanism to implement the (constrained) efficient solution. Since no rent is dissipated in product market competition, lenders maximize their overall expected repayments by maximizing the probability of invention. Product market collusion will occur because banks that lend to firms in the same industry have the incentive to coordinate and finance market entry of only one of two inventors.

Let the interest rate at which firms can obtain financing of I_3 from their lenders at the market-entry stage be preset contractually, and let it equal the safe rate of interest. Then there will be no further scope for competition in providing financing at date $t = 2$, and lenders will earn the same payoff irrespective of which inventor receives the loan of I_3. Lenders can then credibly commit ex ante to finance entry only by the interim-knowledge provider in the event of multiple inventions.

In contrast, under bilateral finance, the privacy of interim knowledge is preserved, and hence some of the ex ante surplus is lost, now even when $P > \frac{1}{2}$. Moreover, in the event of multiple inventions, each lender will wish that its own borrower is the sole market entrant. Collusion occurs only if lenders can commit ex ante to a randomized strategy for permitting product-market entry. However, this strategy is now independent of the outcome of the first-stage knowledge of their borrowers. Hence, the relative advantage of bilateral finance in motivating first-stage research, when $P \leq \frac{1}{2}$, will be reduced. This issue, as well as the possibility of repeated lender–borrower interactions creating even greater incentives for R&D and information sharing, deserves further study.

VI. CONCLUDING REMARKS

This paper has explored the idea that financiers may act as facilitators of knowledge sharing in environments where a market for such proprietary information cannot exist. We have considered informational environments where: (i) a firm's knowledge is proprietary, in the sense that disclosure to competitors in product markets can reduce the private value of such knowledge, (ii) a lender in the process of monitoring learns its borrowers' interim research knowledge, and (iii) a market for selling such proprietary information is made infeasible by legal nonverifiability of such knowledge. In such an environment, knowledge transfer among firms through a common lender is shown to be a partial substitute for explicit contractual mechanisms.

We have focused on the comparative allocational properties of bilateral and multilateral financing, allowing for both long- and short-term debt. We have shown that with multilateral financing (i) information sharing among firms takes place if and only if it is in the lenders' interest, and that this coincides with the first-best criterion, and (ii) a collusive mechanism may be structured so that in equilibrium only one firm among multiple inventors enters the product market. However, the prospect of disclosure of proprietary knowledge to a borrower's competitor creates a free-rider problem regarding a firm's incentive to invest in R&D. This problem does not arise under bilateral financing (especially with long-term debt), because the privacy of proprietary knowledge is always preserved. Hence, when incentive problems are very important, multilateral financing may be replaced by bilateral financing.

Finally, we have shown that with multilateral and possibly also bilateral financing, incentives to make privately observed investments in R&D are enhanced by recontracting possibilities at the stage new information is acquired, and this amounts to issuing short-term debt. Indeed, the use of short-term debt with multilateral financing may lead to efficient elimination of at least one of the firms engaged in R&D, thus reducing duplication; the evidence in Sako (1995) supports this thesis.

The main contribution of our paper is that it shows how the choice of financing source can serve as a precommitment device for pursuing ex ante efficient (but not necessarily ex post incentive compatible) strategies in knowledge-intensive environments. The implications of this general idea for a theory of comparative financial systems, and their implications for equilibrium knowledge sharing (and thus growth), should be pursued further in future research.

APPENDIX A

LEMMA 2. *Multilateral financing with short term debt when $P \leq \frac{1}{2}$.*

Proof. We show here that given that R_1 satisfies (17), an equilibrium in (S, F) necessarily involves information sharing among borrowers. Suppose counterfactually that no information sharing is an equilibrium. Then, we must have the following:

(i) banks' offers are:

$$\tau_F' = \tau_F > V, \tag{A1}$$

and

$$\tau_S' = \tau_S = \tau,$$

satisfying

$$P(1 - Q)\tau = R_1 \tag{A2}$$

and

(ii) bank $j \neq i$, offering τ'_F and τ'_S is the optimal response to bank i offering τ_F, τ_S, where τ'_F, τ'_S τ_F, and τ_S are defined by (A1) and (A2).

Given the loan refinancing offers in (A1) and (A2), the successful entrepreneur refinances $(\frac{1}{2})R_1$ from each bank. The F-type borrower defaults on his first-period debt, losing control at the second stage, thereby leaving no scope for banks to share information across borrowers. Bank i's, $i = 1, 2$ payoff with the combination of strategies defined by (A1), (A2), π, is then

$$\pi = (\tfrac{1}{2})R_1 + (\tfrac{1}{2})Q(1 - P)V. \tag{A3}$$

We now show that condition (ii) fails to hold. Given bank i's offers τ_F and τ_S, bank $j \neq i$ is better off by offering

$$\tau'_F = V \tag{A4}$$

and

$$\tau'_S > \tau_S. \tag{A5}$$

Given bank j's offers {(A4), (A5)}, the S-type borrower repays $(\frac{1}{2})R_1$ to bank j by borrowing from bank i, whereas the F-type borrower repays $(\frac{1}{2})R_1$ to bank i by borrowing from bank j. Because bank j, the deviant, has no more claims on the R&D project of the S-type, it finds it optimal to disclose the interim knowledge to the (originally) F-type borrower. By so doing it raises the value of its claim on the F-type's project to $VP(1 - P) > VQ(1 - P)$. The expected payoff to bank j deviating, π_d, is then:

$$\pi_d = [P(1 - P)V], \tag{A6}$$

which is profitable, i.e., $\pi_d > \pi$, comparing across (A6) and (A3), since

$$V[2P(1 - P) - Q(1 - P)] > R_1, \tag{A7}$$

given that R_1 satisfies inequality (17), and $P > Q$. Hence, an equilibrium in (S, F) cannot be one where information is not shared across borrowers.

Q.E.D.

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