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R&D Cooperation and Competition

In the United States, we largely rely on market forces to give private firms the incentive to conduct research and development. Firms conduct R&D because it can generate the knowledge to produce new products or to produce existing products at lower cost; firms can use the knowledge directly or they can sell it for others to use in production.

Because such a sale of R&D results occurs *after* the R&D has been undertaken, it is a form of ex post cooperation. In recent years, partly because of the rising concern over national competitiveness, the effectiveness of market forces in spurring private firms to conduct R&D has been questioned. Empirical studies have found that the social benefit from R&D may be greater than the benefit available to the innovator. Bernstein and Nadiri, for example, estimate that the social rates of return to R&D investment in both the chemical products and nonelectrical machinery industries were roughly double the corresponding private rates of return in 1981. And they found that the social rate of return was approximately ten times the private rate in the scientific instruments industry.[1]

At a fundamental level, the gap between social and private incentives arises because an individual profit-maximizing firm ignores the effects that its actions have on the welfare of consumers and on the profits of

We thank Ken Rogoza and Jin-Soo Yoo for their research assistance. We are grateful to Benjamin Hermalin, Suzanne Scotchmer, Philip Webre, and the participants of the Brookings Panel on Microeconomics and the Berkeley Industrial Organization seminar for their helpful comments. We also thank our two discussants, who cheerfully undertook the task of wading through a rather murky first draft. Last, Ordover would like to thank the Yale School of Organization and Management for its hospitality while this paper was written.

1. Bernstein and Nadiri (1988, p. 433).

other firms. Hence, to the extent that private R&D activities raise consumer surplus or generate positive externalities that accrue to other firms, the incentive to conduct private R&D is too low. Of course, to the extent that the externalities associated with R&D are negative, the private incentive is too high.

A variety of economic and political forces can produce a spread between private and social incentives to conduct R&D. Technological "spillovers" are one source of divergence: if one firm can employ the research done by another firm without purchasing the right to do so, then the private investment incentive tends to be too low because the firm making the investment decision does not count the spillover as a benefit.[2] And when the spillover may accrue to product-market rivals, it further lowers the incentive of the potential innovator to conduct R&D, relative to the social incentive, because the work may strengthen competitors.[3]

A second source of divergence between private and social incentives to conduct R&D is that the production of new or cheaper products frequently depends on access to complementary technologies and products. To the extent that the incremental rents from production accrue to the owners of the complementary processes or products, the private incentives for R&D investment are diminished relative to the social incentive.

Government policies are a third source of divergence when they stilt the private returns to R&D investment. Many analysts have argued that the United States has pursued mistaken and outdated antitrust policies that limit the ability of U.S. firms to compete in global high-technology markets. In this view, the U.S. error is compounded by the fact that Japan and some other nations have successfully pursued aggressive

2. Indeed, R&D spillovers are the source of the divergence between the social and private rates of return to R&D capital estimated by Bernstein and Nadiri (1988) and reported above.

3. Levin (1988) points out that, as a matter of theory and (for the firms in his sample) practice, a high level of technological spillover does not necessarily reduce the amount of R&D conducted. In fact, to the extent that the spillover of R&D from other firms complements an innovator's own investment and raises its marginal return, spillovers may actually encourage more R&D investment. For our purposes, the key point is that technological spillovers create a substantial wedge between private and social R&D investment incentives, whatever the sign of their effect on private incentives alone.

industrial policies designed to foster technological leadership and to secure market share.

A fourth source of the divergence between private and social R&D investment incentives can arise in the sale of R&D results: when a firm is unable to appropriate fully the benefits generated by the sale of its R&D results to other firms, its incentive to innovate is lower than the social incentive.[4] For instance, in the absence of perfect discrimination, an innovator is unable to appropriate all of the surplus generated by the dissemination of its R&D results even when it has airtight intellectual property rights. Moreover, in many cases, property rights are not airtight, and technological spillovers can limit an innovator's bargaining power in selling or licensing its results.

The inability to appropriate all the gains from the ex post sharing of R&D results has two negative effects on a firm's incentive to conduct R&D: (1) it reduces the expected return to innovation; and (2) since a firm can gain from the R&D conducted by its rivals, it reduces the firm's potential loss from failing to conduct its own R&D.

The innovators' inability to appropriate fully the gains from ex post cooperation also points to weakness in the private incentives to share R&D findings. The fact that the costs of distributing the knowledge generated by R&D are low relative to the costs of discovery implies that the wide dissemination of results is most efficient. For several reasons, however, private firms have inadequate incentives to share the fruits of their R&D programs. The innovator's inability to price discriminate perfectly typically leads the firm to sell its R&D results at prices that induce inefficiently low levels of utilization by other firms. Moreover, this failure to engage in ex post cooperation may lead competing firms to respond by wastefully duplicating research. Also, by the nature of information, problems of opportunism and asymmetric information can greatly limit the effectiveness of the market for R&D results and lead to inefficiently little dissemination of knowledge. In particular, it may be difficult to sell information because the value of the good is hard to evaluate before it is transferred from the buyer to the seller, and information that has been "loaned" to the buyer for evaluation often is difficult to take back.

4. This source of divergence can be thought of as a horizontal bargaining problem, and the second source of divergence can be thought of as a vertical bargaining problem.

In sum, concerns about the level of private R&D in the United States resolve into two: (1) private firms may have incentives to conduct R&D that diverge from the social incentives; and (2) if only ex post cooperation is feasible, private firms may fail to share their R&D output with other firms when such sharing would be socially beneficial.

The gap between private and public returns to R&D investments and the failure of firms to share sufficiently the fruits of their R&D projects can be addressed through three types of policy: (1) direct or indirect subsidies to restore incentives, (2) strengthening incentives to engage in ex post cooperation, and (3) encouraging greater ex ante cooperation.

Tax policies and direct subsidies have been widely used in the United States to raise private R&D incentives. Of the $124.9 billion spent on private R&D in the United States in fiscal year 1988, 47 percent came in the form of direct subsidies from the federal government.[5] Tax policy has been used as well. The Economic Recovery Act of 1981, for instance, provided a 25 percent tax credit for incremental R&D expenditures over the average of the previous three years; the Tax Reform Act of 1986 extended the credit at a rate of 20 percent, and later congressional action extended the credit through 1989.[6]

Spence examined subsidies and concluded that they can be effective in markets where technological spillovers are high.[7] Unfortunately, a policy of relying on subsidies to correct R&D market failures has potentially serious shortcomings. It does not correct the insufficient dissemination of R&D results and thus is ineffective in markets where technological spillovers are low. Moreover, such a policy may be subject to severe moral hazard: firms may engage in specious R&D projects (attempting, say, to count production employees as research personnel) to collect subsidies. Indeed, Brown found that the increases in R&D expenditures reported on tax forms in response to the Economic Recovery Act of 1981 greatly exceeded the growth in spending reported in *Business Week*'s survey of R&D expenditures.[8]

Even if subsidies do raise the level of true R&D, they may further distort the incentives in some industries rather than correct them—

5. National Science Foundation data cited in *Economic Report of the President* (1989, p. 226).
6. *Economic Report of the President* (1989, p. 239).
7. Spence (1984).
8. Brown (1984).

several authors have shown that firms can have socially excessive incentives to conduct R&D.[9] And as Dixit and Grossman have pointed out, shifting resources to one sector means taking them away from another.[10] It is difficult to see why the government should be good at picking "winners" to subsidize. Finally, raising the necessary subsidy revenues through the tax system gives rise to deadweight losses and in any event may be politically infeasible.

Our focus in this essay is on the two approaches that seek to restore private R&D incentives through market forces—rather than government intervention—by improving the incentives to share results. Improving ex post R&D cooperation is one such approach. Such a policy would have two principal components. First, it would expand and strengthen intellectual property rights; for example, patent and copyright laws could be written to provide broader protection, and they could be more strictly enforced to reduce spillovers and increase private appropriability. The second component would give firms greater leeway and control in structuring ex post sharing arrangements; for example, patent holders might be allowed to place greater ancillary restrictions on the behavior of licensees.

Strengthening intellectual property rights can improve market performance by making both R&D investment and the sharing of R&D results more attractive. Stronger property rights strengthen the incentives to conduct R&D because they allow a firm to appropriate more fully the benefits of innovation, thereby reducing the gap between private and social benefits. Stronger property rights improve appropriability in two ways. First, if the firm chooses not to share its R&D results with others, it will not have to contend with spillovers that dilute the value of its investment. Second, stronger intellectual property rights make licensing more profitable by putting the licensor in a better bargaining position—the licensee cannot otherwise rely on spillovers. In fact, stronger intellectual property rights may be needed to make licensing feasible. Strong intellectual property rights reduce the risk that innovators will lose control of information revealed to interest potential buyers. Weak intellectual property rights encourage firms to rely on

9. See Reinganum (1989) for a summary of this literature. Wright (1983) presents an insightful analysis of the problems of subsidizing research when the government has poorer information about the costs and benefits of R&D than do the firms undertaking it.

10. Dixit and Grossman (1986).

secrecy to protect their R&D investment, making the sale of the information difficult if not impossible. By allowing the firm to earn greater revenues from licensing, strengthened patent and copyright protection raises the incentive for R&D investment and improves the extent of ex post dissemination of R&D results, particularly when accompanied by a relaxation of antitrust constraints on the permissible restrictions in intellectual property licensing agreements.

Recent policy has tried to encourage greater ex post cooperation. Since 1983, the Congress has passed fourteen laws strengthening protection of intellectual property rights. Also, the 1982 creation of the Court of Appeals for the Federal Circuit established a single forum for all patent appeals and appears to have increased the enforceability of patents: it has upheld patent rights in 80 percent of the cases that it has heard, compared with the pre-1982 rate of about 30 percent.[11]

A policy of stronger intellectual property rights does not come without costs. Arrow and Spence have separately pointed out that, by limiting the degree of spillover, the policy may reduce the efficient sharing of R&D.[12] Technological spillovers have the socially beneficial effect of forcing firms to share their R&D output. Although dissemination may continue under a regime of strong intellectual property rights, it may do so at inefficient prices, that is, at prices that exceed the marginal cost of dissemination. In contrast, dissemination through spillovers occurs at socially optimal prices.[13] Consequently, public policies that favor appropriability in order to raise R&D investment incentives could reduce the extent to which the results of successful R&D projects are disseminated.

When policies to strengthen appropriability reduce the extent to which firms share intermediate findings, the aggregate productivity of R&D investments might decline (even if aggregate R&D rose), with potentially adverse consequences for the overall competitiveness of firms and industries. Stronger intellectual property rights policies also can reduce R&D investment incentives. Green and Scotchmer found that a policy of broader patent protection may increase the incentive to be the creator

11. *Business Week* (May 22, 1989, p. 82).
12. Arrow (1962) and Spence (1984).
13. However, to the extent that firms expend resources on reverse engineering or corporate spying, reliance on spillovers is an inefficient means of dissemination.

of a first-generation innovation, but it may reduce the incentive for others to produce follow-on innovations.[14] A similar analysis could be applied to the development of complementary, as opposed to successive, innovations. The current, often heated debate in the software industry about the effects of granting patents rather than the traditional copyright illustrates the importance of these concerns.

A policy of relaxing antitrust scrutiny of licensing and other ex post cooperative agreements also has risks. The biggest concern is that firms will use licensing contracts as a means to subvert competition in markets for downstream products. In theory, at least, firms could use dummy licensing agreements that entailed no exchange of information but imposed royalties that induced firms to behave like a cartel in a downstream product market.[15]

In summary, a greater reliance on ex post cooperation has potential costs as well as benefits and will not solve all of the possible market failures.

The other market-oriented approach is to place greater reliance on ex ante R&D cooperation, which refers to any agreement to share the benefits of a future R&D project. Such an agreement may include provisions for sharing the cost or effort of conducting the R&D. Research joint ventures (RJVs) are a prominent form of ex ante cooperation that covers a wide variety of arrangements. One type of RJV is a traditional joint venture, in which two or more parties create a separate entity in which they all have equity interests to conduct well-defined R&D projects for their benefit. Another type of RJV is the research consortium, which may pursue broad programs in basic R&D in those areas where appropriability and spillovers are especially pervasive; and a third form of RJV is the venture capital investment by market leaders in a stand-alone startup company. Ex ante cooperation is not limited to RJVs. A royalty-free cross-licensing agreement, under which firms agree in advance to share R&D results but not R&D costs is another form of ex ante cooperation. Agreements among firms to let their research personnel share ideas or to let the employees of one firm tour the plant of another are still another form of ex ante cooperation.[16]

14. Green and Scotchmer (1989).

15. This possibility is discussed briefly in Katz and Shapiro (1985) and Shapiro (1985).

16. Even without a formal agreement, such tours may be considered to be ex ante cooperation when they are part of an industry custom that all participants expect to continue.

In recent years, many have clamored for the government to encourage, or at least not discourage, ex ante cooperation. The best-known legislation on this point is the National Cooperative Research Act of 1984 (NCRA).[17] Under the provisions of the NCRA, firms that notify the Federal Trade Commission and the U.S. Department of Justice of their intent to enter into a joint R&D agreement can reduce their exposure in private antitrust litigation. In particular, with such notice a per se standard cannot be applied to their joint R&D activities and damages are not trebled under any adverse finding. The NCRA, however, excludes from the definition of "joint research and development venture" various important activities in which co-venturers might engage. The act does not, for example, protect the exchange of information regarding costs, sales, profitability, prices, marketing, or distribution that is not reasonably required to conduct the stated R&D activities of the venture. Consequently, the act provides only a limited reduction in antitrust risks that potential joint venturers might face.

Several new pieces of legislation in this area are pending. The National Cooperative Research and Production Amendments of 1989 (H.R. 1025), the Cooperative Productivity and Competitiveness Act of 1989 (H.R. 2264), and the National Cooperative Research Act Extension of 1989 (S. 1006) all follow the principles embodied in the NCRA but extend protection to the joint production, manufacture, and marketing of any product, process, or services that are the outcome of cooperative R&D. Another bill, the National Cooperative Innovation and Commercialization Act of 1989 (H.R. 1024) provides for a complex approval process that would immunize approved cooperative arrangements from the finding of per se illegality and would limit recovery in civil and criminal cases to reasonable attorney's fees. Finally, the High Definition Television Development Act of 1989 (S. 952) extends the protection of the NCRA to the whole range of activities relating to the development and manufacture of high-definition receivers by domestic firms.

What benefits can be expected from the ex ante cooperation these bills seek to encourage? A simplistic view of the R&D process identifies two primary benefits of ex ante cooperation:

(1) *Greater amount of R&D investment.* An ex ante cooperative R&D agreement can serve as a mechanism that internalizes the exter-

17. 15 U.S.C. Para. 4301 et seq.

nalities created by technological spillovers while continuing the efficient sharing of information. This internalization is accomplished by having firms commit themselves to paying the innovator (possibly an RJV) before the R&D is conducted and, hence, before any spillovers can occur. By internalizing positive R&D spillovers across firms, R&D cooperation may raise the incentive to conduct R&D and hence the total amount of R&D investment.

(2) *Greater efficiency of R&D investment.* To the extent that cooperative R&D is more widely disseminated than individually conducted R&D, ex ante cooperation increases the efficiency of R&D efforts because a single investment benefits a greater number of firms. This efficiency gain has three types of positive effects. First, sharing lowers the cost of investment for each firm, which may induce them to conduct more R&D. Second, even if ex ante cooperation leaves the total amount of R&D investment unaffected or slightly reduced, it might increase the effective amount of R&D. Third, cooperative R&D eliminates the wasteful duplication that would occur if several firms separately undertook the same projects. Even if several firms continue to conduct separate R&D under an ex ante agreement, they still can improve the efficiency of their efforts by coordinating them to insure that the industry has a diversified portfolio of projects. Before reaching any conclusions about the effects of ex ante cooperation on R&D investment levels, we need to make a careful assessment of what drives R&D investment.

The problem with this view is that it is simple-minded. For example, the argument that cooperation raises R&D investment incentives need not be true. When the firms conducting R&D are product-market rivals, R&D investment by one firm may harm the others. In this case, the externality across firms may be a negative one, so that the effect of cooperation is to reduce the incentive to conduct R&D.

Similarly, a careful assessment of the possibilities in the absence of ex ante cooperation must precede any conclusions on the effects that such cooperation has on the dissemination of R&D results. One possibility in the absence of ex ante cooperation is that each firm would conduct R&D for itself only. Another possibility, at least in some cases, is that firms would engage in ex post cooperation such as patent licensing. To ignore these other possible means of cooperation (say, through a model in which firms either share their R&D ex ante or not at all) is to attribute too many benefits to ex ante cooperation. Indeed, circumstances exist, at least in theory, in which ex ante cooperation leads to less dissemination than would ex post cooperation.

In the remainder of this essay, we examine the question of whether ex ante R&D cooperation can be an effective means of correcting the market failures identified here. First, we present a series of simple models to illustrate the fundamental insights that theory can contribute to this debate. Next, we take a brief look at recent experience with ex ante cooperation and then turn to a somewhat more detailed examination of three research consortia. Case studies are particularly valuable in this area because the details of organizational structure may be important determinants of the effects of R&D cooperation, and to date little work has been done analyzing these issues from a theoretical perspective. The paper closes with a brief discussion of public policy.

Theory

The effects of ex ante cooperation on R&D activity can be usefully divided into two broad categories: (1) firms' collective incentives to invest in R&D may differ from their individual incentives, and thus the investment choices arising from cooperative decisionmaking may differ from those that would arise from individual decisionmaking. And (2), ex ante cooperation may alter the relationship between R&D investment and the production and dissemination of R&D results; an ex ante agreement may affect both the efficiency with which R&D is conducted and the pattern of dissemination of the R&D results.

It is easier to understand the basic forces at work if we artificially consider each set of effects in turn. We start out by assuming that ex ante cooperation has no effects on the extent to which an innovation is disseminated or on the nature of R&D itself. We turn to consideration of these sorts of effects later.

Cooperative Decisionmaking

The basic effects of joint R&D on investment incentives can be illustrated by a model of extremely reduced form. Let e_i denote the dollar investment in R&D by firm i.[18] Let **e** denote the industry vector of effort levels. Given the system of intellectual property rights, contract law, the underlying R&D production function, the existing production technology, and the nature of product-market competition, we can summarize the profit levels that result from a given set of R&D effort levels with the reduced-form profit function, $\pi_i(\mathbf{e})$. Note that π_i is the profit of firm i measured *net* of its expenditures on R&D.

Suppose that the sole collective activity of some group of firms is to set their individual levels of R&D effort to maximize the sum of their profits. One can think of this collective decisionmaking as being implemented through R&D cost-sharing rules or through a system of side payments based on the results of the individual R&D programs. Let J_i denote the set of firms that belongs to the same coalition as firm i. For simplicity, we assume that each firm belongs to, at most, one coalition. We denote the absence of any joint decisionmaking by writing $J_i = \{i\}$ for all i.

When the number of firms in the R&D market is fixed, Nash equilibrium entails each firm's investing in R&D until the marginal contribution to the coalition's expected profits is zero given the other firms' investment decisions:

$$\partial\pi_i(\mathbf{e})/\partial e_i + \sum_{\substack{j \neq i \\ j \in J_i}} \partial\pi_j(\mathbf{e})/\partial e_i = 0. \tag{1}$$

Condition 1 shows that adding firms to a coalition may raise or lower incentives depending on whether R&D investment by one firm helps or hurts the others, that is, depending on the sign of $\partial\pi_j(\mathbf{e})/\partial e_i$.[19] An important task for the analysis below thus is to determine the sign of this effect.

Before doing so, consider briefly the social incentives to innovate, which we take to be the change in total surplus, the sum of profits and consumer surplus.[20] Let $S(\mathbf{e})$ denote the level of expected consumer

18. It is straightforward to extend the analysis by allowing e_i to be some complex, multidimensional measure of the firm's research strategy.

19. By focusing solely on first-order conditions, we are being somewhat cavalier about the technical details. Since our results are at best suggestive in any case, we will not worry about these issues further.

20. The implicit assumption here is that labor and other input suppliers receive no rents. While this assumption is inconsistent with the evidence—for example, Katz and Summers (1989)—it simplifies the analysis without changing the basic conclusions.

surplus associated with R&D investment $\mathbf{e}$. If positive, the welfare-maximizing level of R&D for firm i satisfies the first-order condition

$$(2) \qquad \partial\pi_i(\mathbf{e})/\partial e_i + \sum_{j \neq i} \partial\pi_j(\mathbf{e})/\partial e_i + \partial S(\mathbf{e})/\partial e_i = 0.$$

Comparing equations 1 and 2, we find two differences between a firm's private incentive and the social incentive. One, a firm ignores its effects on consumer surplus. Two, a firm ignores its effects on the profits of nonmember firms.

For an industrywide coalition, the second effect does not arise. Hence, whether cooperation results in too little or too much R&D depends on whether consumer surplus is an increasing or decreasing function of R&D investment. For process R&D, and for most product R&D, we would expect $\partial S(\mathbf{e})/\partial e_i > 0$. Hence, the typical case is one in which industrywide cooperation leads to less than the first-best amount of R&D investment. Of course, this fact does not rule out the possibility that the cooperative outcome is superior to the equilibrium that obtains under individual decisionmaking. When $\partial\pi_j(\mathbf{e})/\partial e_i > 0$, cooperation raises the amount of R&D and moves the equilibrium closer to the first best. If welfare is a quasiconcave function of R&D investment, cooperation thus leads to a welfare improvement. The difficult case for welfare analysis is one in which $\partial\pi_j(\mathbf{e})/\partial e_i < 0$. In this case, cooperative decisionmaking lowers the amount of R&D, but we cannot be sure whether the initial level was too high or too low.

The case of cooperation that is less than industrywide raises the question of how nonmembers respond to changes in the R&D levels of the member firms. This comparison is made especially difficult by the fact that one cannot obtain a sensible welfare measure simply by summing R&D expenditures across firms and asking what happens to the total. We will touch upon this issue briefly later.

The reduced form does not reveal which sign for $\partial\pi_j(\mathbf{e})/\partial e_i$ is reasonable or allow for changes in the extent of sharing. To proceed, we need to understand what underlies the reduced-form relationship between R&D investment and profits—we need a more explicit model of R&D competition. The bulk of the theoretical economics of R&D has been built on models of a patent race in which firms compete to develop an innovation. The firm that first develops the innovation is the winner of the race and receives a patent granting that firm exclusive use of the innovation. We will use a generalization of the standard patent race.[21]

Consider a market in which n firms are competing in a race. Let $p_i(\mathbf{e})$ denote firm i's chance of winning the race (obtaining a patent) when the industry vector of R&D levels is $\mathbf{e}$.[22] In this framework, we can write the *change* in firm i's expected profit due to R&D as

$$(3) \qquad \pi_i(\mathbf{e}) = p_i(\mathbf{e})W + \sum_{j \neq i} p_j(\mathbf{e})L - e_i,$$

where W is the change in the firm's profits when it wins the race in comparison with the situation in which no firm wins, and L is the change in the firm's profits when one of the other firms wins the race in comparison with no firm's winning. To simplify the analysis, we assume that the values of W and L are the same for all firms.

One can think of W and L as representing the profits earned when the firms choose their prices and outputs in the downstream product markets given the technologies and costs that they have obtained as a result of their R&D. At this level of generality, the values of W and L can incorporate the effects of ex post licensing, imitation, or inventing around the winner's patent. Under these interpretations, L represents the expected value of being a licensee, imitating the original innovation, or playing in the continuation race to be the second innovator. In these cases, L may well be positive.

What are a firm's incentives to conduct R&D in this setting, and how are they affected by cooperative decisionmaking? As noted above, the sign of the $\partial\pi_j(\mathbf{e})/\partial e_i$, $i \neq j$, is critical for determining the effects of joint decisionmaking under ex ante cooperation. Taking this derivative and combining terms, we obtain

$$(4) \qquad \partial\pi_j(\mathbf{e})/\partial e_i = \partial p_j(\mathbf{e})/\partial e_i\, W + \sum_{k \neq j} \partial p_k(\mathbf{e})/\partial e_i\, L - \delta_{ij},$$

21. Alternatively one could consider a static model, such as the one introduced by Spence (1984), in which R&D investment leads to some level of R&D capital. In this setting, we can write the reduced-form profits as $\pi_i = V_i[\mathbf{c}(\mathbf{e})] - e_i$, where $\mathbf{c}$ is a mapping from R&D investment levels to cost levels and V_i is a reduced-form profit function that maps marketwide cost vectors into profit levels for firm i. If $\mathbf{c}(\cdot)$ were stochastic, this model would be a generalization of a patent race.

22. This model might not seem like one of a race because time does not explicitly enter. The model should be viewed as a reduced form in which time has been collapsed. Reinganum (1989) summarizes several models with similar structures but in which the timing is explicit.

where δ_{ij} is equal to 1 if $i = j$, and 0 otherwise.

We can use equation 4 to explore the effects of cooperative decisionmaking that internalizes the externalities across firms. We can greatly simplify the presentation by confining our attention to symmetric spillovers: for symmetric $\mathbf{e}$, $\partial p_j(\mathbf{e})/\partial e_i = \gamma(\mathbf{e})\partial p_i(\mathbf{e})/\partial e_i$ for all $j \neq i$. We also restrict attention to markets in which firm i's chance of winning rises at least as much from an increase in e_i as does that of any other firm. Finally, we assume that an increase in e_i does not decrease the chance of at least one firm's winning the race. Formally, we assume that $\partial p_i(\mathbf{e})/\partial e_i > 0$ and $\gamma(\mathbf{e}) \in [-1/(n - 1), 1]$.

We can simplify the notation below by defining $\alpha = L/W$. We assume throughout that a firm gains from winning and would rather win than lose: $W \geq 0$, and $W \geq L$. Given these assumptions, $\alpha \in (-\infty, 1)$. In terms of our new notation, equation 4 becomes

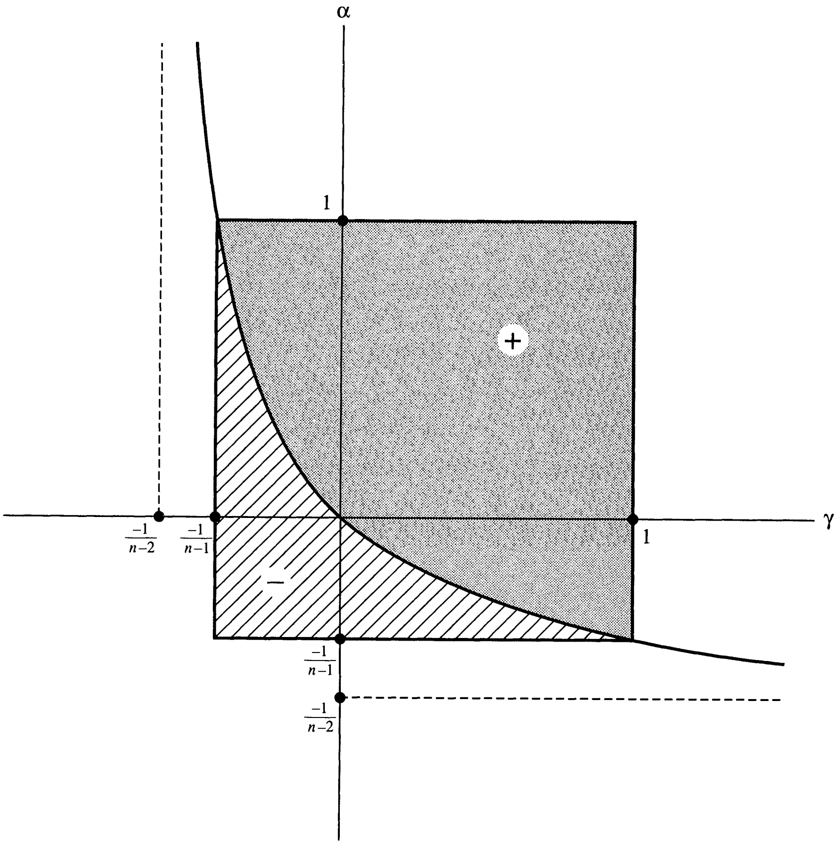
$$(5) \qquad \partial \pi_j(\mathbf{e})/\partial e_i = \partial p_i(\mathbf{e})/\partial e_i \, W\{\gamma[1 + (n - 2)\alpha] + \alpha\}$$

for symmetric $\mathbf{e}$ and $j \neq i$. From this expression, we see that cooperative decisionmaking raises R&D incentives if and only if $\gamma[1 + (n - 2)\alpha] + \alpha > 0$. Figure 1 presents this result graphically, but the picture is not immediately helpful. To what do the different values of α and γ correspond? Does equation 5 suggest that cooperative decisionmaking is likely to raise or lower R&D investment incentives? To answer these questions, it is useful to think of the externalities as being of two types: *competitive spillovers* and *technological spillovers*.

COMPETITIVE SPILLOVERS. Suppose that, without ex ante cooperation, each firm's R&D results depend only on its own effort, that is, there are no technological spillovers. This case arises when there is strong intellectual property protection either through patent and copyright laws or because firms are able to keep their innovations secret. Even with strong intellectual property protection, R&D investment by one firm may affect other firms through competition in the R&D market and in the product market.

R&D-market effects arise when R&D by one firm allows it to obtain intellectual property rights that block, or at least retard, successful innovation by other firms. The effects of R&D-market competition can be captured in two ways. One, the chance of firm j's winning falls as the level of R&D by firm i rises. As firm i increases its R&D investment, there is a greater likelihood that firm i will beat firm j. Moreover, when

Figure 1. Effects of Cooperative Decisionmaking on R&D[a]



a. Plus sign indicates cooperative decisionmaking leads to increased R&D.

firm i devotes more resources to R&D, it may patent intermediate results that make it costly for other firms to succeed in obtaining the principal innovation—they are forced to invent-around these intermediate patents. For either reason, one may have $\partial p_j(\mathbf{e})/\partial e_i < 0$ and thus $\gamma < 0$. The second way in which to capture R&D-market competition is through the size of α. If one interprets W and L as the values of playing a continuation game, greater blocking through intellectual property rights corresponds to lower values of L, higher values of W, and thus lower values of α.

Competitive spillovers may also exist in the product markets. These product-market effects also can be captured through assumptions about the size of α. When the firms are in unrelated downstream markets and no spillovers exist in the R&D market, $L = 0 = \alpha$. When firms are product-market rivals, however, an improvement in one firm's technology or product typically leads to increased competition that harms the other firms in the industry. Hence, when the innovators produce substitute products in the output market, product-market rivalry yields negative values of L and, hence, of α. On the other hand, when the products are complements, say through vertical linkages, product-market spillovers lead to positive values of α.

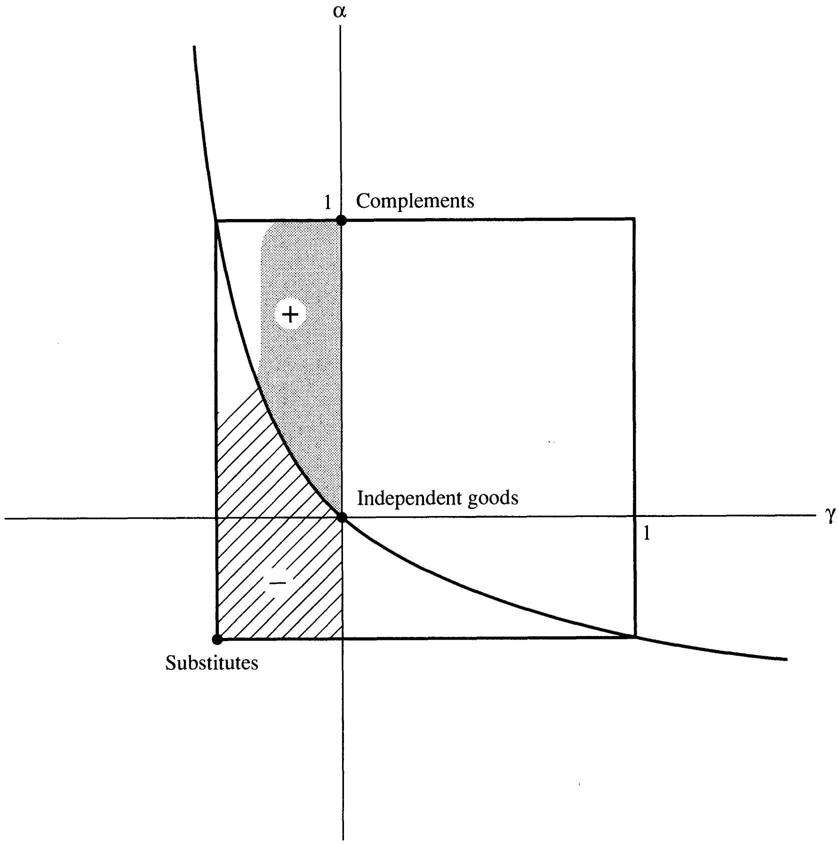
Figure 2 reproduces figure 1 and labels the different parameter values in terms of the degree of rivalry in the product market.[23] The resulting pattern suggests the following tentative conclusion: *Without technological spillovers, cooperative decisionmaking reduces (increases) R&D incentives if the products are substitutes (complements).*

From the industry's perspective, a pecuniary externality exists—a single firm ignores the effects on its rivals' profits that result from an increase in its R&D efforts. Collective decisionmaking internalizes this externality. When the innovators are product-market rivals, both the R&D-market and product-market competitive spillovers are negative, and cooperation leads the firms to undertake less R&D investment.

We are interested in the strength as well as the direction of these effects. The more competitive are venture partners, the stronger is their incentive to cut back on R&D, as compared with the noncooperative level—when product-market rivalry is intense, the benefits of lower production costs largely accrue to consumers. More generally, as the extent of product differentiation decreases, we might expect the competitive spillovers to strengthen and α to fall. The implication of this relationship for ex ante cooperation is that agreements among producers of highly differentiated products may be less likely to lead to a cutback in R&D investment than would agreements among producers of close substitutes. This finding is similar to the one obtained by Katz (1986). There, he explored these issues with a homogeneous-good, conjectural-variations model and with a Dixit-Stiglitz-Spence model of differen-

23. The figure has been drawn to reflect the fact that the effects captured through $\partial\pi_j(\mathbf{e})/\partial e_i$ could be expected to be small if the technologies of the complements are based on largely unrelated technologies.

Figure 2. Effects of Competitive Spillovers with No Technological Spillovers



tiated products. He found that diminishing competition (measured by an increase in the conjectured variation or a rise in the differentiation parameter) shrinks the range of parameter values under which an RJV cuts back R&D.

A natural question is whether this reduction is socially desirable. As already discussed, if consumers benefit from R&D, then industrywide cooperative decisionmaking leads to insufficient investment in R&D. As is well known, however, a patent race with individual decisionmaking can lead to excessive R&D. One can easily construct models showing that the cutback raises welfare and models showing that it lowers welfare. The question of which second-best regime leads to a better outcome is not one to which theory alone can provide a convincing answer.

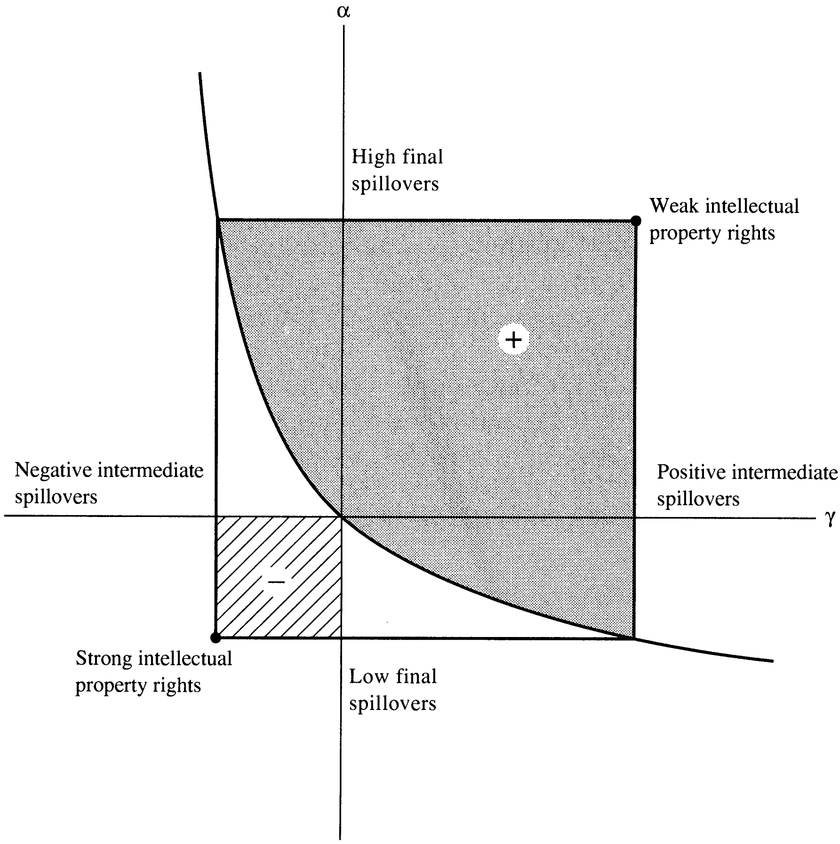
TECHNOLOGICAL SPILLOVERS. As noted at the outset, technological spillovers can create a substantial wedge between private and social returns to R&D investment. Ex ante cooperation often is put forth as an institutional innovation to ameliorate the problems caused by technological spillovers and the resulting incentive wedge. In examining this claim, two types of technological R&D spillover must be distinguished: *intermediate* and *final*. Intermediate spillovers are present when an increase in the R&D level of one firm increases the effectiveness of R&D conducted by rivals. Such a pattern might develop when an R&D project consists of separate tasks or stages that must be completed before a patent can be obtained, and one firm can learn how to complete a stage by observing its rival's success. In the presence of intermediate spillovers, an increase in e_i has two effects on each rival's probability of success. First, as in the absence of technological spillovers, these probabilities are lowered because firm i is more likely to preempt its rivals. The second effect is the new one—in the presence of intermediate technological spillovers, a rival's probability of success, *conditional on not being preempted by firm* i, rises. With sufficiently strong spillovers, γ can be positive.

When patent protection is imperfect, final R&D spillovers may arise once the initial race has been completed.[24] Even though one firm may be said to have won the patent race, rival firms may benefit from the product or process that the winner has developed. For instance, knowledge obtained by an innovator may leak out to rivals, lowering costs industrywide and possibly raising the profits of all firms. Final spillovers affect α through both W and L. When intellectual property rights are imperfect, even those firms that do not obtain the patent may benefit from the innovation, which tends to raise L. And when firms are product-market rivals, such spillovers tend to lower W. In either case, the greater are the final spillovers, the closer is α to 1.

Figure 3 reproduces figure 1. This figure allows us to examine the effects of technological spillovers that depend, in turn, on the strength of intellectual property rights. In the figure, strong intellectual property rights correspond to negative values of α and γ (the lower-left quadrant),

24. Similar sorts of effects arise in the static model of R&D spillovers in Spence (1984).

Figure 3. Importance of Intellectual Property Rights when Products are Substitutes



and weak property rights correspond to positive values (the upper-right quadrant). With complete spillovers (that is, $\gamma = 1$), for instance, the effect on industry profits, gross of R&D costs, is exactly n times the effects on gross profits of a single firm. Hence, if successful innovation raises industry profit (that is, $\alpha > 1/(n - 1)$), cooperation increases R&D investment incentives.[25] This pattern is consistent with the findings of Katz, who shows that ex ante cooperation increases aggregate effective R&D when the potential innovators are product-market rivals

25. If, however, successful innovation lowers industry profit, then there is no individual or collective incentive to conduct R&D, in which case cooperation has no effect.

and final spillovers are substantial.[26] Reinganum obtains a similar result in a model of a continuous-time patent race with intermediate spillovers.[27] These results suggest the following tentative conclusion: *When innovators are product-market competitors and intellectual property rights are strong (weak), cooperative decisionmaking tends to decrease (increase) R&D investment incentives.*

We close this section with a comment on two assumptions that have been implicit in the above analysis. The first is that an ex ante agreement to cooperate on R&D affects the product-market equilibrium only through changes in costs or in product attributes. The formation of an agreement could, however, influence the nature of competition in the product market in several ways:

(1) With a royalty scheme, under which a firm's share of the costs of the cooperative R&D depend on the firm's level of output in the product market, the firm's marginal costs of downstream production would rise.

(2) The firms might form a joint venture to produce the final output. This arrangement would be most worrisome if no independent production existed, because output would then be chosen to maximize joint profits.

(3) A cooperative R&D arrangement might serve as a chance to discuss means of colluding in the product market.

(4) A cooperative agreement might serve as a forum for exchanging information about industry cost or demand conditions. The literature on the theory of information exchange finds that the welfare effects may be positive or negative.[28]

(5) Cooperation may lead to persistent domination of the marketplace by one firm or a handful of firms.[29]

In all five cases, the formation of the R&D joint venture may diminish product-market competition, which tends to lower final output and wel-

26. Katz (1986); and D'Aspremont and Jacquemin (1988).

27. Reinganum (1981).

28. Gal-Or (1985) and Shapiro (1986) provide analyses of the effects of information sharing.

29. This point raises the issue of whether cooperative ventures should be allowed to be exclusive or whether they should be open to all. If the point of a cooperative agreement were to slow the rate of technological progress, then the participants would desire the broadest possible membership.

fare, ceteris paribus. But, as noted above, the collective incentives of firms to conduct R&D may be too low because some of the gains accrue to consumers rather than to the firms. Allowing increased monopoly power in the product market is one way, albeit an inefficient one, to restore the incentives to conduct R&D.[30] The policy decision is similar to that of optimal patent design.

The second implicit assumption was that the international dimension to cooperation and rivalry among firms was important. Our earlier measure of total surplus may be inappropriate for an economy with international trade and investment. In particular, policymakers may want to use a social welfare function that distinguishes between domestic and foreign firms and consumers.[31]

Some American commentators who adopt this social welfare function argue that the private incentives of U.S. firms to reach international cooperative agreements significantly exceed the social incentives.[32] The decision to enter into international technological alliances and licensing agreements can be modeled much like the R&D investment decision. The technology transfer through the cooperative agreement may substantially strengthen the foreign partner and thereby diminish the rents accruing to domestic firms that were not party to the agreement. Consequently, private incentives to enter into collaborative agreements abroad may be stronger than the correct social incentives, depending in part on the effects on consumer surplus. Similarly, the home firm may sell its technology and know-how too cheaply.

The problem of excessively low prices is worst when home firms are in competition with one another either to license existing technologies or to enter into a strategic alliance with foreign firms. When domestic firms compete to license substitute technologies to foreign firms, the domestic firms may well engage in Bertrand-like competition that drives license terms to what are suboptimal levels from the perspective of domestic total surplus. Each domestic firm may reason that if it does

30. D'Aspremont and Jacqueman (1988) present a duopoly example in which allowing the firms to set up a production joint venture in addition to an RJV brings the equilibrium R&D level closer to the first-best level.

31. While it may be relatively straightforward to define a foreign consumer, it may be extremely difficult to define a home firm given extensive linkages among firms and the fact that shareholders may reside in many countries.

32. See, for example, Reich and Mankin (1986); and Uchitelle (1989). For a contrasting view, however, see Reich (1990).

not provide the technology to the foreign firm, another firm will. Domestic welfare would be raised if the competing firms were able to pool their patents and know-how and then collectively behave as a monopolist for purposes of international licensing.[33] Similarly, the government might want to allow firms to cooperate in the exercise of their monopsony power when acquiring knowledge from abroad.

Sharing R&D

To this point, we have restricted the form of ex ante cooperation to the collective setting of R&D investment levels. In practice, ex ante cooperation can entail much more. Indeed, one of the principal reasons put forth for ex ante cooperation is to increase the sharing of R&D results. In this section, we will examine the effects of ex ante cooperation on the dissemination of innovations. To consider such effects properly, one must not focus solely on the ex ante agreement but also consider the possibility of ex post cooperation. In some settings, ex post cooperation will lead to even wider dissemination than will ex ante cooperation.

A DUOPOLY EXAMPLE. A simple example illustrates many of the basic forces affecting dissemination. Suppose that two product-market rivals are engaged in a patent race to obtain a discrete innovation. To examine the firms' explicit choice of the degree of sharing, we introduce some additional notation. Let $g(m)$ denote the change in product-market profits per firm (that is, profits ignoring the costs of R&D) when m firms have the innovation in comparison with no firm's having it. Similarly, let $b(m)$ denote the corresponding change in the product-market profits per firm of the remaining firms that do not have the innovation. For purposes of this example, suppose that $2g(2) > g(1) + b(1)$—the duopolist's joint profits are greater when both have the innovation than when only one does.

Given this assumption about profits, ex ante cooperation would be expected to result in both members' receiving the innovation. But before concluding that ex ante cooperation leads to greater dissemination, we need to know what would happen if the firms relied instead on ex post

33. Similar considerations arise in product markets. This is, in fact, the rationale for the Webb–Pomerance Act, which allows American firms to collude for purposes of selling abroad.

cooperation. When bargaining in the licensing market is efficient, ex post cooperation leads to the joint-profit-maximizing dissemination of the technology. Suppose that only fixed-fee licensing agreements are feasible (say, because informational asymmetries make the monitoring necessary to enforce royalties infeasible); then efficient ex post licensing leads to both firms' obtaining the innovation.[34] In this example, ex ante and ex post cooperation give rise to identical patterns of dissemination.

Even when ex ante and ex post cooperation lead to the same distribution of R&D results, it does not follow that they generate the same R&D investment incentives. Let F be the fixed fee paid by the licensee to the licensor. In terms of our earlier notation, $W = g(2) + F$, $L = g(2) - F$, and the firm's incentive to increase e_i (equation 4) is

$$\partial p_i/\partial e_i\{[1 + \gamma]g(2) + [1 - \gamma]F\} - 1, \tag{6}$$

where, as before, $\partial p_j/\partial e_i = \gamma\partial p_i/\partial e_i$ for $j \neq i$.

If the firms cooperate ex ante, and they agree to conduct no independent research, the joint incentive to conduct R&D is given by the difference between joint profits when both firms have the innovation and joint profits when neither has it:

$$\partial p_i/\partial e_i\, 2[1 + \gamma]g(2) - 1. \tag{7}$$

Taking the difference between equations 6 and 7, we find that R&D investment incentives are higher under ex ante cooperation if and only if

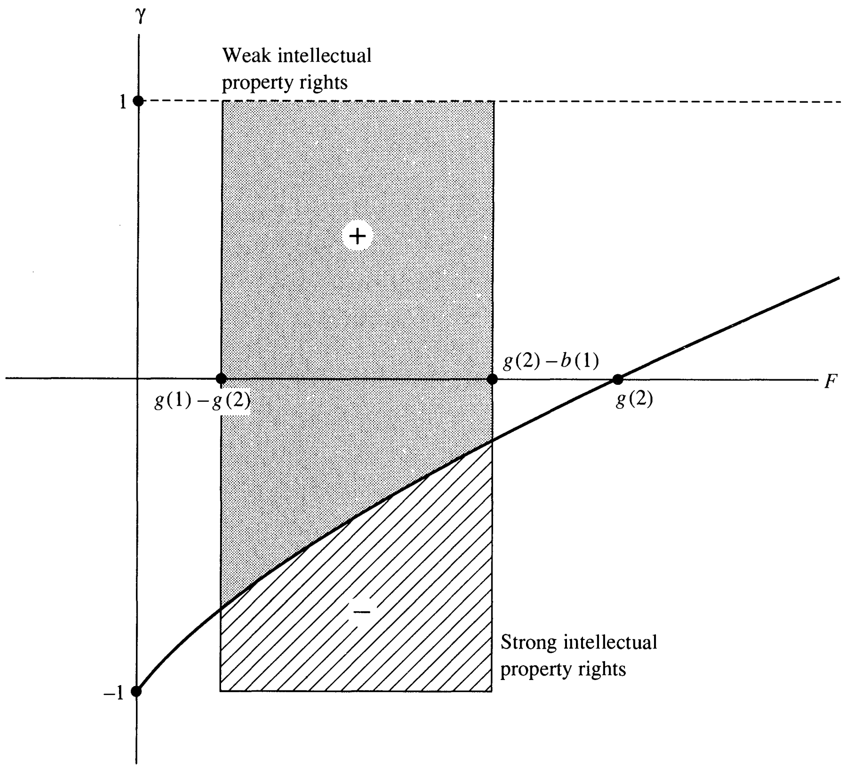
$$[1 + \gamma]g(2) > [1 - \gamma]F. \tag{8}$$

Figures 4 and 5 illustrate how the comparison between the ex post and ex ante R&D investment incentives depends on the values of γ and F. Note that $F = g(1) - g(2)$ corresponds to a licensing regime in which the licensee appropriates all of the gains from trade, while $F = g(2) - b(1)$ corresponds to a licensing regime in which the licensor appropriates all of these gains.

When strong intellectual property rights exist, we might expect γ to be negative and F to be near $g(2) - b(1)$. In this case, not surprisingly, ex ante cooperation leads to weaker R&D investment incentives. Given

34. See Kamien and Tauman (1986) for a discussion of licensing with volume-sensitive royalties.

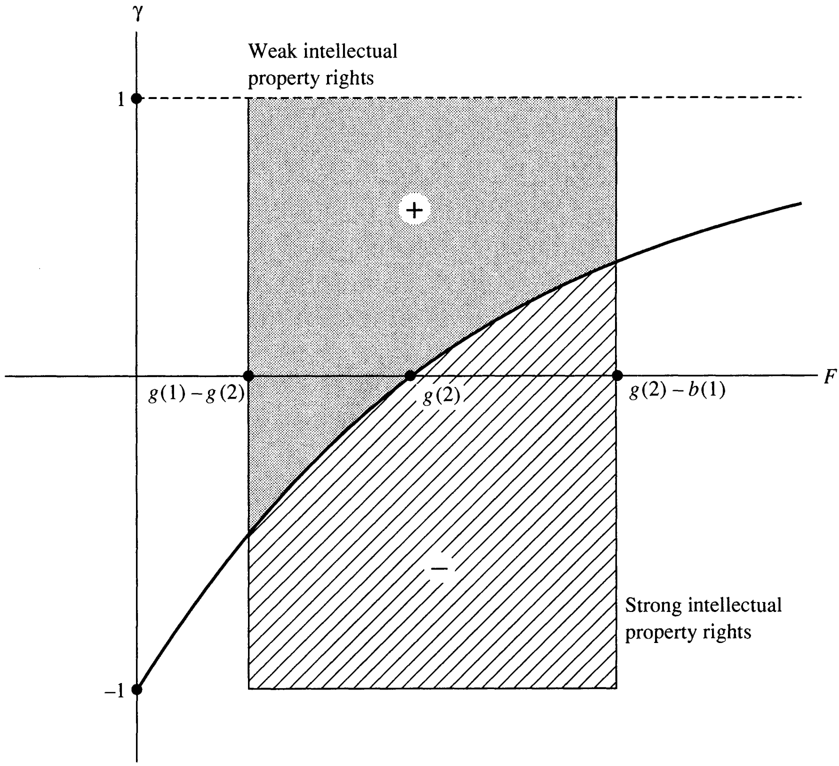
Figure 4. R&D Incentives with Ex Ante Cooperation versus Incentives with Ex Post Cooperation: Case 1.[a]



a. Drawn for $b(1) \geq 0$, $g(1) \geq g(2)$, and $2g(2) > g(1) + b(1)$. Plus sign indicates that ex ante cooperation leads to stronger R&D incentives than does ex post cooperation.

that the licensor has the bargaining power, each firm is motivated to conduct R&D in order to appropriate surplus that might otherwise accrue to its rival. Collectively, however, the firms do not count mere transfers of surplus as a benefit, and hence their collective R&D investment incentive under ex ante cooperation is lower than their individual incentives under ex post cooperation. With weak rights, we might expect γ to be positive (or near 0) and F to be near $g(1) - g(2)$. For high values of γ, ex ante cooperation leads to greater R&D incentives because it internalizes the positive spillovers. The overall pattern exhibited in diagrams 4 and 5 supports our earlier conclusion that ex ante cooperation

Figure 5. R&D Incentives with Ex Ante Cooperation versus Incentives with Ex Post Cooperation: Case 2.[a]



a. Drawn for $b(1) < 0$ and $g(1) < 2g(2)$.

is more likely to increase R&D incentives when intellectual property rights are weak than when they are strong.

A GENERAL CASE. Although a duopoly provides a useful simplification, more generalized cases must also be considered. Katz and Shapiro examined the case of an arbitrary number of firms, some of which have formed an RJV that has successfully innovated.[35] They looked at the RJV's choice of to how many firms to issue fixed-fee licenses. One might assume that the parents get the technology for free in exchange for their equity investment, but as our discussion below of the Microelectronics and Computer Technology Corporation demonstrates,

35. Katz and Shapiro (1986).

some consortia do not automatically grant royalty-free licenses to their members. An RJV can be operated as a stand-alone profit center that licenses its technology to the parents under one formula and distributes the profits under another.

Katz and Shapiro showed that, when the value of obtaining a license falls as the number of other firms who have obtained a license rises (that is, when $g(m) - b(m - 1)$ is a strictly decreasing function of m), a joint venture with $(k - 1)$ firms issues at least as many licenses as does one with k firms. In particular, a single firm that has successfully conducted R&D will share its results at least as widely as would a joint venture, and the formation of a joint venture may actually lower the extent to which the fruits of a successful R&D project are disseminated. Intuitively, this result arises because the product-market profits of rival firms fall when an additional firm receives a license. The larger is the RJV, the greater the extent to which it internalizes these negative, product-market competitive spillovers.

Katz and Shapiro also examined the incentives to innovate, albeit in a restricted setting.[36] In particular, they considered a market in which firms do not race because only one party (either a single firm or a single RJV) is capable of obtaining the innovation. They showed that, when the value of obtaining a license falls as the number of other firms who have obtained one rises, the single innovator's R&D incentives fall as the number of firms in the innovator's organization increases. The intuition is just like that underlying the dissemination result—in their model, innovation and the resulting licensing lead to negative competitive spillovers, and a larger joint venture more fully internalizes those spillovers. At least in this model, our earlier results concerning the effects of competitive spillovers when dissemination is exogenous continue to hold when it is endogenous.

At this point, one might object to the nature of R&D cooperation that we have been considering. The models discussed so far are best thought of as ones in which the firms reach an ex ante agreement to share research conducted by the individual members of the consortium subject to cost sharing sufficient to bring a single innovator's incentives in line with the collective incentives. In contrast, one might take the view that "true" joint research would entail the sharing of assets. These

36. Katz and Shapiro (1986).

shared assets might be intermediate research results (or firms might agree not to exercise the legal preemption of other innovators). Formally, we could model these effects as an increase in the value of γ, which raises the collective ex ante incentives as well as the efficiency of R&D.

Before concluding that increased sharing always is a good thing, notice that, while increased values of γ increase the *collective* incentive to conduct R&D, the return to any one firm may fall. Hence, an agreement that raises γ by sharing intermediate R&D results but does not call for sharing R&D costs (for example, an ex ante royalty-free cross-licensing agreement) can induce each firm to undertake less R&D. From equation 6, we see that this happens when $b(1) < 0$ and $F > g(2)$. In other settings, similar disincentive effects can come from the sharing of final R&D. To see how such effects might arise, consider the limiting case of firms that are Bertrand competitors in a homogeneous product market with a technology exhibiting constant returns to scale and equal unit costs of production. In such a setting, any cost reduction brought about by R&D that had to be shared with other firms would reduce the equilibrium price by the full amount of the cost reduction (that is, $g(m) = 0$ for all $m > 1$). Consumers would appropriate all of the economic gains of the cooperative R&D, and firms would have no incentive to conduct R&D under a cooperative agreement.

FAILURES IN THE MARKET FOR EX POST COOPERATION. The preceding results suggest that the rise in the incentives to innovate and the dissemination of the results may both be greater under ex post sharing, when it is feasible, than under ex ante cooperation. But settings exist in which ex ante sharing is feasible but ex post is not. For instance, a cooperative research arrangement can serve as an institutional mechanism for avoiding the problems of opportunism and asymmetric information that arise in the sale of innovations. Firms may find it much easier to monitor R&D inputs (measured in dollars) than to measure R&D output before actually using the innovation—the latter would be required to sell innovations ex post. The inputs are particularly easy to measure when there is a separate, jointly run research entity. In cases where all firms agree on the desired direction of R&D effort, moral hazard among the members will not be a serious problem.[37] And when

37. Of course, whether or not the R&D is performed cooperatively, firms still face problems of moral hazard by their research personnel.

R&D output is shared completely, the output of this entity only has to be observed, not measured, for all firms to be sure that they are receiving their shares of the R&D output.

These considerations may be particularly important in markets in which secrecy provides the main form of intellectual property protection. When the protection afforded by secrecy is strong, and the protection afforded by patents is weak, firms will be able to keep their innovations for themselves but be unable to license them to other firms (the potential licensee might demand to see the innovation before purchasing a license and then simply steal the innovation). As a result, a regime of ex post cooperation would lead to little dissemination of results, either intentional or unintentional, while ex ante cooperation would still be feasible.

Licensing also runs into difficulties when spillovers are high. Ex ante cooperation accomplishes internalization of spillovers by forcing (some or all) potential recipients of the spillover to commit their ex ante R&D expenditures before the outcome of the project becomes available. With an ex ante agreement, firms can commit themselves to R&D levels in stages. This timing allows firms to build in greater reactions to one another and better sustain cooperation.

Obviously, once the project is under way (or has succeeded), potential beneficiaries face a different trade-off: if the anticipated spillover is high, the rationale for joining the venture diminishes. In effect, ex ante cooperation replaces the marginal R&D investment decision with a discrete decision (should the firm join an RJV?). This fact tells us that an important part of modeling ex ante cooperation is to describe the membership process.

Ex ante agreements also may be a response to problems of commitment posed by the existence of the bargaining power created when some firms have innovated successfully and others have not. For example, suppose two firms can each obtain an increase of g in their product-market profits by investing r^*, where the value of g for each is independent of what the other firm does and $g > r^*$. One can think of the two firms as operating in different product markets without the possibility of preemption through patenting; instead of looking to patents for protection, the firms rely on secrecy. Suppose that the innovation is defined well enough that an innovator has the option of licensing it to the other firm.[38] Technology transfer is assumed to be costless. Clearly, the efficient outcome is for the two firms to expend r^* once and share the results. This is what one would expect to happen under ex ante cooperation. The only question would be how the gains from cooperation, the r^* R&D-cost savings, would be split. In contrast, consider these firms under a regime of ex post cooperation. If both conduct R&D, then each one enjoys a net gain of $g - r^* > 0$. If, however, only one firm conducts R&D, the other relies on the purchase of a license. If the licensor has enough bargaining power, the licensee will get less than $g - r^*$ incremental profit. In the extreme case of a take-it-or-leave-it offer by the licensor, the licensor would set the license fee at $F = g$, leaving the licensee with no incremental profit. Barring an ex ante agreement, the licensor cannot commit itself not to exercise its bargaining power, and neither firm has anything to gain by relying on a license; hence, each firm is driven to innovate on its own, which is an inefficient outcome.

This result is much more general than the model used to produce. For instance, this result could be straightforwardly extended to a model in which a firm always has the option to innovate on its own but in which innovation entails a time lag. One could also allow for the success of R&D projects to be stochastic. The key to the result is that a firm gains bargaining power as it conducts R&D and other firms do not. Moreover, in the more realistic case of inefficient bargaining, the fact that the ex post market power of firms may exceed their ex ante market power implies that ex ante cooperation may lead to less severe monopolistic pricing distortions in the pricing of R&D results.

Ex ante cooperation also may serve to share assets that are not readily transferable by other means, such as key personnel or laboratories. Ex ante cooperation could thus serve to counter failures in the markets for these assets and, compared with ex post cooperation, allow such assets to raise the cooperative R&D incentive by increasing the value of $\partial p_i / \partial e_i$. The shared assets may also be financial. If capital markets are imperfect, an ex ante agreement may provide a means by which firms can obtain sufficient capital to finance large R&D projects. Capital

38. In his survey of 37 U.S. firms, Rostoker (1984) found that 68 percent of the licensing agreements involved at least some information not subject to patent protection.

markets can fail to share risk because, as Arrow has pointed out, moral hazard limits the availability of insurance against the failure of an R&D investment.[39] Ex ante cooperation in the form of equity arrangements may be a way to raise capital while attenuating problems of moral hazard. Finally, ex ante cooperation may allow risk sharing among firms, which can be important to managers and, thus, even to diversified stockholders.

WELFARE RESULTS. To the extent that cooperative R&D is more widely disseminated than individually conducted R&D, ex ante cooperation increases the efficiency of R&D efforts. Ex ante cooperation may also eliminate wasteful duplication or improve the efficiency of firms' R&D efforts by coordinating the directions of their individual projects to insure that the industry has a diversified portfolio of projects. If the coventurers differ in their R&D skills, an RJV may be able to assign the R&D to the more efficient partners. As a result of these effects, welfare may rise even if an already suboptimally low level of R&D investment is lowered further—the increased efficiency may dominate the cutback in expenditures.

On the other hand, if the projects are independent of one another, then the benefits from coordination or rationalization may be few (the returns to scale in R&D are essentially constant). Having two teams trying to accomplish the same goal need not be an indicator of wasteful duplication, and one does not want to overstate the benefits of rationalization or the elimination of duplication. Moreover, we have seen that, in some circumstances, ex ante cooperation may reduce the extent of dissemination.

Reaching an Ex Ante Agreement

To this point we have paid little attention to the process by which an ex ante agreement is reached or how the institutions that govern the cooperative research are structured. Unfortunately, this shortcoming is largely that of the literature. Comparatively little theoretical work has been done on how firms actually direct their cooperative efforts. At least two crucial sets of issues exist. One is what we might call the membership game: How do firms choose to form coalitions, and what determines the equilibrium pattern of coalitions among firms? The sec-

39. Arrow (1962).

ond set of issues revolves around questions of organizational microstructure: How do the firms in a coalition organize their collective research activities?

Consider first the membership game. When the ex ante cooperative venture is formed in response to pervasive technological spillovers, the firms conducting the R&D provide a public good for the industry; other firms may be reluctant to join, choosing instead a free ride. When the intention of R&D cooperation is to retard the rate of technological progress, the firms that collectively cut back their R&D levels may again provide a public good for the industry, and the free-rider problem again arises.[40] What all of this tells us is that firms may not want to cooperate. This finding runs against the popular belief that U.S. firms would engage in extensive ex ante cooperation if not for the threat of antitrust litigation. The recent demise of U.S. Memories indicates that, even when allowed to cooperate, firms may not find it to be in their self-interest to do so. More research is needed on this important issue.

As to the issue of organizational microstructure, economic theory clearly should be able to provide interesting and testable answers to questions of organizational design. For instance, when members differ in their research abilities, having the more capable firm conduct the research offers potential benefits to all the members. But individual firms may have incentives to mislead the coalition. In a model where co-venturers are not informed about each other's technical capabilities, Gandal and Scotchmer examine the design of a mechanism that permits the RJV to proceed efficiently with the task of performing R&D.[41]

In addition to using theory to say what types of governance structures should be adopted, one can use it to predict the effects of actual governance structures. For example, by themselves, the cost sharing provisions of ex ante agreements raise the incentives to conduct R&D. The

40. Many of the issues raised in the analysis of the membership game are similar to those that arise in the study of cartels. It would be a potentially fruitful line of research to translate the results from the cartel literature to the study of RJVs. For a survey of the cartel problem, see Jacquemin and Slade (1989).

41. Gandal and Scotchmer (1989). In settings other than the one examined by Gandal and Scotchmer, there may be a problem when firm *A*, believing itself superior to firm *B*, is reluctant to reveal its technological capabilities to its rival for the fear of spillover of technological know-how. Harrigan (1985, 1986) makes this point persuasively. Bhattacharya, Glazer, and Sappington (1987) also examine a firm's incentive to reveal its ability to its rivals.

analysis of provisions to share R&D results is more complex, as we have already seen. Suppose that two firms sign a mandatory, royalty-free cross-licensing agreement. Then each firm has lower incentives to conduct R&D because it recognizes that this R&D will help its rival. But sharing the results of R&D projects also raises the efficiency of R&D. The *net* effect may be to raise or *lower* the equilibrium level of effective R&D.[42]

Finally, one can examine an ex ante cooperative agreement to see what restraints it places on R&D that is conducted by members independently of the agreement. Independent R&D may limit the ability of an ex ante agreement to restrict R&D. Intuitively, if the members attempt to use their agreement to lower the amount of effective R&D in comparison with the no-agreement equilibrium, a firm might find it profitable to conduct additional independent R&D.

Allowing independent R&D is generally not sufficient, however, to ensure that a cooperative R&D arrangement does not lower the level of effective R&D. For example, if setting up an independent R&D project entails substantial fixed costs, independent R&D may be unprofitable for a firm given that it already is receiving the output of the RJV.

Despite this note of caution, independent R&D can be an important check on attempts to use ex ante agreements to restrict R&D, and one should closely scrutinize agreements that attempt to limit the R&D that member firms may conduct without sharing. In a similar vein, one would be more confident that an ex ante agreement would not serve as a vehicle to retard the pace of innovative activity in those settings in which members of the agreement face strong competition from nonmembers.[43]

Practice

Our examination of models suggests that: (1) the greater the product-market competition between member firms, the less likely is an agreement to increase effective R&D; and (2) ex ante cooperation is most

42. The possibility that effective investment would fall was first raised in Spence (1984).

43. The logic behind this conclusion has been developed by Grossman and Shapiro (1986), Katz (1986), and Ordover and Willig (1985), among others.

likely to raise R&D incentives in markets that have strong technological spillovers even in the absence of cooperation, that is, in markets in which intellectual property rights are weak. These results are useful, but several sets of fundamental issues remain to be addressed, particularly with respect to the microstructure of the cooperative agreements and their formation. These issues are sufficiently complex that economic theory needs empirical evidence as a guide. Ideally, one would subject the theoretical propositions developed in the first part of this article to empirical tests. Unfortunately, the requisite data are not available. Our tack is, instead, to use theory to better understand three large-scale consortiums in the semiconductor and computer industries and to use the case studies to see where theory needs to be developed and altered. Before examining the case studies we survey the registrations made under the National Cooperative Research Act.

The National Cooperative Research Act

The National Cooperative Research Act of 1984 was enacted as a partial response to antitrust constraints on cooperative R&D agreements among firms.[44] While the adverse effects of the constraints have never been rigorously demonstrated, either theoretically or empirically, the notion that the threat of antitrust litigation might reduce the extent of cooperation seemed quite plausible to many observers despite the fact that such agreements have been treated more and more leniently by the courts and by the antitrust enforcement authorities.

As a response to these concerns, the NCRA aimed to reduce the threat of antitrust action against legitimate research joint ventures. The act places RJVs under the rule of reason, which entails a balancing of the procompetitive and anticompetitive consequences of the joint venture.[45] If a joint venture has been registered under the act, no treble damages are awarded if a plaintiff prevails in antitrust litigation. The

44. See Jorde and Teece (1989) for an extensive statement of this viewpoint.

45. Scrutiny under the rule of reason may be a small consolation because little guidance is available on how to assess the conflicting consequences. Ordover and Baumol (1988) have suggested that in the case of research joint ventures these conflicting effects are often more imaginary than real.

NCRA does not, however, provide explicit protection to joint ventures aimed at commercializing new technologies and products.[46]

It is fair to say that U.S. firms have not rushed into registering under the NCRA to obtain its limited protections. Table 1 summarizes the registrations reported in the *Federal Register* through the end of 1989. The 159 registrations under the act (169 in the table, which counts 10 dual-industry registrations in each industry) is a relatively moderate number in comparison with overall joint venture activity involving U.S. firms. For example, we found almost 140 joint ventures involving U.S. firms in the semiconductor industry alone during the period from January 1985 through July 1989, and a significant portion of them had substantial R&D components.[47] The moderate decrease in antitrust risks provided by the act appears to have created only minor incentives for registration. But why would an R&D joint venture forgo the potential insurance afforded by registration under the act? The data are not adequate to answer the question. For some RJVs, antitrust exposure may be so minimal as to obviate the need for registration. Although the monetary cost of registration may be a disincentive to register, a more important one may be the need to disclose the broad outlines of the venture to the public through the registration notice. (Additional detailed information disclosed to the enforcement authorities is, presumably, reasonably secure from leakage.) Lastly, joint ventures frequently encompass activities besides research and thus do not qualify for coverage under the NCRA.

Table 1 reveals that the majority of registrations are in a small number of industries: telecommunications (18.3 percent), computers and semiconductors (17.8 percent), automotive (14.3 percent), and manufac-

46. For a discussion of the issues raised by this limitation, see Jorde and Teece (1989) and the comments by Campbell (1989). But compare comments by Wood (1989). Writing in 1988, some of these commentators predicted that U.S. Memories, a proposed joint venture for the domestic fabrication of computer memory chips, would fail to get off the ground unless the antitrust laws were modified to extend protection to such ventures. With the benefit of hindsight, we know that antitrust concerns had nothing to do with the failure of U.S. Memories—many leading U.S. computer firms simply preferred to obtain their chips from existing suppliers.

47. Our data base was made up from entries located in the Predicast F&S Index (January 1985–October 1989), the Wall Street Journal Index (January 1985–August 1989), and the Business Perodicals Index (January 1985–October 1989). The list of agreements may be obtained from the authors.

Table 1. Joint R&D Ventures Registered under the 1984 National Cooperative Research Act, 1985–89[a]

Industry	*Joint ventures*	*Percent of total*[b]	*R&D as a percent of sales*	*Effectiveness of product patents*	*Effectiveness of process patents*
Aerospace	3	1.8	4.1	3.8	3.1
Automotive					
Vehicles	18	10.7	3.4	n.a.	n.a.
Parts	6	3.6	2.1	4.5	3.7
Chemicals	13	7.7	3.6	5.2	4.6
Computers					
Hardware	3	1.8	8.2	3.4	3.3
System design	5	3.0	9.2	n.a.	n.a.
Software	9	5.3	13.3	n.a.	n.a.
Consumer products	2	1.2	1.6	n.a.	n.a.
Food	1	0.6	0.7	n.a.	n.a.
Fuel (oil and gas)	24	14.2	0.7	4.3	4.9
Health care (drugs)	2	1.2	10.0	6.5	4.9
Housing	2	1.2	1.9	n.a.	n.a.
Leisure	5	3.0	4.6	n.a.	n.a.
Manufacturing					
General	11	6.5	3.3	n.a.	n.a.
Special	7	4.1	2.5	n.a.	n.a.
Metals					
Aluminum	1	0.6	1.3	n.a.	3.5
Steel	3	1.8	0.9	5.1	n.a.
Other	3	1.8	1.1	n.a.	2.6
Paper and forest products	2	1.2	1.0	3.3	4.6
Plastics	1	0.6	n.a.	4.9	3.2
Semiconductors	13	7.7	8.9	4.5	3.1
Telecommunications	31	18.3	5.7	3.6	n.a.
Utilities (electric)	3	1.6	n.a.	n.a.	n.a.
Total	169	100.0	...	...	...

Sources: For number of registrations, *Federal Register*, various issues, January 1985–December 1989; for R&D as a percent of sales, "R&D Scoreboard," 1989, *Business Week* Special Bonus Issue (July):177–232; for effectiveness of patents, Levin and others (1987, p. 797).

n.a. Not available.

a. Wherever possible, joint ventures were placed in industry classifications reported in the *Business Week* "R&D Scoreboard." Ventures involving vertically related industries were recorded in the downstream industry. In 10 cases, venture partners were involved in two different industries and were recorded in both. These 10 cases cause the 159 actual registrations to be shown here as 169 ventures. Effectiveness of patents measured on a scale of 1 to 7, with 7 being most effective.

b. Percentages are rounded.

turing (10.6 percent).[48] There are some obvious explanations for the observed pattern. In telecommunications, for example, the modified final judgment accompanying the breakup of AT&T places strong re-

48. In some cases, it was not apparent to which industry a particular venture belonged. For example, the five ventures in the leisure industry involved cable and network television,

strictions on the ability of the Bell operating companies to develop and commercialize new telecommunications products and technologies. Thus, the operating companies and their research arm—Bellcore—are forced to create joint ventures, frequently with foreign partners, in order to participate in evolving telecommunications markets. This fact, coupled with their significant fears of antitrust exposure, goes a long way to explain the frequency of registered telecommunications joint ventures. The automotive industry, for another example, has been engaged in many research projects on environmental issues. An earlier project—the ''Smog Project''—allegedly was used by U.S. car manufacturers to restrict R&D on controlling auto emissions. It is not surprising, therefore, that firms in the automotive industry would take all available steps to minimize their antitrust exposure from joint research. Scott has found that registered cooperative projects have on the whole been in more concentrated industries.[49] One plausible explanation is that antitrust risks are higher for large joint ventures in highly concentrated industries, and thus they are more likely to register.

Table 1 also reveals that the registered joint ventures were formed in industries in which patent protection of intellectual property rights is not particularly effective, at least according to the rankings generated by Levin.[50] If one assumes that the ineffectiveness of patents also signifies a serious spillover problem, then the table could suggest that the internalization of spillovers drove the formation of the registered ventures. Scott found, however, that the registered joint ventures have not been predominantly in the industries in which *overall* appropriability is perceived as a problem, at least according to rankings devised by Levin.[51] This pattern suggests that firms rely on nonpatent means (such as secrecy and first-mover advantages) to protect their intellectual property. However, a more detailed review of the stated objectives of the registered ventures reveals that many of them are engaged in industry-specific environmental research, safety-related research, or research

motion picture studios, and recording companies. General manufacturing includes glass/ceramics, cement, packaging, general manufacturing, and industrial systems. Special manufacturing includes more sophisticated computer-assisted design systems, specialized mechanical systems, and automation and robotics.

49. Scott (1988).

50. Levin and others (1987).

51. Levin and others (1984, 1987).

undertaken in response to governmental directives.[52] These lines of research could potentially be characterized by spillovers (poor appropriability) worse than in the average R&D project in a given industry. As a consequence, an uncorrected correlation of frequency of joint R&D with some industry-specific measure of R&D appropriability may not be an appropriate test of the proposition that, within some range, greater spillovers create incentives for joint venture formation. Indeed, firms may selectively form joint ventures on those projects with potential spillovers that are higher than the industry average.

Many of the research projects undertaken by the registered ventures are not likely to be sources of competitive spillovers as we have defined them. The outcomes of these nonstrategic projects do not shift the firms' best-reply functions and thus do not affect the nature of competitive interactions. This is true, for example, for those projects that principally affect the fixed costs of production for the firm (such as the development of some safety device) and of those that yield benefits not directly perceived as such by consumers (such as pollution controls). This pattern suggests that cooperation in these areas has not served as a means of retarding the rate of R&D investment to minimize competitive spillovers.[53]

Case Studies

We turn now to a more detailed look at three large-scale research consortia in semiconductors and computers: Sematech and the Microelectronics and Computer Corporation (MCC) in the United States and the Very Large Scale Integration (VLSI) consortium in Japan. These three ventures share four characteristics. First, each of them comprises a large number of participants. In this respect, our sample is not a representative one. The overwhelming majority of cooperative technology agreements have many fewer members—often as few as two.[54]

52. This was already noticed by Jorde and Teece (1988a).

53. Of course, the possibility of organizing the industry to game against government regulators, as was in the case of automobiles, remains.

54. On the other hand, a review of NCRA registrations indicates that some ventures have many more members than those we examine. The Portland Cement Association, for example, has approximately 100 members.

It is useful to look at these outliers for two reasons. One, they are particularly important cooperative ventures. Two, because they are large, these joint ventures face particularly extreme versions of the coordination and coalition-formation problems that can afflict this type of agreement.[55] Consequently, theory would suggest that they might have difficulties in accomplishing their R&D objectives, and it is informative to see what institutional arrangements have been developed to deal with these problems.

Second, all three fall within the broad industry grouping of computers and related industries and thus face some common elements of industrial structure. Levin reports that in computers, semiconductors, and communications equipment, patent protection of manufacturing processes is less effective than in the sample mean, a condition that suggests high spillover rates and a large incentive to create joint ventures.[56] But, as Peck concluded from this analysis of the same data, other means of appropriability, such as first-mover advantages, learning by doing, and trade secrets, serve to improve appropriability in these industries.[57]

Third, each group was organized at the time of perceived international threats to the viability of key sectors of the domestic economy, including semiconductors and computers. The VLSI consortium was designed as Japan's competitive response to U.S. leadership in computers in general and to IBM's leadership in particular. More recently, Sematech has been presented as an almost last-ditch effort to end Japanese domination of the U.S. merchant market in semiconductors and all the negative externalities that such domination allegedly entails for U.S. firms, the economy, and the military. And much of the stimulus for the MCC came from the forecasted Japanese domination of the next (''fifth'') generation of computers. A partial explanation for the formation of each of these cooperative ventures, then, is that public authorities, at least, perceived a need to increase the effectiveness of R&D programs to improve the international competitiveness of domestic firms.

55. Even two-firm joint ventures are subject to severe problems of coordination, as has been discussed extensively in the management literature, because of disagreements such as conflicting objectives and expectations of the parents. See, for example, Harrigan (1985, 1986).

56. Levin and others (1987, p. 797, table 2).

57. Peck (1986) argues that internalization of technological spillovers has not been a motivating factor for the formation of the MCC.

Fourth, the focus of the R&D programs in these three groups has mainly been on "precompetitive" research. Precompetitive research aims to deliver knowledge that is not in a marketable form but that can be commercialized by its recipients as new products and processes. Such research is more likely to have appropriability problems and to carry greater time lags and risks than "competitive" research, which leads directly to commercial results. Moreover, cooperation in precompetitive R&D is less likely to undermine strategic advantages that a firm may gain from applying complementary, proprietary, applied R&D that has direct commercial applications.[58]

THE VLSI CONSORTIUM The Very Large Scale Integration (VLSI) consortium (1976–79) is commonly regarded as one of the most successful Japanese cooperative ventures. Sponsored by the Ministry of International Trade and Industry (MITI), VLSI was to develop advanced semiconductor technology that would enable the Japanese systems firms to compete effectively with the fourth generation of IBM computers. The venture comprised Fujitsu, NEC, Hitachi, Mitsubishi, and Toshiba. All of these firms had previously participated in other MITI-sponsored research projects and had cooperated with each other in computer-related R&D. Each member assigned some of its research employees to the project. In addition to company personnel, researchers from MITI's Electro-Technical Laboratory (ETL) participated in the project.

The organizational vehicle for the consortium was an engineering research association (ERA) formed by the five consortium members. The Japanese legally established their ERA system in 1961, patterning it after research associations developed in the United Kingdom following World War I. An ERA is organized for a specific project, generally disbands when the project is completed, and is exempt from the scrutiny of antitrust laws.[59] The VLSI Engineering Research Association was financed, like most ERAs, under the *hojokin* formula, whereby the government provides 40 to 60 percent of the funds as interest-free, conditional loans to be repaid from profits derived from technology developed in the ERA. The government contributed approximately

58. The theoretical results developed by Bhattacharya, Glazer, and Sappington (1987) can be interpreted as saying that competitive spillovers are less likely to undermine incentives to share precompetitive research than incentives to share competitive research.

59. See Sigurdson (1986); Levy and Samuels (1989); and Flamm (1987).

$150 million to the VLSI group, and the five participating firms contributed a similar amount.[60]

The *hojokin* system would seem to create strong incentives for nonpayment of the debt to the government and a potential accounting nightmare. According to Okimoto, however, the repayment system has functioned reasonably well.[61] Perhaps the repayment problems are ameliorated by the repeated nature of interactions between MITI and the industry groups. According to data cited in Levy and Samuels, ERAs are a major funnel through which the Japanese government allocates R&D subsidies.[62]

As we noted, the goal of the VLSI consortium was to close the gap between the Japanese computer makers and IBM. According to MITI, achieving this goal was possible only if the computer makers developed semiconductor capabilities to rival those of IBM and U.S. merchant semiconductor fabricators. The VLSI group was to deliver to its members the generic technology for the manufacture of random-access memory (RAM) chips capable of storing 64 thousand bytes (64K) of data.[63] The pertinent research paths and technological objectives were already clearly laid out by U.S. firms. Seen from this perspective, the VLSI consortium was a high-technology cooperative catch-up program. Its success in delivering the technology to manufacture 64K integrated circuits and in advancing Japanese capability in 256K technology can be attributed, to a large extent, to the clear-cut R&D tasks facing the consortium members. This clear definition of tasks also implied that the R&D goals facing the firms supplying inputs to the device makers were clear, permitting better coordination along the vertical chain. Indeed, some commentators believe that the equipment and material suppliers who worked under contract with the device makers in the VLSI consortium have been the main beneficiaries of the program.[64]

The VLSI consortium experienced significant start-up difficulties because each of the participating firms feared the loss of proprietary

60. Okimoto (1989, p. 78, table 2.1). Flamm (1987, table D.2) gives the total cost to have been approximately 29 billion yen.

61. Okimoto (1989, p. 79).

62. Levy and Samuels (1989).

63. A byte contains eight binary digits (zeroes and ones, or bits) and is comparable in amount of information to about one word of text.

64. This conclusion is advanced by Chesnais (1988, p. 76).

knowledge they possessed at the outset of the project. Each firm was also engaged in separate collaborative R&D with some other members of the consortium and, most important, some firms also had links to U.S. computer makers.[65] With all these connections, each participant feared the deterioration of its strategic position in the market from leaks of its proprietary technologies.

The organizational structure of the VLSI group reflected some of these difficulties. Its solution to the problem of enhanced spillovers and the erosion of strategic positions was to rank the R&D projects in terms of their "distance" from commercial applications. The most distant (most precompetitive) research would be conducted jointly in one of the newly established VLSI Cooperative Laboratories; more nearly commercial research would be performed in the two existing joint laboratories of the co-venturers; and, finally, actual product development (for example, chip design) would be undertaken by individual firms on their pilot production lines.[66]

This organizational structure is quite consistent with theoretical developments discussed earlier. Focusing close cooperation on precompetitive (basic) research ensures that participants benefit from strong intraventure spillovers. In addition, to the extent that basic research is less easily appropriable, cooperation at that stage supplements inadequate private incentives to undertake such research. At the same time, collaboration in basic research has fewer immediate implications for rivalry in downstream markets. In the VLSI project, much of the applied work, as measured by patents issued, was done in the private laboratories of participating companies (although these patents were assigned to the Engineering Research Association in order to qualify for public subsidy).

The creation of the Cooperative Laboratories was a major innovation. Earlier forms of cooperation in the Japanese computer industry and earlier, ERAs in other industries involved research undertaken by the

65. See Flamm (1988, chapter 6) for a description of the links. The presence of these links created some serious problems in the patent area. In particular, the Research Association had to decide whether the patents from the project could be licensed to third parties, including U.S. firms, with which ERAs' members had cross-licensing agreements. In the end, it was decided to make patents available for cross-licensing.

66. See Sigurdson (1986) and Vonortas (n.d.) for additional descriptions of the division of the tasks.

firms themselves, which then shared the results with the other participants. The prospect of actual collaborative research undertaken in a joint laboratory exacerbated the fears of unwanted technology transfer.[67] Even the collaborative laboratories of the VLSI research association did not, however, fully shed the more traditional mode of Japanese collaborative research, characterized by Doane as "together but separate" and by Levy and Samuels as "distributed collaboration."[68] The traditional form of cooperation entailed only a limited interchange of research personnel and highly controlled flows of information. In the case of the VLSI project, each cooperative laboratory was led by a representative from a different participating company, so there was a "NEC" laboratory, a "Hitachi" laboratory, and so on (figure 6). Furthermore, each laboratory was staffed predominantly, but not exclusively, with researchers from the director's company. This explains, in part, why only 16 percent of the patents generated by the VLSI consortium were filed jointly by researchers from different companies or by MITI.[69] Another reason why cross-firm patents were not more significant could be that laboratories were assigned distinct research objectives.

Exchange of information among the separate laboratories initially was quite poor.[70] As the project progressed, however, formal and informal exchanges of information among researchers from different laboratories and different companies increased markedly. The fact that these researchers returned to their companies after the VLSI association was disbanded must have increased the degree of technological spillover and facilitated continued technology transfer from the project to the participating firms.

No evidence exists to show that research teams from the participating companies tried to obtain a free ride on each other's efforts, a situation attributable, perhaps, to the division of tasks. But more important, incentives to shirk may have been attenuated by the fact that the participating firms knew that in the future they would cooperate with each other either in private ventures or in other consortia sponsored by MITI.

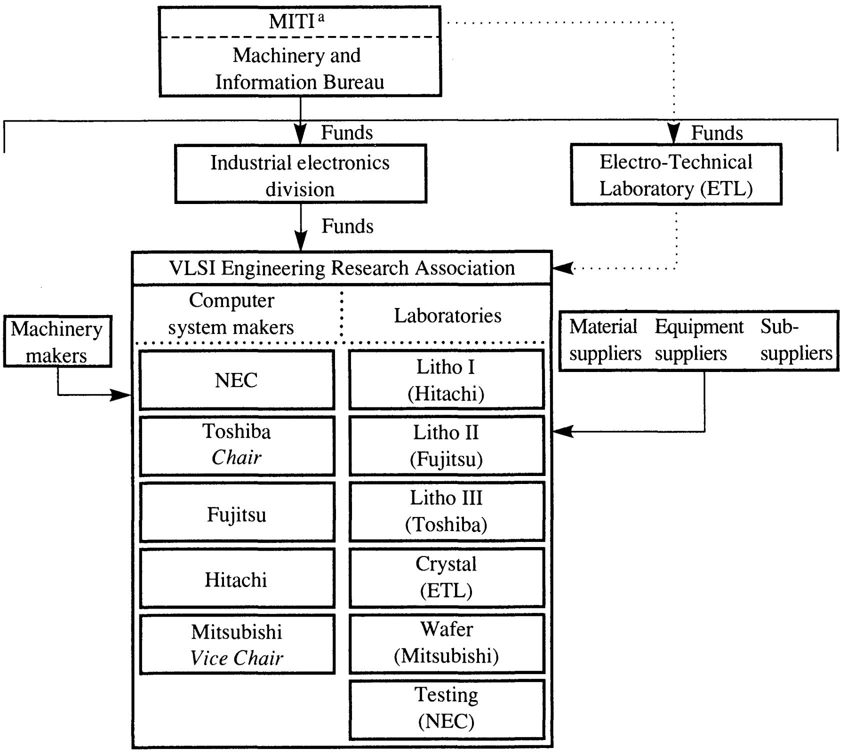
67. Okimoto (1989, p. 71).

68. Doane (1984, p. 180); and Levy and Samuels (1989, pp. 65–66).

69. Twenty-five percent of the patents were developed by several individuals from the same company. See Doane (1984, p. 185).

70. Doane (1984, pp. 183–84).

Figure 6. Organizational Structure of the Very Large Systems Integration (VLSI) Consortium



Source: Sigurdson (1986); and Hayashi, Hirano, and Katayama (1989).
a. Ministry of International Trade and Industry.

This possibility is consistent with the view that incentives to cooperate are strengthened through repeated interaction.

Despite the fears and reservations of the computer firms about the joint project, the consortium did get off the ground; and judging by the current position of the Japanese firms involved in semiconductors and related equipment and materials, the VLSI project must be seen as a success.[71] As Flamm observes, "the VLSI program, including work on ultrafine lithography and electron-beam etching, brought its participants to the frontiers of advanced semiconductor technology." Oki-

71. See, however, Vonortas (n.d.), who points to other factors that increased the competitiveness of Japanese firms.

moto cautions, however, that the VLSI project perhaps only advanced the speed of R&D without producing many breakthroughs.[72]

The success of VLSI can be attributed, in part, to the important role of MITI officials in guiding the project from its inception. Not only did the MITI officials engage in lengthy pre-planning of the research to be undertaken by the ERA with the interested companies, but they also assigned scientists from the MITI Electro-Technical Laboratory to participate in the project. Moreover, the day-to-day management of the consortium was in the hands of an engineer from MITI's laboratory and a former high-ranking MITI official. Such staffing surely smoothed cooperation between MITI and the consortium members.

The fact that MITI could be expected to be involved in many research projects in which the VLSI-member companies would be participating created additional incentive for firms to act cooperatively with MITI and with each other. The expectation of future subsidies from the ministry together with the potential threat of exclusion from future projects and thus a loss of important R&D subsidies provided a countervailing force to whatever reluctance firms may have had in participating in joint research.[73] The VLSI was not simply a cooperative venture among private firms—government money and incentives appear to have played an energizing role in its formation and ultimate success. Nevertheless, the visible success of the consortium in boosting the competitiveness of the Japanese signaled that closer collaboration in large scale consortiums is feasible without generating significant free-rider problems and uncontrolled spillovers of core proprietary information. Thus, the consortium has played a significant demonstration role for subsequent collaborative endeavors.

72. Flamm (1987, p. 196); Okimoto (1989, p. 71). Flamm (1987) and others cite the large number of patent applications resulting from the VLSI association—more than 1,000—as yet another measure of success. Here caution is advised for several reasons: (1) the Japanese patent system encourages patenting of individual applications; (2) it is not clear how many of those patents will turn out to have commercial value in the end; and (3) only a small portion of those patents have been filed jointly, suggesting some barriers in collaborative efforts. For more on this point see Ordover (1990). Saxonhouse (1981) believes, however, that the VLSI group and other ERAs basically diffused preexisting know-how without generating much that was new.

73. Oki was not allowed to participate in the VLSI project, for example. See Levy and Samuels (1989) and Okimoto (1989) for discussions of MITI's ability to guide and influence participation. Compare, however, Sanger (1989), who suggests that MITI is now less able to direct the R&D and investment decisions of firms.

SEMATECH. The Semiconductor Manufacturing Technology Consortium (Sematech) was organized in 1987 as a U.S. response to a growing dominance by the Japanese of the worldwide markets for commodity chips (DRAMs and SRAMS).[74] Its basic mission is "to drive the development of manufacturing technology, and to provide a vehicle [device] for the demonstration and refinement of the technology."[75] Sematech's membership consists of the fourteen largest U.S. manufacturers of semiconductors and the Department of Defense.[76] The consortium also has links with manufacturers of semiconductor materials and equipment through Semi/Sematech, which was organized in 1987 as an independent chapter of the international Semiconductor Equipment and Material Institute (Semi). Semi/Sematech's membership is restricted to U.S. firms. This pattern of membership and the goals of Sematech reflect the fact that it was formed in part in response to concerns about spillovers mediated by vertical relationships among makers of equipment and makers of semiconductors.

Like the VLSI consortium, Sematech is supported by public as well as private funds. Member firms are expected collectively to provide about $100 million per year over the projected six-year life span of the project. Individual contributions are made in proportion to the member's share of the group's semiconductor sales.[77] The Department of Defense also is expected to contribute approximately $100 million per year. Member companies contribute personnel to Sematech's research and administrative staff. Less than half of Sematech's employees come from member companies, however, in contrast to the VLSI consortium, which relied almost exclusively on employees assigned from member firms. IBM and AT&T also contributed proprietary knowledge, devices, and engineering support to allow a quick start-up of Sematech's operations.

The organizational structure of Sematech includes three advisory bodies that influence the operations of the consortium (figure 7). Mem-

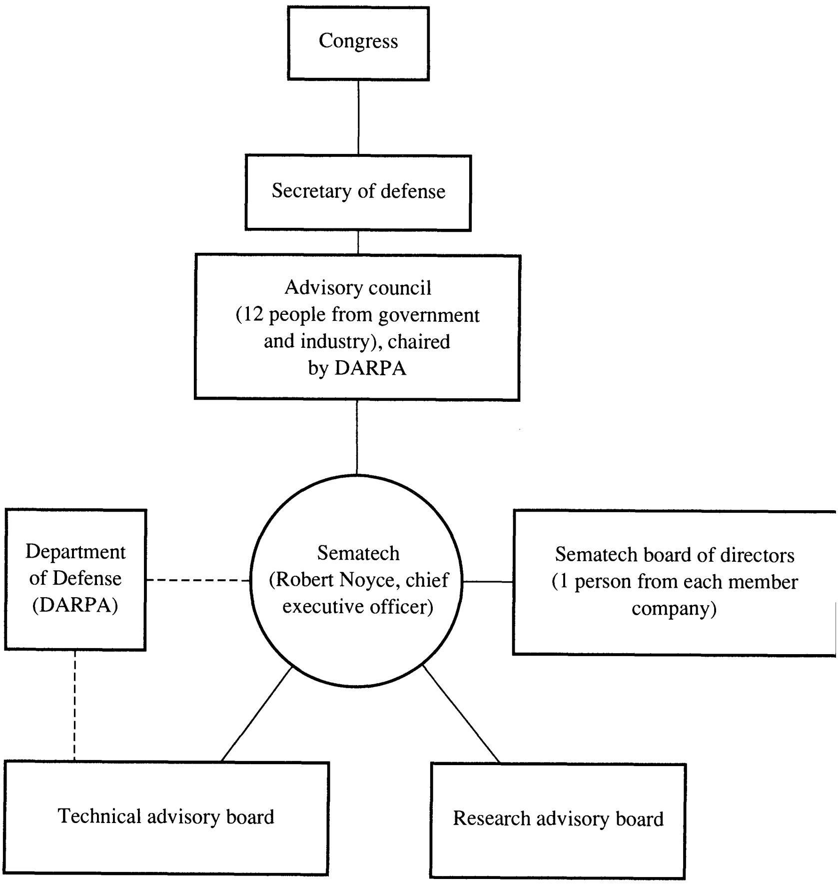
74. Plans for a Sematech-type consortium were being developed as early as 1985. For additional background on Sematech and the perceived need for government intervention, see Congressional Budget Office (1987); Mayer (1989); and Williams (1988).

75. Mayer (1989, p. 12).

76. The manufacturers are Advanced Micro Devices, AT&T, Digital Equipment, Harris, Hewlett-Packard, Intel, IBM, LSI Logic, Micron Technology, Motorola, National Semiconductor, NCR, Rockwell International, and Texas Instruments.

77. Because IBM and AT&T have no merchant market sales, we assume that their fees must be related to an estimate of their internal consumption.

Figure 7. Organizational Structure of Sematech[a]



Source: Williams (1988).

a. Sematech comprises fourteen U.S. manufacturers of semiconductors and the Department of Defense (see text note 76 for names of firms). DARPA is the Defense Advanced Research Projects Agency of the Department of Defense.

The Technical Advisory Board consists of one representative from each of the member firms, one from the SRC, one from DARPA, and one from Semi/Sematech (a chapter of the Semiconductor Equipment and Material Institute.

The Research Advisory Board consists of three representatives from dARPA and three from industry.

bers of these advisory boards can exercise direct financial control over the affairs of the consortium through their willingness to fund the ongoing activities, and members of these boards have an institutional stake in the success of the joint venture. The board of directors retains, however, a final say over the technology ''roadmaps'' that define the consortium's strategic technology plans.

Figure 7 also reveals the significant role that the Defense Advanced Research Projects Agency (DARPA) plays in Sematech's activities. Even though DARPA apparently refrains from detailed control of consortium activities, disagreements between Sematech and DARPA delayed the release of government funds in 1988.[78] The disagreement was resolved when Sematech agreed to expand its strategic focus to include research related to application-specific integrated circuits (ASICs) and X-ray lithography technology. We shall return to the importance of these changes below.

Sematech's original plans for research and resource allocation have been modified in several other ways. The emphasis of Sematech has shifted, or perhaps drifted, away from the diffusion of best-process technology for the manufacture of high-volume commodity chips and toward the increased viability of the supplier base and improved linkages between the device makers and suppliers. This shift is reflected in the growing share of the outside contract work that is going to members of Semi/Sematech. The 1990 budget for Sematech allocates almost 33 percent of $240 million in total resources to financing the R&D of equipment and material vendors, an increase of $52 million over the 1989 allocation. In contrast, Sematech's purchases of equipment to be used for demonstrating manufacturing techniques on its own fabrication lines will have declined from $119 million in 1989 to a mere $45 million in fiscal 1990.[79]

Sematech's existence raises a number of the issues discussed throughout this paper. The first is, can Sematech act anticompetitively to retard the speed of critical R&D expenditures? Sematech's members are the major U.S. fabricators of semiconductors, but the global competition in the markets for semiconductor devices, equipment, and materials belies the importance of domestic market shares in assessing the competitive consequences of the consortium. On the other hand, to the extent that U.S. firms lobby (or threaten to lobby) for government-imposed restraints on foreign producers, foreign competition may provide less of a check on anticompetitive behavior than initial appearances suggest. In addition to foreign competition, the structure of the Se-

78. Earlier, Sematech had run into problems in the Congress because it could not find a chief executive officer. Robert Noyce, of Intel, was finally selected as CEO.

79. Hayes (1990, p. D4).

matech agreement makes it unlikely that it can serve to retard technological progress. Members are free to pursue independent research outside of the consortium. In fact, some of the consortium members are involved in other, private joint ventures that not only complement but also parallel some of the Sematech's R&D projects. IBM and Siemens are now engaged in a joint development project for 64-megabit DRAMs, placing them ahead of Sematech in this area.[80] Sematech will not address process technology for 35 micron geometries, which are needed for the 64-Mbit DRAM, until a later phase of its research plans.[81] Similarly, IBM has begun work with Motorola on X-ray lithography, which may be required for fabricating the next generation of chips. Sematech has not budgeted the funds necessary to pursue this line of research. IBM is not the only member to form partnerships outside of Sematech. Intel has signed an agreement under which it will market chips manufactured by NMB of Japan, and thus it will reenter the chip market without having to expend the over $250 million that it can cost to start up a modern fabrication facility.[82] The presence of these parallel research projects serves to lessen fears that Sematech might slow the pace of R&D; any attempt by members of Sematech to slow the pace of their collective research would likely lead some or all of them to intensify their individual R&D efforts outside the consortium.

Another issue is, how will Sematech affect the R&D activities and competitive strength of nonparticipating firms? A large-scale consortium can affect the R&D incentives of nonparticipants in a variety of ways. On the positive side, a consortium that increases the amount of effective R&D can also increase spillovers to nonparticipants. Furthermore, nonparticipants in a product market that is downstream from the one in which innovation occurs can benefit from improvements in an upstream technology made possible by the consortium. Thus, improvements in the state of technology in the equipment and materials sectors engineered by Sematech's research contracts could flow to nonparticipating equipment and device makers. Sematech, however, has tried to reduce horizontal competitive spillovers in the device market by restricting the dissemination of information by equipment manufac-

80. Markoff (1990).
81. See Mayer (1989) for a description of Sematech's research phases.
82. Kehoe (1990).

turers to their non-Sematech customers in general and to their foreign customers in particular.

On the negative side, a major venture with government assistance can divert public resources from nonparticipants and skew the direction of R&D programs supported by public funds toward the needs of the dominant venture participants. The formation of Sematech generated a conflict over technological priorities: consortium members argued for programs with an immediate payoff in the fabrication of commodity chips, and DARPA argued that support should also go to programs that would benefit producers of custom chips. Seen another way, consortium members argued that commodity chip manufacture is the "technology driver," meaning that large technological spillovers flow from that portion of the chip industry to other segments. DARPA and others argued, however, that improving manufacturing techniques for customized chips (ASICs) would result in greater overall social payoff. This conflict stymied Sematech's earlier plans. It also pointed up the potential danger of putting all of society's R&D eggs in one basket.

Apart from the controversy over commodity chips versus custom chips, broad agreement existed within Sematech about the need to increase cooperation with, and strengthen, the domestic equipment and materials suppliers, whose inefficiencies have been identified as an important factor in the weakening competitive position of the U.S. semiconductor industry.[83] The designers of the VLSI project had reached a similar conclusion for Japan, and, as we noted, one of the major payoffs from the VLSI project was the emergence of a competitive Japanese industry in semiconductor equipment and materials.

The perceived importance of strong domestic suppliers for the economic health of semiconductor manufacturers leaves us with two questions. One is why suppliers would treat their foreign customers differently than they treat their domestic customers. A possible explanation is that cooperation between different vertical stages is critical, and long-term relationships are needed to substitute for what would otherwise be extremely expensive and complex long-term contracts. It may well be that sharing a common culture and government is important in forming these long-term relationships. Another question is whether the distribution of technological spillovers could be affected by nationality and physical

83. See Dertouzos and others (1989).

location. Interindustry coordination is perhaps easier domestically than internationally, again because the parties share a common culture and government and because geographic proximity facilitates face-to-face communication and may lead to increased linkages as employees move from one firm to another.[84] If technological spillovers do attenuate with distance or the crossing of national borders, one would have a policy justification for encouraging cooperation among domestic firms and for keeping foreign firms from locating ''near'' the domestic firms.

MCC. The Microelectronics and Computer Technology Corporation (MCC), organized in 1982, began operations in 1983 as a large-scale research consortium of firms engaged in the information technology industry. As the first of the new wave of large-scale research consortia in the United States, it served as a proving ground for strategic cooperative research among rivals. The consortium was conceived partly as a competitive response to the just-announced Fifth-Generation Computer Project in Japan, which was expected to catapult the Japanese firms to world leadership in new computer architectures, including artificial intelligence.[85] The consortium members also hoped that, by pooling their financial resources, they could gain a competitive edge over nonparticipating U.S. firms, including IBM and AT&T. The latter two firms were not invited to participate ostensibly because of antitrust concerns.

According to Peck, enhancing the appropriability of R&D through internalization was not the primary motive for the formation of the consortium.[86] As noted above, appropriability in the computer and semiconductor industries is accomplished primarily through lead time, secrecy, and movement down the learning curve; patents are of lesser importance. Peck also observed that likely technological spillovers from the MCC would not be so large as to induce firms to stay outside of the venture and thus stymie its formation. Recent changes in the MCC's research objectives, discussed below, lend additional support to the view that the desire to share the cost of R&D, rather than concerns

84. Indeed, modern growth theory, which thrives on positing intraindustry nonconvexities (see, for example, Romer, 1990), seems to postulate precisely this type of relationship.

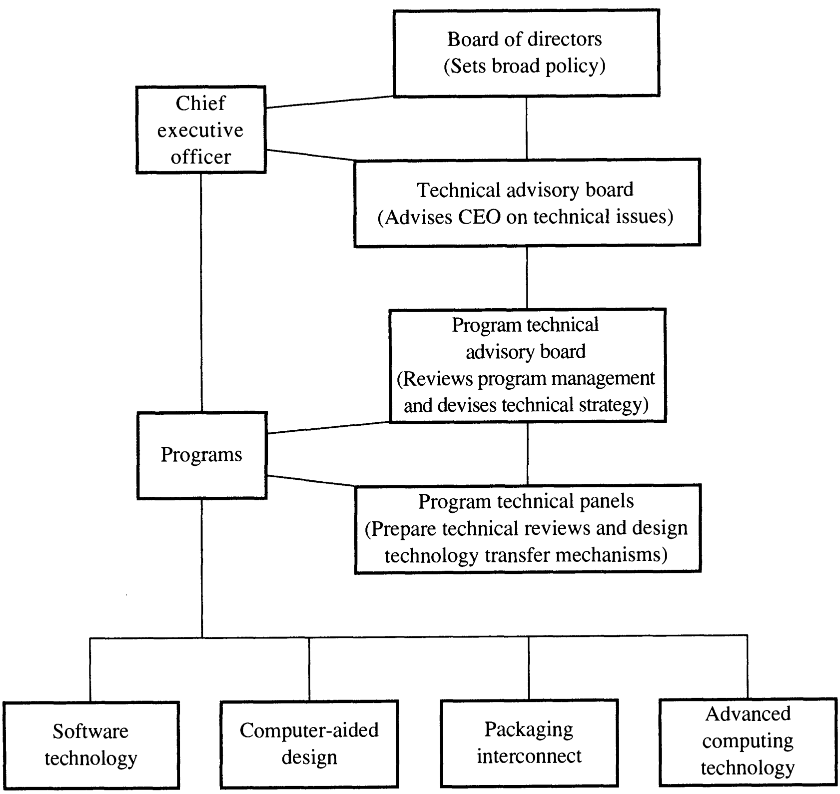
85. It is now commonly recognized that the computer project has fallen significantly short of the initial expectations.

86. Peck (1986, pp. 223–24).

about appropriability, was the major motive behind its creation.

The MCC set itself an ambitious and far-ranging research program in information technology and related disciplines. The structure of the MCC (figure 8) reflects the diverse nature of research programs undertaken by the consortium. The MCC has two membership categories: shareholders (now 19, down from 21 in 1986) and associate members (now 17, up from 13 in 1984 and 5 in 1986). The two categories of members contribute different amounts to the MCC's overall research budget, have different access to the research results generated by the consortium, and play different roles in the organization. Shareholders

Figure 8. The Structure and Programs of the MCC[a]



Source: Dove (1989).

a. The Microelectronics and Computer Technology Corporation, which consists of 19 shareholder firms and 17 associate firms in the information technology industry.

have preferential access to research results, which they can obtain under license from the MCC. Shareholders (unlike associates) participate on the board of directors and the other advisory boards, and thus shareholders can exert more influence on the overall direction of research than can associates.[87]

Each consortium member pays a membership fee plus a fee for participation in specific research projects. Participation entails access to results before they are made available to nonparticipants. Initially, the licenses are royalty-free up to a limit related to the participant's contribution to the project, an arrangement that provides more free technology to shareholders than to associates.

The research structure of the MCC is markedly different from that of the VLSI and Sematech. Unlike the other two, the MCC has a large and independent research staff and acts, in effect, as a supplemental research organization for shareholders and associates. The MCC has not received any infusion of background knowledge from its shareholders beyond the broad identification of research tasks. Interaction among the consortium members' own researchers and the MCC's research staff appears limited. Most of the interaction between the MCC and the member firms occurs through the process of technology transfer.

Perhaps not surprisingly in light of the limited interaction between the firms and the consortium, and in light of the broad original mandate to the consortium, the research goals of the MCC staff have diverged somewhat from the goals of the firms. As a result only a few of the technologies delivered by the MCC have been embedded in commercial products.[88] Contributing to this divergence between the goals of the staff and the goals of the member firms is the fact that MCC's initial research objectives have been quite diffuse. As a result of diffuseness, the research staff had a great deal of freedom to pursue different avenues of research as they saw fit. Ultimately, however, the research staff is subject to oversight from the shareholders' technical staffs through the board of directors and through technical advisory boards. This authority had to be overtly exercised at one point in order for the shareholders to stop a computer-aided design project based on the Lisp programming

87. The structure of the MCC is discussed in OECD (1989, pp. 124–25).
88. See, for example, Lineback (1987, 1988) and Dunn (1989).

language and to force the MCC researchers to use more popular languages for the software.

The lack of focus in the research agenda of the MCC relative to the agendas of the VLSI and Sematech suggests the following tentative hypothesis. As a matter of venture design, consortiums that perform precompetitive but well-focused R&D work are more likely to deliver usable technologies to their members than are those whose mandate is vague and overly broad. The MCC experience also points out the need to apply economic models of organization to the problem of structuring cooperative arrangements. None of the black-box models of ex ante R&D cooperation discussed earlier in this report would have predicted that a joint venture would pursue its own goals, even if doing so came at the expense of its parents.

Recently, the MCC repositioned its research projects to serve members' needs more effectively; it also became an open-market supplier of contract R&D in computer-aided design and engineering and in computing technology. The consortium has shifted its emphasis from long-range projects with horizons of six or seven years to more short-term, focused research with "deliverables" becoming available in as little as six weeks. The MCC changed the rules of participation in its most successful program, the Advanced Computer Architecture Program (which was renamed the Advanced Computing Technology Program) to attract more and smaller participants. Under the new rules, ACT allows participants to participate selectively in only those components of the program that best meet their own commercial objectives. At the same time, the research results from the Computer Aided Design project have been aggressively marketed for licensing to the users in the electronics industry.[89] The goal of these moves has been to attract financing and, perhaps more important, to make the consortium more valuable to its members.

This review of the MCC's research and marketing activities strongly indicates that it has been well able to appropriate the benefits of its research; otherwise, it would have found it difficult to license the fruits of its research, particularly to third parties, who could be expected to free-ride if spillovers were substantial. It follows that in the absence

89. See Coelho (1989) for a discussion of the effects of the MCC's commercial activities on start-up companies and on the availability of venture capital.

of the MCC, firms that undertook R&D programs similar to the MCC's would also have been able to appropriate their results. The social justification for the MCC, then, must turn on its ability to generate knowledge for its members more cheaply than they could generate it themselves. The current strategies of the MCC for delivering its R&D well illustrates the proposition that joint ventures and research consortiums are in part a substitute for ex post cooperation through licensing.

CONCLUDING OBSERVATIONS. Our look at the three large-scale research joint ventures points to the benefits of studying such arrangements as a guide to future modeling of technological cooperation. For example, although the theoretical literature offers insights on the forces that motivate the choice of merger, joint venture, or ex post contract to improve the efficacy of R&D investments, we need to better explain the forms of governance selected when the chosen vehicle is a joint venture.

The closer look at these joint ventures also reveals that theoretical research will have to take a more detailed approach to modeling the internalization of technological spillovers and to reassess their importance as motivations for cooperative research. The experience with VLSI and Sematech can be read as indicating that the concerns about positive competitive spillovers from one level in the vertical chain to the other may play a role equal to, or even more important than, concerns about horizontal technological spillovers.

Remarks on Policy

Theoretical modeling indicates that when spillovers are significant and when cost savings from better coordination and fuller dissemination are pronounced, ex ante cooperation in R&D can yield first-order welfare gains. At the same time, formal modeling indicates that under certain circumstances, ex ante cooperation may diminish competition in either the conduct of R&D or in the downstream exploitation of the results of R&D. The goal for policy design is to distinguish the settings in which ex ante cooperation plays a positive role from those in which its effects are negative.

Our theoretical discussion suggests that ex ante cooperation is most likely to be beneficial when competitive spillovers are limited and when the level of technological spillover is high. Moreover, when cooperating firms face strong competition from other firms or also conduct independent and competing R&D, they are less likely to use ex ante cooperation as a means of reducing R&D competition.

The possibility that a joint venture might succeed in restricting R&D investment below its socially optimal level is more likely when the joint venture controls a large share of assets that are critical to the production, dissemination, adoption, and commercialization of new knowledge leading to new products and processes. Such restriction is also more likely if the venture participants have more to fear from losing markets to each other than to firms that would provide the needed downstream competitive constraint. Attempts by a venture to limit independent R&D should also raise concern.

Unfortunately for policy formulation and antitrust enforcement, economics currently provides inadequate guidance on how best to assess the shares of pertinent assets that are being coordinated by the joint venture.[90] The question of shares is relevant to the current debate concerning the degree to which U.S. antitrust policy should allow cooperation among competitors to commercialize R&D that is close to the product market. Proponents of a more relaxed antitrust treatment of such collaboration argue that successful R&D requires ''continuous and simultaneous feedback'' between and among the stages of the innovative process, as well as production and marketing.[91] This view of the innovation process squarely identifies the standard downstream assets of the innovators, such as a solid customer base and well-functioning marketing and distribution channels, as relevant to the assessment of rivalry in the R&D realm. If this position is correct, then the analyses of R&D rivalry are off the mark if they focus merely on firms' abstract abilities to conduct R&D that could be competitive with that of the venture.[92] If they are to illuminate the issues of this important debate, models must account for the interplay between upstream and downstream assets in technological competition, as well as pay greater attention to the importance of organizational design.

90. See Ordover and Baumol (1988, pp. 31–32) for a more detailed discussion on this point.

91. Jorde and Teece (1989a, p. 535).

92. See, for example, the U.S. Department of Justice news release of June 26, 1985, regarding the CAM-1 research joint venture, as discussed and cited in Scott (1988, pp. 183–84). See also Grossman and Shapiro (1986).

Comments and Discussion

Franklin Fisher: This is not one paper but two. The first covers theory; the second is a discussion of three important examples. But the theory does not inform the empirical material. What the authors have to say about the case studies is very sensible, and the theory is interesting, but one part could have been written without the other.

I turn now to some remarks on the subject of R&D cooperation, on which I am in general agreement with the authors. The force behind the drive to allow cooperation is the idea that "all these foreign governments"—it is always useful to wave the Rising Sun at this point—"are doing these terrible things, and American firms cannot possibly compete because the antitrust laws hold them back."

It is hard to understand how allowing people not to compete can make them more efficient, but in research and development it could possibly be true. I suspect that allowing cooperation is popularly supposed to be true because R&D is supposed to have economies of scale that accompany it, and somehow, either for this or for risk-taking reasons, American firms, unless their name is IBM, are just not big enough to compete with the Japanese. Maybe such economies of scale do exist, but I do not know of much evidence of them. And the authors' discussion of the case of VLSI suggests that economies of scale are not really important.

A second reason for the push to allow cooperation is less technical. It is fear and the belief that foreigners know deep secrets that we do not. I do not believe such fear to be soundly based, especially if it is based on the advances they have made unilaterally. At the same time that the Japanese were doing much better in the computer business because supposedly—and perhaps truly—of their research into semiconductors, the two biggest Japanese computer firms were also doing well in the computer business largely because they were stealing trade secrets from IBM (in software, not in semiconductors).

I turn now to the issues of intellectual property spillovers, and so on. The view that allowing firms to cooperate will *necessarily* expand R&D is simply wrong. It might and it might not. It could very well reduce R&D, and it is not at all clear whether expansion or reduction is going to be optimal.

Here is a story about allowing firms to cooperate that is at least illustrative of some of these points. In 1976 various airlines got together and obtained an antitrust exemption allowing them to work on the joint development of computer reservation systems (CRS) for travel agents to use when they made reservations. Airlines had typically developed the systems internally in various degrees, but CRS were now to be extended to independent travel agents. This venture, known by the euphonious name of JICRS, Joint Industry Computer Reservation System, did not get far. United Airlines, which had one of the well-developed systems, and American Airlines, which had the best-developed system, decided that they did not want to join, despite the antitrust exemption.

There were two reasons for this, one of which United and American admitted to: they plainly thought they had something, and they did not want to be in an industry effort that would give it to their competitors. The second reason—the one that prompted considerable regulation and litigation—was that individual airlines quickly recognized that their own systems could be biased to give a display preference to their own flights. Because travel agents tend to pick flights from the first lines or at least the first screen presented, the host airline could earn a great deal of money at the expense of its competitors. A joint industry system would not have done that.

Thus there were large negative externalities from the point of view of the competing firms. An individual firm had a big private incentive to develop its own biased CRS. Allowing the antitrust exemption would do no good because the firms would have had to have been forced to cooperate. Further, assuming they had been so forced, research and development would have been greatly reduced. Whether that would have been a good idea or not depends on the implications for the use of the product.

This illustrates the general problem that there are externalities in research and development. Such externalities can be positive, but they can also be negative. If firms cooperate, they can internalize the externalities. If such cooperation succeeds, the result will be Pareto-efficient for the firms. But this does not get one very far because Pareto efficiency for the firms does not imply Pareto efficiency for society, and the welfare of the consumers is not likely to be taken into account.

I take a very skeptical view of a policy of allowing cooperation where one is unsure that it is a good idea. Firms cooperating in R&D will tend to talk about other forms of cooperation. Further, in learning how other firms react and just in living with each other, each cooperating firm will get better at coordination. Hence competition on the product market is likely to be harmed.

There are thus possibly serious costs involved in permitting R&D cooperation. And as the authors make clear, there is really no convincing case for believing that such cooperation has important social benefits. In general, the view that such a policy is a good one has been foisted on the body politic.

Richard Schmalensee: This is a difficult paper for a discussant, and not only because of its length. It covers a wide range of materials from case studies to patent-race models but it does not have a core model; it has several little models. It does not have a core empirical exercise; it has bits of evidence.

Franklin Fisher said there are two papers here. I think there are two papers with the promise of a third in the introduction and other places that discuss public policy. The authors mention pending litigation on cooperative ventures. They discuss how important all this analysis is for policy. I will discuss the promise later.

I share with Fisher a number of opinions about the paper. First, what it does it does well. There are two good papers, and the third might be very interesting when it is written. The introduction talks about how important R&D is, and it attempts to define the problem. The introduction is a spicy stew consisting of at least three ingredients. The first is a fairly unobjectionable discussion of the reasons for a gap between private and social returns to R&D, the sorts of things we are familiar with. The second is a set of what might be called pseudoclaims. These have the form, "The gap *may* be widening for reason x: anecdote."

This is not a persuasive style. The third ingredient relates to Fisher's observation that interest in relaxing policy toward cooperative ventures has arisen, to some extent, for bad reasons. The third element here is the vague allusions to competitiveness that run through the introduction.

Thus a reader is not initially sure whether the authors are interested in ex ante R&D cooperation because of reasons everyone understands, because of a recent adverse change in the relationship between private and social returns, or because foreign competition will kill us all soon. I must say, having heard a lot of loose talk about competitiveness lately—whatever it is—I found the last ingredient a little too spicy for my taste.

One could disagree with various discussions of current policy in this paper. For instance, the authors are critical of the success of attempts to tighten intellectual property rights, despite the rights' occasional concern with competitiveness. They implicitly criticize efforts to require foreign countries to respect U.S. patents and copyrights. Surely, in light of the authors' interest in competitiveness, criticizing those efforts is odd.

This paper does provide a nice survey of themes and effects in the recent theoretical literature. It does not come to sharp conclusions. Rather, it serves, I am afraid, both to illustrate what the literature is about and to illustrate its limitations. The authors lead one to wonder whether that literature can be used to enhance our understanding of the empirical evidence.

The authors criticize a number of features of the current literature. I would add just two points to that discussion. The first is that most of the literature and most, but not all, of the discussion in the paper compare a situation in which all firms in an industry cooperate and one in which all firms in an industry go their own ways. If one looks at cooperative research in practice, the case of universal cooperation is rare. That is why there are few case studies of that sort. Research joint ventures involving subsets of industries are common, however, and these are where the policy debate mainly lies and where the legislation that they discuss is mainly concerned.

The second point about the theoretical literature is this. I was surprised that the authors focus strongly on R&D spending, and on forces that may increase or decrease it, despite the concern throughout with spillovers. As we all know, a little less spending and a little more spillover can result in more technical progress. It thus wasn't clear from the paper whether the objective was to speed technical change or to increase R&D spending.

At any rate, I do come to the negative conclusions that the authors do: this topic is such that the more careful and the more detailed the models, the more opposed noncomparable effects one comes up with. It is, of course, at this point where one turns to the empirical work.

In the empirical work, one learns a reasonable amount about R&D cooperation in various places at various times, especially about the Japanese experience. The authors argue that those who think that the United States should emulate the Japanese model typically give the Japanese Ministry of International Trade and Industry (MITI) more credit than it is due. They also state that although R&D cooperation is common in Japan, it is generally of a form that would be legal in the United States. The kind of production or marketing joint ventures that are at the center of the current policy debate are relatively rare in Japan.

I was surprised as I read the empirical section at the extent to which success in these ventures is defined privately—from the point of view of its participants. This is, of course, to some extent inevitable because there are few good controls handy about what would have happened if the venture had not taken place and because obvious measurement problems prevent defining success from a social point of view. Thus it is not clear whether either the theoretical or the empirical literature provides much material for the promised third paper—that is, for an analysis of policy toward ex ante cooperation in R&D.

I would be interested in the authors' reactions, after their exhaustive and exhausting analysis, to policy proposals now on the table. The National Cooperative Research Act of 1984 singles out research joint ventures for rule-of-reason treatment under the antitrust laws and, in addition, provides that the ventures registered with the enforcement agencies shall be subject only to single damages for the consequences of their research activities or the activities encompassed in their registration statements. There are two basic proposals on the table. The first is to extend that sort of treatment to joint ventures that also involve production and, in some variants, marketing. The argument for single damages is that the main rationale for treble damages is detection probabilities less than one, a rationale that does not apply when the venture is public. And, because rule-of-reason treatment is a better way to look at these things than per se treatment, extending rule of reason to these joint ventures formally, rather than waiting for the courts to do it in a definitive fashion, is good policy. The second kind of approach, associated with Jorde and Teece, goes beyond this to grant antitrust immunity to research joint ventures that meet a variety of standards and are certified as clean by the enforcement agencies.

The authors note that research joint venture activity increased after the 1984 act. It is my understanding that, in fact, if the ones mentioned in the *Wall Street Journal* were counted, the increase occurred a couple of years before the passage of the 1984 act. I also understand that there has been a more recent increase, again using the *Wall Street Journal* as the basis for the count, in production joint ventures. In both cases, one can think about causation as one will.

At any rate, I would be interested in learning, given the paper's initial charge into the policy area, the authors' attitudes toward these proposals or whether they think we should be considering something else entirely.

General Discussion: Suzanne Scotchmer noted that the ability of firms to extract monopoly rents in the product market comes from patent protection. The main purpose of R&D collusion, she asserted, is to increase efficiency in achieving patents (in particular, by avoiding duplication of research). This means that cooperate R&D agreements could reduce the inefficiencies of patent races, thereby increasing profits, and could increase efficiency. Michael Katz stressed, however, that if the purpose of R&D is to get ahead of rival firms, then ex ante cooperation might involve an agreement not to engage in R&D, with negative overall consequences for efficiency.

Susan Rose-Ackerman claimed that there might be an optimal level of R&D cooperation and competition in an industry. She said that in the agricultural industry, research is organized at the state level through a system of subsidized state experiment stations. Growing conditions and production functions differ across states for products that are very close substitutes in competitive output markets. Thus even though an overall increase in agricultural productivity would benefit mostly consumers rather than producers, farmers in one state, say Minnesota, may support productivity-enhancing R&D because it will permit them to benefit relative to farmers in Oklahoma. If the R&D agenda were determined in a more centralized way—by the federal government, for instance—farmers might support less R&D activity.

Jean Tirole said that the authors might have overstated the dangers arising from ex ante R&D cooperation. He claimed that the authors assume a joint venture operates as a single firm, enabling it to write complete contracts about reduced investment and reduced output. Tirole doubted that such complete contracts could be written, in particular because of the uncertainty of R&D. Without such contracts, the problem of collusion still exists but is alleviated.

Robert Hall asserted that establishing effective property rights for technology, not encouraging R&D cooperation, was the key to obtaining the socially optimal amount of R&D activity. He said that there should not be a problem with the duplication of research as long as all the participants anticipate that the owner of a technology will license it for somewhat less than its reproduction costs. Licensing, according to Robert Hall, is the alternative to joint ownership of technology.

Bronwyn Hall noted that the problem with creating property rights is that the average length of effective patent protection in certain industries (for example, semiconductors) is only a few years. Scotchmer said that the solution to this problem would be to broaden patent protection.

Martin Baily noted that as the technological gap between the United States and the other Western countries has closed in such industries as computers and semiconductors, the optimal industrial organization of these industries in the United States has changed. In the 1950s and 1960s U.S. firms had a substantial lead in technology, making it difficult for foreign firms to compete in U.S. markets. At that time R&D collusion by U.S. firms could have led to monopoly power. Today, however, the competition from foreign firms has reduced the potential for monopolization in U.S. markets. Correspondingly, more R&D cooperation among U.S. firms can be tolerated.

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