Market Failures and the Design of Innovation Policy

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I. Introduction and Overview

A. Private Innovation in a Market Economy

The analysis of innovation in a free enterprise system was long framed by the work of Joseph Schumpeter, who at different stages in his career entertained two conflicting views of the relationship between market structure and technological performance.

The early Schumpeter[1] envisioned technological advance as the consequence of a never-ending cycle of entry by innovative firms, commercial application of new products or processes, displacement of incumbents, followed by entry of a new generation of innovative firms. This model of innovative activity suggests that ease of entry will promote innovation, and the small- and medium-sized firms will often be the vehicles of technological advance.

The later Schumpeter[2] conceived of technological progress as emanating from the industrial research laboratories of large firms that enjoyed positions of static market power. In what might in modern terminology might be called a theory of technological contestability, he argued that such firms would use their economic profits to finance risky, large-scale R&D activity that would simultaneously leave society better off, in a dynamic sense, and allow the firms to maintain positions of static product-market dominance.

This second view suggests that the rate of technological advance will be greater where product markets are dominated by a few large firms. Such firms would be better able to finance investment in innovation, could take advantage of such economies of scale as might exist in the R&D process, and, because they operate on large (perhaps,

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[1] Schumpeter (1934) (Schumpeter Mark I, in the terminology of Malerba and Orsenigo (1995).

diversified) scales, would be more likely to find commercially viable applications for new technological developments. He also viewed risk as an inherent aspect of research, development, and commercialization, and saw market power as a way to provide "insurance" against such risk.[3]

The early stages of the modern economic literature on research and development were largely devoted to sorting out the implications of these two positions. While this debate remains a lively one,[4] the resulting literature has produced the recognition that *the level of investment in research and development is likely to be too low, from a social point of view, whether market structure is nearly atomistic, a highly concentrated oligopoly, or in between*. Given the large number of policy instruments available to promote private investment in R&D — competition policy and tax policy, as well as subsidies and actual R&D carried out by public research units — the question of the design of policy instruments to promote R&D has moved to center stage.

This emphasis is reinforced by the endogenous growth literature, which pictures technological progress as a general engine of economic growth. That wants exceed means may be accepted as a truism, but the judicious allocation of resources to expanding society's means can go a long way toward relieving the transitional problems that accompany economic development, globalization, and structural readjustment. The most effective way to allocate such resources is to target the specific types of market failure that hold back innovation in different sectors. If capitalism and democracy are to survive the 21st century, governments must identify the sources of the important market failures in the generation of technological change,

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[2] Schumpeter (1942) (Schumpeter Mark II).
[3] See Baldwin and Scott (1987, pp. 2-3).

and devise ways to correct underinvestment in innovation that do not founder on government failure. Our paper is a contribution toward those important goals.

B. The Design of Innovation Policy

It is instructive to consider the advice economists can offer for the design of innovation policy in light of the evolution of industrial economics itself.

At the start of the 1970s, industrial economics was organized around the structure-conduct-performance paradigm. From a current perspective, perhaps the most striking characteristic of the S-C-P paradigm was its self-avowed generality. The basic unit of observation was the industry. An industry could be described in terms of its characteristics. Given information about industry characteristics, predictions could be made about industry performance. Suggestions for the promotion of R&D were similarly general: across-the-board tax breaks for firms that invested in R&D, for example, or increases in patent length or breadth.

The modern game-theoretic approach makes no such claims to generality. Today's organizing framework for industrial economics is a collection of highly specific game-theoretic models, each tailored to fit a market that is described in terms of detailed assumptions about strategic variables, sequences of moves, information sets, and solution concepts.

To take full advantage of the insights offered by modern industrial economics, policy advice should be similarly specific. We take as our starting point the consensus of the literature[5] that reliance on market processes alone will result in an underinvestment in research and development, from a social point of view. Rather than debate whether innovation is promoted *in general* by unconcentrated market structures

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[4] See, in particular, Fisher and Temin (1973) and Kohn and Scott (1982).

[5] Perhaps one of the few points on which there *is* consensus.

and ease of entry or enduring dominant positions of leading firms, we argue that R&D policy should draw on the received catalog of specific sources of market failure to inform the design of innovation policy.

In what follows, we survey the extensive and not always mutually consistent theoretical and empirical literature on innovation, with a view to identifying the sources of innovation market failure in different types of industries and highlighting the kinds of remedies that are most likely to be effective in specific circumstances. General schemes to promote private innovation will be ineffective if they target problems that do not afflict a particular industry and fail to target the specific sources of market failure that are present.

Questions we will encounter along the way include

(1) Are innovation market failures large enough to justify public support for private innovation?

(2) What types of institutional arrangements are best suited to address different types of innovation market failures? Possibilities include but are not limited to (Link, 1997) direct support in the form of

- subsidies;
- tax credits;
- provision of public R&D resources to work with the private sector;

and indirect support through infrastructure design, including

- competition policy, particularly toward cooperative R&D;
- patent policy;
- procurement policy; and
- trade policy.

Under this heading, we will also ask

(2a) What are the implications of globalization of product and financial markets for the design of public innovation-supporting policy?

(2b) How close to the final product market should public support be targeted?

(2c) How can government ensure that its support exerts maximum leverage on private investment?

C. Summary of Main Conclusions

There is substantial evidence of private-sector underinvestment in innovation. Government can implement policies that work to correct this underinvestment. If such policies are ill-designed, they will at best be ineffective, and may at worst harm technological performance.

"Innovation" in modern economies involves not only the formal R&D that takes place in dedicated (public or private) research laboratories, inputs (funding, scientific and engineering employment) and outputs (patents) which can be measured and reported to government agencies, but also incremental improvements in product design and production processes that take place on the shop floor and reflect the accumulation within individual firms of tacit, uncodified knowledge that cannot be costlessly transmitted to or appropriated by rivals.

Formal R&D typically has a large science-based component; incremental innovation typically has a large applied component. The balance between formal R&D and incremental improvement differs from sector to sector in the economy, and innovation policy can and should take these differences into account. Policies that are appropriate for the semiconductor industry will not be appropriate for machine tools, and vice versa.

The nature of knowledge spillovers in a particular sector will reflect the mix of basic and applied research in innovation in that sector. It is costly to take advantage of the knowledge produced by other firms (at least, to take advantage of the knowledge produced by other firms in a way that has feasible commercial applications); innovation free-riding is not as serious a problem as might be thought from an examination of the theoretical economics literature on the subject (Peck, 1986).

Outside of a few specific sectors (biotechnology, chemicals, pharmaceuticals) patents are not a particularly important device for limiting innovation spillovers. Policies that fixate on limiting spillovers (enhancing private appropriability of the returns to R&D) are not likely to be effective and will not in general improve technological performance.

Substantial case study evidence suggests that although cooperative R&D may push out technological frontiers in a few sectors where R&D is extremely costly and the risk of being outside the first cohort of innovators threatens the survival of a firm, the general beneficial effect of cooperative R&D comes from the diffusion of information among participants that such cooperation entails, and the vigorous product-market competition that follows from such diffusion. Product market rivalry, which pressures incumbents to adopt state-of-the-art developments in a timely manner, promotes good technological performance.[6]

In sectors where the cost of R&D is extremely high, subsidies for joint or single R&D may be called for. Indirect subsidies in the form of R&D tax credits are likely to be ineffective (among other reasons, they are not likely to be of much benefit to start-up firms, which will often have only limited tax liabilities). Where direct public subsidies are granted, a quid pro quo should be agreement by recipients that the results of research will be, at least eventually, openly licensed at reasonable rates.

Public policies that encourage R&D cooperation but attempt to exclude firms based outside the national economy are likely to be ineffective, since firms that cooperate domestically can (and will, when it is privately profitable for them to do so) conclude separate R&D cooperation agreements with foreign firms. Given the increasingly global nature of information flows, to the extent that national policies actually succeed in limiting cooperation between domestic and foreign firms, they are likely to worsen technological performance.

New firms are often the vehicle by which new products or processes are brought to market. Competition (antitrust) policy that seeks to deter strategic entry-deterring behavior by incumbent firms promotes entry of new firms, to the extent that this is consistent with productive efficiency, and therefore promotes good technological performance. So does government procurement policy that encourages supply-side diversity (second-sourcing) for high-technology products.

Transactions costs in financial markets are likely to raise the cost of capital and limit the supply of capital to small- and medium-size firms (SMEs). An active venture capital market can ameliorate this problem. Public support for venture capital markets can direct public resources where they will do the most good, without relying on the (doubtful) ability of public officials to identify likely technological winners.

Basic research inevitably involves substantial knowledge input from public and university research laboratories. In any particular scientific area, basic research tends to be driven by the internal logic of the field, rather than the prospect of immediate commercial application. The interest of basic researchers is normally wide diffusion of their results, while the interest of commercial researchers is to defer diffusion until lead-time and learning curve advantages give them an advantage over product-market rivals. In such sectors, public support for innovation may take the form of bridging institutions (Freeman, 1982; Dosi, 1988) (public-private contract research

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[6] This is close to the Schumpeter Mark I model of innovation.

organizations, demonstration projects) that facilitate the application of the results of basic research to specific problems.

In some sectors (agriculture, light industry), technological advance typically takes the form of applying innovations developed in input-supplying industries. Market failure stems from the cost of applying such innovations relative to the size of the using firm and the high ratio of external to internal benefits. Public support for innovation in these sectors may take the form of extension services that serve as a repository of technological information to which private firms can turn for assistance in solving specific problems.

Overall, we argue that there is good reason for policy makers to promote private innovation, and that there are measures they can take to do so. Such measures will differ from sector to sector. Policy design that does not take into account differences across sectors in the sources of innovation market failure is likely to be less than fully effective.

II. Sources of Innovation Market Failure

A. Theory

1. Competition versus monopoly

Arrow (1962) offered the seminal formal analysis of the issues raised by Schumpeter. In a very simple framework, he compared the profitability of a cost-saving innovation for a monopolist of R&D and production and for a single firm in a competitive industry operating in markets that are identical except for the structures of their supply sides.

Arrow left aside many aspects of the R&D process that are thought to be important. He did not take account of uncertainty or imperfect appropriability of the profit that flowed from successful innovation. He did not take account of time, or deal with strategic interactions in R&D among competing suppliers: these were excluded by assumption since he limited himself to the extreme cases of a single firm (monopoly) and many small firms. He did not investigate the cost side of the R&D process or the financing of R&D. He simply compared the profitability of a cost-saving innovation to a monopolist with the profitability of the same innovation to a single competitive firm, with the demand side of the market the same in both cases.

Arrow showed that in the context of his model the competitive firm would profit more from successful innovation than would a monopolist. For the monopolist, the incentive to innovate is the incremental economic profit from producing at lower unit cost instead of higher unit cost, but acting as a monopolist in both cases. Some of the economic profit that the monopolist earns after innovation simply replaces economic profit that it earned before innovation.

If the product market is perfectly competitive, all firms earn zero economic profit before innovation. All the profit that a firm is able to earn after innovation is a net gain, compared with the pre-innovation period. This is sufficient, in Arrow's model, to ensure that a firm in a perfectly competitive industry will profit more from successful innovation than would a firm in an otherwise identical monopolized industry.[7]

2. Deterministic dynamic models

Early generalizations of Arrow's work introduced time to the analysis. They did so by making development time a choice variable of the firm: by spending more, a

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[7] Demsetz (1969) compares the incentive to invent in a competitive industry with the incentive to invent in a monopolized industry that is twice as large as the competitive industry, so that pre-innovation output is the same in both industries. It is difficult to see why this is interesting, although an amazingly long list of articles chased each other down this and related paths. See Baldwin and Scott (1987) for a lengthy list and review.

firm could develop a new product or process somewhat more rapidly, but within limits implied by the technology of research and development. The fundamental assumption in this literature is that there are decreasing returns to research effort: doubling R&D effort means quicker discovery, but it does not cut discovery time in half.

Scherer (1967) presents such a model. In addition to taking the development time to be a deterministic variable, it takes the income stream that flows from successful innovation to be exogenous. There is a basic annual return *V* to successful innovation, but this return is not itself explained in terms of characteristics of the underlying product market.[8]

Scherer emphasizes the duopoly case (and also discusses extensions to the case of *n*-firm oligopoly). He finds that noncooperative oligopoly R&D behavior results in more rapid development than would monopoly.[9] He notes that this is not necessarily beneficial from a social point of view — a fact that is sometimes lost sight of in policy debates — and that an explicit welfare evaluation is called for.[10] Making such a comparison, he argues that when privately profitable innovation creates new markets or expands existing markets, it will be socially beneficial as well. Otherwise, the resources used to accelerate innovation may be more valuable than the benefits that flow from having the innovation in place a little bit sooner.

We mention only two contributions to the subsequent literature based on this type of model. Baldwin and Childs (1969) generalize Scherer's model to concentrate on markets in which it might be more profitable to be the second firm to bring an innovation to market — to imitate rather than to innovate. Such a situation might arise

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[8] It is clear (Scherer, 1967, p. 367, fn. 4) that Scherer is aware of this, and makes the specification to keep the analysis focused.
[9] A condition for this is that the development times of rival firms be strategic complements (Scherer, 1967, pp. 378-382).

if the information that is diffused when the first successful innovation is disclosed sharply reduces followers' innovation costs. If knowledge spillovers are large in this sense, a market might settle into an "After you Alphonse, after you Gaston" equilibrium, with all firms waiting for some other firm to take the lead and a consequent unsatisfactory rate of technological progress. The later literature has suggested that R&D joint ventures are appropriate for such markets.

Kamien and Schwartz (1972) present an early discussion of the implications of possible cooperation in research and development.[11] They argue (1972, p. 53) that a merit of R&D cooperation is that it eliminates wasteful duplication of effort. This is a recurring theme in the subsequent literature on R&D cooperation.

It is not clear how important duplication of research effort is in practice. In their seminal study of a sample of 17 specific innovations, Mansfield et al. (1977, p. 227) report that for most of their sample, no firm other than the eventual innovator was engaged in efforts aimed at the same goal. Nor (as we note shortly) is it clear that duplication is actually wasteful, from a social point of view, once one leaves behind deterministic models of innovation.

3. Racing models

A class of models beginning with Loury (1979) and Lee and Wilde (1980) relaxes the assumption that development time is deterministic. This literature treats development time as a random variable: by making a greater R&D effort or spending more on R&D, a firm can reduce the *expected* time to discovery, but actual discovery time depends on luck.

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[10] Barzel (1968) subsequently addressed the issue of welfare evaluation.

[11] Their model treats a firm's own development time as deterministic, but models the firm's expectations of rival development time as a random variable, using the

Early contributions to this literature took the income that would result from successful innovation to be exogenous, and asked how the expected time to discovery would change as the number of independent R&D projects increased. Results differ depending on details of the specification of the R&D cost function, but generally suggest that the expected time to discovery falls as the number of firms carrying out R&D projects rises.

Once research and development is thought of as an inherently random process, the argument that it is wasteful for several different firms to pursue the same research goal is seriously weakened (Nelson, 1961). Different research projects seeking to develop a new product or process will not follow identical strategies. Some research strategies will be more likely to succeed than others, in a way that is impossible to know in advance. Multiple R&D projects seeking the same goal increase the likelihood that at least one project will be successful. Given that it cannot be known in advance which project will succeed first, it makes little sense to look backward after innovation has occurred and brand the projects that did not succeed first as being wasteful.[12]

A later stream of work in the racing literature (Gilbert and Newbery, 1982, 1984; Reinganum, 1983, 1984) asks whether an incumbent firm or a potential entrant would innovate sooner, in an expected value sense. These models generalize Arrow's

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formulation later adopted by the racing literature. In this discussion of cooperation, R&D cooperation is not separated from product-market cooperation.

[12] The path-dependence literature involves the argument that in some cases second or later versions of an innovation may be more desirable, from a global point of view, than the first arrival, yet be precluded from effective implementation solely due to timing considerations. This is an argument against too early concentration on a particular line of development. At the same time, when multiple lines of development are followed, strategic behavior may influence the eventually successful path, and it is by no means certain that the first variety off the starting block will win the race; see Cusumano et al. (1992) for an example.

(1962) approach to allow for rivalry in the R&D process, and they deal directly with Schumpeter's visions of market-based innovation: are large firms more likely than small to invest in innovation? Once again, specific results depend on details of model formulation, but the nature of the results suggests that smaller firms and potential entrants are likely to invest more in innovation than large incumbents.[13] This supports the "creative destruction" view of innovation rather than the product market power-innovation view.[14]

4. Sequences of innovations

One justification for public funding of public-private partnerships is the consumer surplus that results because of an innovation itself. The innovator does not appropriate that surplus, although it represents a gain for society. A more important reason for public funding, however, is that the innovator of a product or process will not only fail to appropriate the consumer surplus created by the innovation itself, but also will typically be unable to appropriate the consumer and producer surpluses created by subsequent innovations that build on the technology and knowledge

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[13] Gilbert and Newbery (1982) examine the case of deterministic innovation, and find that an incumbent will prevail in a contest with an entrant for nondrastic innovation; Reinganum (1983) finds that an entrant will (in an expected value sense) prevail in a race for a stochastic drastic innovation.

[14] While racing models are formally dynamic, most use a modeling device to eliminate the nastier aspects of fully dynamic models. In most of the racing literature, R&D effort is described by a *hazard rate* — a parameter that indicates how likely it is that a project will succeed — that is treated as a constant. By spending more, a firm can get a larger hazard rate and make it more likely that its project will be successful. But once a firm picks its level of research activity, that level — and the firm's probability of research success — is fixed. From a technical point of view, this is very convenient: all the income streams of the firm and its rivals, which determine incentives to invest in R&D, collapse into expected present discounted values and the decisions that optimize private returns can be analyzed using techniques from static optimization theory. The assumption that the hazard rate is constant rules out learning-by-doing. If it becomes more likely that a project will succeed as time passes, then the hazard rate rises over time. It is possible to model such processes within the racing framework (see, for

introduced by the initial innovation (Baldwin and Scott, 1987, pp. 56-61; Scotchmer, 1991). The consumer and producer surpluses generated by other innovations that follow in a sequence because of the initial innovation can be quite large (Caballero and Jaffe, 1993).

While this discussion justifies public support for innovation, it should not be understood as suggesting the need for enhanced appropriability. Full realization of the potential benefits of a discovery will often require that subsequent innovations (which include commercial application of basic innovations) be carried out by an economic agent other than the original innovator. Appropriate public involvement in such cases will involve setting up bridging institutions[15] to facilitate the transmission of information.

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example, Fudenberg et al. (1983)) but the explicit use of dynamic optimization techniques then becomes unavoidable.

[15] Dosi (1988, p. 1136) attributes this term to Freeman (1982).

5. Spillovers

This introduces the topic of information spillovers. In a seminal paper, d'Aspremont and Jacquemin (1988) present what they themselves call an example to explore the implications of knowledge spillovers on independent R&D, R&D cooperation, and technological performance. Their model is a two-stage game with deterministic innovation. In the first stage of the game, each firm decides how much to spend on R&D. Each level of spending is associated with a specific, deterministic reduction in unit cost. In the second period, the cost reductions are realized, and firms compete according to rules that vary in different versions of the model. Following the usual backward induction methodology, when firms make their R&D spending decisions in the first period, they do so in the light of the profit they expect to make in the second period. Spillovers arise in that the spending of one firm on R&D may (depending on the value of a parameter in the model) reduce the unit costs of rival firms.

d'Aspremont and Jacquemin consider three scenarios:

- independent R&D with independent output decisions;
- R&D cooperation with independent output decisions; and
- R&D cooperation with product market cooperation.

Specific results depend on the size of the spillover parameter, but generally suggest that cooperation in R&D alone or at both levels (R&D and production) improves welfare, particularly if spillovers are large.[16]

[16] R&D cooperation may make it easier for firms to sustain tacit product-market collusion (Wegberg and Witteloostuijn, 1995; Martin, 1996a). If this occurs, the resulting worsening of static product-market performance would need to be set against any improvement in technological performance.

The d'Aspremont and Jacquemin model has been generalized in a large number of ways.[17] Kamien et al. (1992) incorporate product differentiation and an arbitrary number of firms.[18] They also distinguish R&D cooperation depending on whether firms do or do not set the spillover parameter at its maximum level.[19] They find that when spillovers are high, independent R&D decisions with the sharing of research output worsens equilibrium performance: individual firms free ride, reducing own research efforts because they anticipate that they will benefit from the research efforts of other firms. But if firms coordinate research efforts while sharing information, performance is improved.

In racing models, spillovers reduce the R&D efforts of single firms but improve market performance. The larger are spillovers, the less any one firm will find it profitable to spend on R&D, since some of the knowledge generated by R&D increases the likelihood that some other firm will discover first.[20] But precisely this

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[17] In addition to the papers mentioned below, see Henriques (1990), d'Aspremont and Jacquemin (1990), Suzumura, 1990), and Ziss (1994).

[18]The introduction of product differentiation makes it possible to allow (in an interesting way) for price-setting behavior in the product market.

[19] It is not immediately obvious that firms can control the extent of spillovers, either within or outside of cooperative R&D activities. The extent of spillovers may simply be a technological datum that reflects the tacitness of knowledge, the way information circulates in a particular scientific and engineering field. Fölster (1995, p. 54) cites instances in which R&D employees exchange information whether or not their home firms consent to the exchange, which is consistent with the view that the extent of spillovers is not a control variable of the firm. See Katz (1986) for a model in which cooperation increases the spillover rate for cooperating firms, but subject to an upper bound that is technologically given.

[20] However, as Dosi (1988, p. 1140) notes,

> the partly tacit nature of innovative knowledge and its characteristics of partial private appropriability makes imitation, as well as innovation, a creative process, which involves search, which is not wholly distinct from the search for "new" development, and which is economically expensive...

In sectors where a firm must undertake its own R&D to access the knowledge generated by other firms, individual firm R&D may rise as the potential for knowledge spillovers goes up. See also Spence (1984), Cohen and Levinthal (1989).

fact means that such R&D as does take place is more effective, resulting in a greater level of expected net social welfare, all else equal.

The policy conclusions to be drawn from these results depends on what is the policy goal. If the goal is to maximize the rate of technological progress, spillovers are undesirable, and policy action to neutralize the effects of spillovers may be called for. If the goal is to maximize net social welfare, spillovers are desirable, at least within the context of racing models.

6. R&D Cooperation Policy

At the risking of seeming to state a tautology, domestic antitrust or competition policy (as contrasted with international "competition" policies such as promotion of national champions) typically maintains a presumption in favor of competition: not competition in the classroom sense of a market supplied by many small price-taking firms, but in the sense of independent decisions by firms that pursue their own self-interests.

Arguments that favor relaxing this presumption as far as research and development is concerned are based on two assumptions. The first is that, left to its own devices, private investment in innovation will be less than is socially desirable. We have reviewed some theoretical arguments that favor this assumption, and we will see that empirical evidence generally supports it.

The second assumption is that adopting a permissive competition policy attitude toward R&D cooperation will improve technological performance. This is far from clear.

It is perhaps noteworthy that the single U.S. antitrust case involving R&D cooperation was based on allegations that the such cooperation was an instrument of automobile manufacturers to delay the development of emissions control technology.[21] Katz and Ordover (1990, p. 169) hold that the limitation of private R&D because firms fear antitrust or competition policy prosecution has “never been rigorously demonstrated, either theoretically or empirically.” Mowery (1995, p. 526) notes the absence of empirical support for the efficiency effects often ascribed to R&D cooperation.

Theoretically, as we observed in the preceding section, in multi-stage game racing models of innovation followed by production, R&D cooperation can improve market performance, but not necessarily because it increases innovative effort or output. Indeed, innovative effort may fall in such models, yet overall market performance[22] typically improves. Joint R&D insures that several firms will have access to the new technology (or new products) in the post-innovation market. This is good for consumers, since it ensures greater product-market rivalry after discovery than would be the case if a single firm enjoyed the right to control the innovation.[23] It is precisely this greater rivalry that reduces the incentive for a cooperative project to invest in R&D. Innovation is therefore delayed (in an expected value sense), but consumers are so much better off, after discovery takes place, that the overall effect of R&D cooperation on expected welfare is positive.

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[21] *U.S.* v. *Automobile Manufacturers Association* 1969 Trade Cases (CCH) Para 72,907 (S.D. Cal. 1969) (consent decree), modified 1982-3 Trade Cases (CCH) Para 65,088 (C.D. Cal. 1982).

[22] That is, the expected present discounted value of firm values plus consumers’ surplus, before and after innovation.

[23] If participants may use the innovation in different product or geographic markets, this product-market rivalry effect will not be present.

Vonortas (1994) distinguishes between cooperation in generic research and cooperation in development. He also considers two types of joint ventures:[24]

- *secretariat RJVs*: firms coordinate research and or development activities, but those activities are carried out independently by the coordinating firms;

- *operating entity RJVs*: coordinating firms establish a common laboratory at which research and or development is carried out.

Although the details of his results depend on specific parameter values, they suggest that secretariat RJVs, which do not eliminate strategic overinvestment in research by rival rivals, do not improve welfare, while operating entity RJVs are more likely to do so. A critical question regarding the last point is whether or not joint R&D is a substitute or complement for private R&D. If firms expand their own R&D because of participation in a research joint venture, then joint R&D definitely increases overall research effort. If firms cut back their own R&D because of participation in a research joint venture, then the net impact of the joint venture on overall R&D is uncertain.[25]

Much of the theoretical literature on R&D cooperation compares a situation in which all firms in an industry form an R&D joint venture with a situation in which each firm carries out its own R&D project. Real-world R&D cooperation in many industries consists of a bewildering thicket of alliances and cross-alliances, with firms partners in some projects and rivals in others. Theoretical models of this sort of partial R&D joint venture are offered by Kamien and Zang (1993), Martin (1994), Yi and Shin (1997),

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[24] He attributes this terminology to Ouchi (1989). Hagedoorn (1990) develops a more elaborate classification, which includes regimes that permit cooperation in production.
[25] This theoretical result is consistent with Mowery and Steinmueller's (1990, p. 50) discussion of the integrated circuit industry:

> If collaboration, even in precommercial research, reduces the number and range of technological avenues that are being pursued by independent

and Yi (1998). Partial joint ventures mitigate the impact of spillovers among members of a particular R&D joint venture, ensure rivalry among different R&D joint ventures, and guarantee that there will be post-innovation product market competition in use of the new product or process at least among the members of the successful joint venture.

7. R&D Subsidies

Allowing R&D cooperation is one approach government can take to promote private R&D. Government can also subsidize independent R&D. Indeed, government can subsidize cooperative R&D activities, combining the two approaches.

R&D cooperation deals with knowledge spillovers directly, by allowing firms that benefit from spillovers to coordinate their R&D activities. Subsidies deal with spillovers indirectly: spillovers reduce the marginal benefit that flows from successful innovation, and properly designed subsidies provide a counterbalancing reduction in the marginal cost of investing innovation. Since firms (even cooperating firms) make decisions based on the consequences for their own profitability, they do not take the external benefits to consumers of additional R&D into account: subsidies are a way for government to influence firms' decisions in the direction that this external-to-the-firm consumer benefit requires. As conventionally implemented, however, subsidies may not be sufficient to correct market failure and consequent underinvestment in R&D (Scott, 1995).

Subsidies may also be a way for government to influence the form of R&D cooperation: a subsidy may induce cooperation where firms, left to their own devices, would have chosen independent R&D. Subsidy may induce firms to set up an operating entity joint venture, where if left to their own devices they would chosen an

firms, one of the powerful forces for innovation and growth in the industry's early years may be weakened.

operating entity joint venture. And government may, if it wishes, condition the grant of subsidies on an agreement to license eventual innovations on reasonable terms.

Subsidies must be financed. Theoretical models often assume that subsidies are financed by lump-sum taxes on the industry that benefits from the subsidy.[26] This clearly is not the way subsidies are financed in the real world. If the arguments about the "public good" nature of knowledge production are taken seriously, there would seem to be an excellent case for a net transfer from the rest of the economy to investment in innovation.[27] This does not eliminate the practical aspects of this problem for policy makers who face multiple demands for funding with increasingly limited funds from which to meet those demands.

Hinloopen (1998) incorporates optimal subsidies into the d'Aspremont and Jacquemin model. He finds that subsidies are more effective in promoting R&D than permitting R&D cooperation, and (perhaps unexpectedly) that subsidizing noncooperative R&D and subsidizing cooperative R&D leads to the exactly the same outcome.[28]

8. Patents

A large literature studies the impact of patents on firms' incentives to engage in research and development. Patent design includes the issues of patent length and breadth, as well as institutional factors determining the extent of information disclosed in the process of obtaining a patent.

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[26] The lump-sum nature of the tax ensures that incentives, which depend on marginal payoffs, are not affected by the tax.

[27] Many of the same issues arise with respect to export subsidies; see Dixit (1988) for a discussion of the desirability of explicitly modeling the opportunity cost of funds allocated to subsidies. Romano (1989) takes such an approach.

[28] The subsidy level in each case (noncooperative, cooperative R&D) is set to maximize the same social welfare function. The welfare level achieved is the same in both cases, although the subsidy levels differ.

The issue of patent breadth involves a tradeoff between competition in R&D and competition in the product market. If patent coverage is very broad, the reward to first success in R&D is very great, since the firm that obtains a patent gains property rights over a wide range of related products or processes.

Broad patents therefore maximize incentives for firms to compete in R&D. But once a patent is granted, broad patent coverage limits product market competition, since a broad patent grants a legal monopoly over a large range of processes or a large segment of product space. Overly broad patents may also inhibit follow-up innovation.

Narrowly defined patents reduce the incentives for firms to invest in R&D, but make it more likely that there will be product-market competition among holders of patents over highly substitutable processes or products. Once a patent is obtained, there may be greater incentives for the patent-holder to license use of the patent to others, to minimize incentives to “invent around” the patent.[29] This will encourage diffusion of the patented innovation.

The questions of patent breadth and patent length are related: narrowly defined patents reduce the incentive to invest in R&D, but this can be counteracted by increasing the length of patent coverage. LaManna et al. (1989) explore these issues using a racing model. They compare the welfare consequences of a regime of broad patent protection — the first firm to invent gets an exclusive patent — with a regime in which follow-up inventors can also obtain patents. A broadly defined patent system yields better results if there are economies of scale in production or if invention is difficult; otherwise results are ambiguous.

[29] On imitative innovation, see the discussion of Mansfield et al. (1981) in Section C (1).

Patent rights are not self-enforcing: if a patent-holder believes that rights covered by the patent have been infringed, the patent-holder must undertake costly legal action to enforce those rights. As a practical matter, this may be equivalent to a system in which some follow-up inventors can obtain patent rights that overlap with the patent rights of a first inventor. Such overlapping is encouraged by the information that is revealed when a patent is applied for (Ordover, 1991).

In the same vein, Matutes et al. (1996) note that a narrow patent regime may encourage innovators to delay patenting, privately developing commercial applications before disclosing the characteristics of the innovation to rivals. This delay of disclosure reduces the rate of technological progress. The proper scope of patent protection is to be broad enough to encourage initial investment in R&D and use of discoveries, but not so broad as to stifle the search for subsequent improvements.

R&D incentives and product-market competition are affected in much the same way by narrowly-defined patents and by R&D cooperation. Narrowly defined patents reduce the reward that a single successful inventor receives; so does joint R&D. Narrowly defined patents ensure rivalry in the post-innovation market; so does joint R&D. If the high cost of R&D in some markets justifies encouragement of joint R&D, so that rivals can share costs, it may also be appropriate to define patent rights broadly for such markets: this would maximize the payoff to single-firm investment in R&D.[30] But if joint R&D is thought to be desirable because it ensures post-innovation rivalry, then it may also be appropriate to define patent rights narrowly.[31]

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[30] Cockburn and Griliches (1988) present evidence that the effectiveness of patents varies from industry to industry. There are instances in which the terms of patents have been tailored to the needs of specific sectors (pharmaceuticals, for example).

[31] Scotchmer (1991) emphasizes the interrelationships between patent policy and policy toward R&D cooperation.

The patent literature generally assumes that patents are effective, in the sense that a patent succeeds in establishing property rights over the income stream that flows from the patented product or process. There is by now substantial evidence that this is not the case, and that businessmen are aware of this.[32]

Levin et al.'s (1987) survey of R&D executives indicates that in most R&D-intensive industries, secrecy, lead time, learning-curve effects, and sales and service efforts were ranked ahead of patents as appropriability mechanisms. This no doubt reflects the fact that there is a significant "learning-by-doing" investment required to use information (Vonortas, 1994, p. 415):

> technological knowledge involves a combination of poorly-defined, and often incomplete, know-how and a set of highly codified information which is hard to acquire and utilize effectively.

This will ensure some degree of appropriability of the income that flows from innovation, independent of the nature of the patent system.

The role of patents may be entirely different, at least in some sectors. Mowery and Steinmueller (1990, p. 18) suggest that in the U.S. semiconductor industry, patents historically served as bargaining chips that allow a firm to trade licenses for access to technology covered by patents held by other firms. In such cases, patents effectuate the diffusion of technology. Mowery and Rosenberg (1993, p. 57) suggest that the Semiconductor Chip Protection Act of 1984, which strengthened patent protection for computer chip designs, made patent infringement suits more likely and raised barriers

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[32] There is a famous story among economic theorists of a man about to enter a parking lot late at night to pick up his car, when he notices a friend walking all around a street light, looking at the ground. He goes over and asks his friend if there is anything he can do to help, and the friend replies "Yes, I lost my car keys over there in the parking lot; you might try to help me find them." The first man then says "If you have lost your keys over in the parking lot, why are you looking here?" The friend answers "This is where the light is." It seems likely that economists model patents as an appropriability-

to entry for the kinds of start-up firms that had historically been vehicles for technical progress in this industry.

Although it is the premise of the patent system that technological progress is facilitated by increasing post-innovation appropriability, this premise will be incorrect in the presence of extensive knowledge externalities. For example, a 1956 antitrust consent decree required AT&T to openly license patent-controlled technology at reasonable rates; operating under this constraint, AT&T required cross-licenses of patents from firms to which it granted licenses. This pattern of cross-licenses contributed to rapid entry into and growth of the U.S. semiconductor chip industry (Steinmueller, 1987, p. 13; 1988, p. 335).[33] The diffusion of knowledge in this sector was also facilitated by free movement of personnel among competing companies, including start-up firms financed in venture capital markets (a factor to which we will return).[34]

Cremer and Scotchmer (1997) argue that patents overcome a moral hazard problem, unlike subsidies, tax breaks, and other direct innovation support mechanisms. If public support for innovation takes the form of a subsidy, a firm might pocket the subsidy and not attempt to develop the innovation. Given the uncertain nature of the innovation process, failure to innovate could always be attributed to bad luck; public administrators would be unable to distinguish between good faith plus bad luck and bad faith.[35]

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enhancing device more because they know how than because patents actually are an appropriability-enhancing device.

[33] It also contributed to the development of the UNIX operating system (Salus, 1994, pp. 56-59).

[34] Regarding semiconductors, product-market rivalry was also promoted by Department of Defense second-sourcing policy, which we discuss below.

[35] These issues are also discussed by Fölster (1991). Any innovation support mechanism that requires the firm to wait until after successful innovation to obtain the

9. Product Market Competition Policy

Theoretical and empirical evidence suggests that an antitrust or competition policy that seeks to promote product market rivalry will also promote good technological performance.

Martin (1998) uses racing models to examine the impact of competition policy on private investment in innovation. In such models, the incentive to innovate depends on the difference between pre-innovation and post-innovation profit. Tough competition policy reduces profits both before and after innovation, but the reduction in pre-innovation profit is relatively greater than the reduction in post-innovation profit, with the result that a tough competition policy stimulates innovation and reduces the expected time to discovery.

It is widely thought that one of the reasons for the strong technological performance of Japanese firms is the high level of product-market rivalry in the domestic Japanese market. Mowery (1995, p. 525) argues that a low level of product-market rivalry held back European firms:

> Particularly in European programmes, the perceived scale requirements for domestic technology led governments to couple R&D and product development subsidies with industrial restructuring that produced large domestic firms with near-monopoly power in a domestic market. This market structure reduced competitive pressures to reduce costs and move efficiently to commercialization.

The Schumpeter Mark I model views small- and medium-sized start-up firms as vehicles for the introduction of innovations. A strong competition policy, which

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benefit will avoid the moral hazard problem. The usual sort of trigger strategy argument would seem likely to establish that if the rate of time preference is low enough, the equilibrium strategy for a firm receiving direct support would be to act in good faith.

discourages strategic entry-deterring behavior by incumbent firms, facilitates this process.[36]

10. Procurement Policy

Baldwin's (1980) study of the spillovers from government spending for procurement to commercial markets demonstrates that vastly different results obtain in different situations. In electronics, the government's spending with prominent, established firms had no significant effects on technological breakthroughs, while in marked contrast the start-up companies of Silicon Valley generated the technological change without public support.[37]

With helicopter industries, in the Vietnam era when the product characteristics desired by the military — speed, range, and carrying capacity — overlapped with civilian needs, there were large and significant spillovers from the government procurement spending to the commercial markets. Conditions for spillovers from procurement spending can of course change, even within one industry. Baldwin observes that in the post-Vietnam era, when military demands shifted toward heavy armored helicopters designed for potential land wars in the terrain of Europe as contrasted with Southeast Asia, the spillovers from government procurement spending to commercial helicopter markets ceased. For many sectors, there will be a greater payoff to the establishment of infrastructures that house long-term efforts to promote

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[36] Mowery and Rosenberg (1993, p. 62) argue that U.S. antitrust policy played this role in the postwar period.

[37] Chesnais (1993, p. 215) writes

> ...the disastrous balance of the French electronics industry ... cannot be dissociated from the fact that the military has had priority in fixing the industry's R&D and industrial objectives.

and contribute to private investment in R&D than to high-profile operations of limited duration.[38]

Discussions of the impact of U.S. Department of Defense procurement policy often highlight the importance of steady demand from a large customer willing to pay for the highest-possible quality product. As important as the level of purchases for defense purposes may have been their institutional framework. To guard against the possibility of disruptions in the supply of critical components, Department of Defense second-sourcing policy required a successful contractor to demonstrate the availability of an independent alternative supplier. The effect of this policy was to encourage the diffusion of commercially applicable knowledge and promote product-market rivalry (Mowery and Rosenberg, 1993, p. 46).

11. Overview

Limited appropriability, financial market failure, external benefits to the production of knowledge, and other factors suggest that strict reliance on a market system will result in underinvestment in innovation, relative to the socially desirable level.[39] This creates a *prima facie* case in favor of public intervention to promote innovative activity. Theoretical results should be supplemented by an examination of empirical and case-study evidence before we turn to the formulation of policy recommendations.

B. Empirical evidence

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[38] Link and Scott (1997) discuss such infrastructure investments made by the National Institute of Standards and Technology.

[39] The rent-seeking literature (Fudenberg and Tirole, 1987; Anderson et al., 1997) suggests at least the possibility of overinvestment in innovation: competing rivals, each seeking a post-innovation competitive advantage, may spend more in total than the innovation, from society's point of view. Baldwin and Scott (1987) characterize this as "the overbidding problem" as contrasted with the "appropriability problem" that causes underinvestment. Empirical evidence, to which we now turn, suggests that it is underinvestment that is observed in the field.

1. Spillovers

An extensive body of research confirms that knowledge spillovers are an important part of the innovative process.

Mansfield et al. (1981) study a sample of 48 new product innovations in the chemical, drug, electronics, and machinery industries. They report that the costs of imitating these products averaged 65% of the cost of the original innovator, and that imitation time was about 70% of the time taken to first develop the product (in both cases, with substantial variation around the average). They also report that patents increased the cost of imitation (by about 11%), but that 60% of patented successful innovations in their sample had been imitated within 4 years.

Based on a sample of 100 firms in US high-technology industries, Mansfield (1985) reports that more than half the firms believed rivals were aware of their development plans within 18 months of the time decisions were taken. Detailed information about new products leaked out within 12 months of development, on average. For new processes, the diffusion lag was 15 months, on average. As for the mechanisms by which spillovers occur, Mansfield (1985, p. 221) writes

> In some industries there is considerable movement of personnel from one firm to another, and there are informal communications networks among engineers and scientists working at various firms, as well as professional meetings at which information is exchanged. In other industries, input suppliers and customers are important channels (since they pass on a great deal of relevant information), patent applications are scrutinized very carefully, and reverse engineering is carried out. In still others industries, the diffusion process is accelerated by the fact that firms do not go to great lengths to keep such information secret, partly because they believe it would be futile in any event.

In a similar vein, Henderson and Cockburn (1996, pp. 35-6) say of the pharmaceutical industry that it

> is characterized by high rates of publication in the open scientific literature, and many of the scientists with whom we spoke stressed the importance of keeping in touch with the science conducted both within the public sector and by their competitors. Nearly all of them had a quite accurate idea of the nature of the research being conducted by their competitors, and they

> often described the ways in which their rivals' discoveries had been instrumental in shaping their own research.

In a study of R&D by Swedish firms, Fölster (1995, p. 62) reports that most firms could provide information about competitors' research projects, and that such feedback as could be obtained directly from competitors confirmed the accuracy of the information provided. This is consistent with the view that patents are weak guarantees of appropriability and that firms cannot control the extent of spillovers.

Jaffe (1986) examines spillovers from technological clusters to firm patents, profits, and stock market value.[40] He estimates that for a firm undertaking the average amount of research and development, the elasticity of own patents with respect to the R&D of other firms is 1.1: because of spillovers, patents rise more than in proportion to a general increase in R&D effort.

Bernstein and Nadiri (1988) estimate R&D rates of return for a sample of 5 high-tech industries; Bernstein (1989) reports results from a similar study for 9 Canadian industries. In 4 of the 5 US industries, private rates of return to intangible R&D capital were between 50 and 100 per cent greater than the rate of return to physical capital. The social rate of return to R&D capital (estimated allowing for cost savings in other industries due to spillovers) was often substantially greater than the private rate of return. Similar results are obtained with the Canadian sample. These studies also suggest that across-industry spillovers occur along networks of technically- and commercially-related industries, rather than generally throughout the economy. These results are consistent with those of Scott and Pascoe (1987) who find evidence of knowledge spillovers affecting total factor productivity growth among sets of technologically close industries. Scherer (1982) and Griliches and Lichtenberg (1984) trace the productivity effects of knowledge spillovers between vertically related industries.[41]

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[40] This appears to be the empirical study of spillovers that comes closest to approximating the theoretical concept of spillovers that is used in d'Aspremont and Jacquemin (1988) and related work.

[41] Scott (1993, pp. 128-131) provides further discussion of the work of Bernstein, Bernstein and Nadiri, Scherer, and Griliches and Lichtenberg, as well as other

Along the same lines, Audretsch and Vivarelli (1993), based on their examination of R&D spillovers in Italian industry, suggest that small firms are more likely to enjoy the benefit of spillovers from universities than are large firms. Acs, Audretsch, and Feldman (1994a, b) report similar results from studies of state-by-state spillovers in the USA.

Supporting evidence is provided by Caballero and Jaffe (1993), who use patent citation data for the United States to estimate the rate of diffusion of information about innovations: they find rates of diffusion so large that it is an acceptable approximation to regard diffusion as being instantaneous. They also find, however, that the productivity of patent-embodied knowledge in stimulating new knowledge has fallen over time. According to their results, knowledge circulates very rapidly, but contributes less and less to the expansion of knowledge.

Suzuki (1993) studies main firm-supplier spillovers in vertically-related Japanese electrical machinery groups. He finds evidence of knowledge spillovers from a core firm to its suppliers and of spillovers between supplying firms in different groups.

Henderson and Cockburn (1996) study the impact of economies of scale and scope on innovation in pharmaceuticals. Their results are interesting in their own right and also for the light they shed on the small-firm, large-firm dichotomy identified by Audretsch and Vivarelli (1993) and Acs, Audretsch, and Feldman (1994a, b). As regards scale, Henderson and Cockburn examine the impacts of the size of a research project and of the size of the firm on research productivity. They also test for the presence of economies of scope, which arise if research productivity rises where the number of projects is greater, all else equal. The latter effect, if found, may reflect the common use of inputs or knowledge spillovers across research projects. Their sample permits them to use individual research projects as the unit of observation. When they do so, they find firm-level economies of scale and of scope (1996, p. 48):

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important studies, such as Geroski (1991), of the impact of R&D spillovers on productivity.

> Ceteris paribus, programs embedded in larger and more diversified firms appear to be significantly more productive.

There is also evidence of spillovers across firms, although the effect is modest compared to other estimates of spillovers in the literature (1996, p. 50):

> At the mean, ... a program whose competitors' programs in the same and in related fields are roughly 10% more productive will be approximately 2% more productive itself.

Regarding the impact of spillovers within firms on firm structure and the structure of R&D, they conclude (1996, pp. 53-55):

> As pharmaceutical research has moved from a regime of "random" research to one of "rational" drug design, the evolution of biomedical science has placed an increasing premium on the ability to exchange information within the firm. The primary advantage of size has become the ability to exploit internal returns to scope—particularly the ability to exploit internal spillovers of knowledge—rather than any economy of scale per se.

It will be difficult to carry out project-specific studies in other industries. The results of Henderson and Cockburn suggest, however, that one role for public support of R&D is to promote spillovers across projects by providing an institutional framework within which independent smaller firms can enjoy the benefits that larger firms enjoy as a result of internal spillovers.

2. The rate of return to R&D

Griliches (1992) reports estimates of the rate of return to public R&D in agriculture that range from 28 to 67 per cent. The agricultural sector may offer a paradigm for public support for R&D in sectors dominated by small firms, and we will examine below the way such support has been carried out.

In case studies of 17 innovations, Mansfield et al. (1977) estimate median social rates of return of 56%, median private rates of return of 25%. There is substantial variation in rates of return across innovations, suggesting that investment in R&D is a risky enterprise.

A large empirical literature estimates the social rate of return to R&D by including some measure of R&D input or R&D output as an explanatory variable in an estimating equation explaining growth in total factor productivity. The estimated coefficient of the R&D variable gives an indication how much greater productivity growth would be if R&D activity were increased.

Jones and Williams (1997, Table 1) survey typical results from this literature, which suggest a rate of return of about 30% if attention is limited to the returns to R&D within the industry carrying out the R&D. If returns in other industries that use R&D are taken into account, estimates of the rate of return rise as high as 100%.

Jones and Williams decompose the social rate of return to investment in R&D into components reflecting the value of extra ideas *per se*, the value of increased spillovers, and the value of the extra output permitted by increased knowledge. Based on this analysis, they suggest the empirical estimates are best regarded as lower bounds of the true social rate of return to R&D, and that if the social rate of return to R&D is 30%, then R&D investment in the US would need to be multiplied by a factor of four to reach the optimal level.

In addition to the studies showing that the social rate of return typically exceeds the private rate of return to R&D, and hence suggesting that from a social standpoint the private sector underinvests in R&D, there are studies providing evidence about factors that affect the rate of return to R&D. Some of these studies have been discussed in the context of our evidence about spillovers; others actually consider publicly funded R&D as a separate determinant of productivity and hence can estimate the effect of public funds on the rate of return to R&D. Link (1987, pp. 56-57) provides review of some of these studies; the results are mixed although Link's own evidence suggests (1) that for his sample of manufacturing firms federal support of basic research increased productivity growth more than federal support of applied R&D and (2) that overall the presence of government funding lowers the estimated private rate of return on R&D. One interpretation is that public funding allows private firms to undertake projects that are socially beneficial put less privately profitable than the typical projects in the private companies' R&D portfolios.

3. Subsidies

In their study of spillovers and creative destruction, Caballero and Jaffe (1993) use a calibrated model of the US economy to estimate an optimal R&D subsidy rate of 33%. In their model, such a subsidy would double the rate of growth.

Fölster (1995) studies the impact of subsidies on the extent of R&D and form of R&D cooperation in a sample of R&D projects carried out by Swedish firms. His results suggest that (1995, p. 67)

> subsidy programs that require cooperation but allow a choice of various cooperative agreements ... do not increase the likelihood of cooperating. Moreover, such subsidies increase incentives to conduct R&D to about the same extent as a normal R&D subsidy would. A subsidy that requires a result-sharing agreement ... significantly increases the chances of cooperating, but seems to decrease incentives to conduct R&D.

4. Cooperation

Japan: The VLSI Project

The VLSI (Very Large Scale Integrated Circuits) Project was an Engineering Research Association organized by MITI, in part as a strategic reaction to what was believed to be an IBM project to develop a one-chip computer. It included 5 companies: Fujitsu, NEC, Hitachi, Mitsubishi, and Toshiba. Over the four years of its existence (1976-79), its budget was 60 million yen, half provided by the companies and half by MITI.

The VLSI project is rich in lessons for the public support of cooperative research, although those lessons are not necessarily those that are usually drawn.

The VLSI project involved 6 joint laboratories. One of the 6 was a genuine collaborative operation, in the sense that it involved balanced participation of representatives from all the partner companies. Each of the other laboratories was dominated by one or another of the specific companies. One of the tangible indices of VLSI research output reflects this: the VLSI project generated more than 1,000 patents, of which 16% were put forward by applicants from more than one partner company, 25% by more than one applicant employed by the same company, and 59% by a single applicant (Sigurdson, 1986, p. 50).

From the beginning of the project, the companies' attitudes toward proprietary knowledge dictated the nature of the goals that it would be possible to set (Sigurdson, 1986, pp. 45-6):

> In selecting the themes of the research project it soon became evident that it would only be possible to carry out research ... which was fundamental in nature and which was of great common interest. Thus it was necessary to find out the common interest in order to make cooperation possible. Then, there would be no introduction of company know-how and that problem would disappear.

Diffusion of company-specific knowledge was not a purpose of the VLSI project, and was not responsible for its success.

The typical Japanese R&D joint venture is of the secretariat rather than the operating entity type (Odagiri and Goto, 1993, p. 88; see also Sigurdson, 1986, p. 110):

> for MITI, [Research Associations] have been a convenient way to distribute its subsidies to promote the technology MITI (and participating firms) believed important, most notably semiconductors and computers, and have been used to avoid favoring particular firms and to minimize the cost of supervising the use of subsidies. ...only two of the 87 associations had joint research facilities; in all other cases, each member firm simply took its share of research funds and carried out the research in its own laboratory. Therefore, how coordinated the research really was among participating firms within each RA is doubtful except for a few cases.

Mowery (1995, p. 527) argues that the role of most cooperative Japanese joint ventures was not so much to generate new knowledge as to circulate and diffuse existing knowledge.[42] The VLSI project was exceptional in having one genuinely joint research laboratory; for the most part, it followed the general pattern.

Furthermore, while the VLSI project is often credited with responsibility for successful establishment of a leading Japanese presence in the world semiconductor market, it is important to understand what the nature of that presence is. Dysters and Hagedoorn compare the performances of EU, Japanese, and US microelectronics firms

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[42] This would increase product-market competition, which may in part explain the reluctance of Japanese firms to delegate their best research personnel to cooperative joint ventures.

in the 1980s and conclude that EU and US firms outperform the Japanese from a technological point of view (1995, p. 219):

> Aggressive price competition and low cost production enabled Japanese firms to drive US competitors out of ‘commodity’ markets such as DRAMs. The inability to compete with Japanese companies in price-sensitive mature markets induced European and US firms to upgrade their product line and move into high-end growth markets such as microprocessors and custom chips.

Indeed, European strength in the ASIC (Application Specific Integrated Circuit) segment of the market has been noted (for example, EC Commission, 1994, p. 10-12).

Callon (1995) argues that the Japanese industrial policy promoting high technology has in fact disintegrated and is no longer successful. He states (p. 2):

> the heart of Japanese industrial policy [is] the promotion of leading-edge or high-tech sectors, specifically through MITI’s use of high-tech consortia. Three aspects of Japan’s new situation have eroded the basis for these policies since the 1970’s. First, as Japan moved to the leading edge of many technology sectors in the 1980’s, it could no longer follow proven technology paths blazed by the world’s leading high-tech economy, the United States. In this context, Japan’s traditional industrial targeting strategies began to go astray. Simply put, it was no longer clear what to target. Second, the major Japanese companies that were dependent on MITI for protection against U.S. competition in the 1970’s became increasingly confident of their own competitive strength by the 1980’s and began to resent and resist MITI’s industrial policy intrusions. Finally, as the U.S. trade deficit with Japan soared in the early 1980’s, U.S. government pressure on MITI became intense. The United States demanded that MITI abandon its aggressive promotion of Japanese industries.

EU: Jessi/Medea

Support for cooperative research in the European Union follows a two-track system. The two tracks are designed to take account of some of the lessons about publicly-supported cooperative research that emerge from past experience.

The European Union supports a range of basic research projects under (most recently) the Fifth Framework Programme. These projects emphasize basic research (this can be seen as seeking to avoid the kinds of conflicts that arose early in the VLSI project) and participation of small- and medium-sized enterprises. Diffusion is also sought: research results are owned jointly by the EU and the companies involved.[43]

R&D that is closer to the marketplace is carried out under the aegis of EUREKA, an organization that dates from 1985 and now includes 24 countries and the European Union as members. EUREKA programs emphasize commercialization rather than basic research; research results of a project are the property of the partners involved.

Among the EUREKA projects are JESSI (1988-96) and its successor MEDEA. JESSI was in part a vehicle for public subsidy: half of its 3.8 million ECU budget was funded by participating companies, the other half by various government and public sources. JESSI is credited with upgrading EU technology with respect to both specialty chips and computer aided design manufacturing techniques. MEDEA, which anticipates a 2 billion ECU budget over the 1997-2000 period, will concentrate on 6 areas and aim to maintain a European presence in the semiconductor chip industry.

US: Sematech

Sematech (Semiconductor Manufacturing Technology) was formed in 1987 as a joint industry-government sponsored research consortium intended to revitalize the US semiconductor industry. Just as Japan's VLSI project was very much a strategic response to perceived developments at IBM, so Sematech was very much a strategic response to the rise of Japanese semiconductor manufacturers. Sematech was founded with 13 corporate members. A fourteenth joined in short order; 3 of the 14 have since withdrawn.[44]

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[43] For the Fifth Framework, the European Commission seeks to reduce the number of research themes supported and concentrate efforts on a smaller number of areas. It remains to be seen whether this attempt will be successful.

[44] LSI Logic and Micro Technologies withdrew in January, 1992, the former indicating that Sematech 's goals provided too indirect a return on its investment and the latter citing Sematech's focus on semiconductor equipment manufacturing. Harris Semiconductor withdrew at the end of December, 1992; it sought to develop analog signal processing and power semiconductors rather than the submicron process technology that had become central at Sematech.

Sematech has arranged some joint projects with JESSI. It maintains its own research facility, which seeks to simulate manufacturing conditions. It signs contracts with outside laboratories to carry out research in specified areas. That Sematech has its own research facility makes it exceptional (Peck, 1986, p. 219):

> the most common pattern in ... U.S. R&D joint ventures has been for the research to be carried out by participants in their own facilities or by contract with universities and independent organizations...

That the VLSI project and Sematech have, exceptionally, set up their own research facilities suggests that there may be exceptional characteristics of the semiconductor industry that induce firms to opt for this form of cooperation. We will see, below, that these exceptional characteristics include the high cost of semiconductor R&D and the risk associated with *not* being in the first wave of developers.

Sematech is also associated with two other collaborative efforts, the Semiconductor Research Corporation (SRC) and SEMI/Sematech. The SRC provides a framework for university-industry cooperation, and may be thought of as an umbrella for research that is more basic in nature than that pursued by Sematech. SEMI/Sematech is a semiconductor manufacturer industry association.

Sematech is widely credited with enabling the US industry to regain world market share, reversing losses to Japanese suppliers. In 1994, it announced its intention to give up US government support at the end of the 1996 fiscal year.

From a policy point of view, it is important not only to ask if Sematech was successful but also what results might have been obtained without cooperative R&D. Irwin and Klenow (1996) estimate that Sematech member firms reduced their overall R&D spending, inclusive of their contributions to the consortium, by $300 million per year. Sematech's research budget during this period was $200 million per year, of which the member firms contributed about half of the funds. If the Irwin and Klenow result is accepted, the net effect of Sematech was to reduce industry spending on R&D. The member firms put about $100 million a year into the consortium and reduced their own R&D spending apart from their contributions to the consortium by four times that amount yielding the net change in their overall R&D spending as a reduction of $300 million. One may take the view that the reduction might reflect the elimination of wasteful duplication, and that a benefit of joint R&D is the knowledge diffusion that it entails.

Link, Teece, and Finan (1996) examine the benefits from the Sematech collaboration and conclude (1996, p. 750):

> SEMATECH has provided an organizational structure in which important processes and technologies have been advanced, which could not have been justified on economic grounds, based on the estimates presented herein, outside of a collaborative research arrangement. Government funding has been helpful.

In terms of the present context, Link, Teece, and Finan find that a public-private partnership was needed to bring about the innovative investments undertaken by Sematech. But Irwin and Klenow's estimate that the Sematech consortium of chip manufacturers cut back on their non-Sematech R&D investments by far more than they contributed to the subsidized consortium's R&D investment sounds a cautionary note.

5. Cross-sectional evidence

Another line of research has used cross-sectional evidence to look directly at the Irwin and Klenow question of whether or not government funding displaces private spending. Scott (1984) and Mansfield (1984) use very different samples and very different methodologies — different from each other and from Irwin and Klenow — and reach essentially the same conclusion (which is at odds with that of Irwin and Klenow): public funding does not displace private R&D spending; instead the private spending increases somewhat from what it would have been without the public funds.

Scott (1984) found in a large cross section (over 400 firms with over 3000 observations on their activities in various industries) that for each federal research dollar received by the typical company, the company spent an additional eight one-hundredths of a dollar of its own money on R&D, other things being held equal, including a complete set of firm and industry effects.

One way to characterize the issue addressed by the diverse findings cited above regarding the displacement of private spending by public spending is to ask whether there are identifiable circumstances in which joint and/or public R&D is either a substitute for or a complement to independent, private R&D. One answer that is potentially consistent with the empirical literature on public funding of R&D investment is that in general public R&D is a complement to private R&D carried out by small firms — recent work by Acs, Audretsch, and Feldman (1994a; 1994b) points in that direction, as does the work by Lerner (1996). Substitution may be the relationship for larger firms such as those sponsoring the Sematech venture.

However, Mansfield (1984, p. 132) reports results remarkably consistent with Scott's (1984) finding, and both Scott and Mansfield were examining very large corporations in their samples — Scott examined in a cross section of data the private and public R&D performed by large companies reporting to the Federal Trade Commission's Line of Business Program, while Mansfield used survey methodology and focused on a sample of major firms in the chemical, oil, electrical equipment, and primary metals industries, Perhaps Lichtenberg's (1987) concern about the link between public and private R&D and private sales versus sales to the government could explain the complementarities found for the larger firms, leaving intact the interpretation that smaller firms are the ones most likely to benefit from the public funding to support privately performed R&D investments.[45]

Thus public funding of R&D does not appear to displace private spending *in general*, although it may for particular cases.

Kleinknecht and Reijnen (undated) analyze the determinants of R&D joint venture formation using a sample of 1929 firms in the Netherlands that reported R&D activity in 1988.[46] They find that firm size had no significant impact on the probability that a firm would engage in cooperative R&D with other firms. Larger firms were

[45] For additional discussion of Lichtenberg's idea in the context of Scott's estimation, see Scott (1993, p. 234).

[46] The data come from a survey of all Netherlands firms with more than 10 employees. Roughly half the firms in the sample were in the manufacturing sector, half in services.

more likely to cooperate with institutions (for example, universities), all else equal. Another interesting result, particularly given the open nature of the Netherlands' economy, is that the likelihood of joint R&D rises with exporting activity.

Röller, Tombak, and Siebert analyze the determinants of R&D joint venture formation using a sample of firms that registered joint ventures under the National Cooperative Research Act of 1984 in the United States. They examine data on 174 research joint ventures formed by 445 firms over the period January 1985 through July 1994, and find

- there are more research joint ventures formed among small firms than large;
- firms are more likely to form research joint ventures with other firms of roughly the same size;
- product market complementarities make it more likely that firms will form research joint ventures.

This last finding is thoroughly consistent with the findings of Scott (1988; 1993, chapter 12). However, Scott's findings also suggest that the joint ventures may not promote desirable R&D. Examining the early cooperative ventures filed under the National Cooperative Research Act (NCRA), he concludes (1988, p. 183):

> The co-operative R & D protected by the NCRA has occurred in industries that were, during the 1970s, concentrated, with higher productivity growth and having R & D activities purposively combined by diversified firms with R & D in other industries. Also, co-operative R & D has not been more prevalent in those industries for which Levin *et al.* (1984) found appropriability difficulties, and therefore the act does not appear to be fostering R & D where competing firms dared not invest because of appropriability problems. Further, co-operative R & D appears to be more likely in industries where diversified firms were already investing relatively heavily, and to be less likely in those industries where they had low R & D intensity. Finally, broad areas of R & D investment combined by the co-operative R & D projects protected by the NCRA in the mid-1980s parallel closely the areas combined by the diversified firms of the mid-1970s. It is then plausible that the NCRA will stimulate cooperative projects that . . . reduce the net social benefit of R & D investment.

In a more recent study of research joint ventures, however, Scott (1996) interprets new evidence as supporting the hypothesis that research joint ventures improve the efficiency of innovative investments; further, his findings support the hypothesis that government involvement in public-private partnership in the form of providing infrastructure (rather than direct funding) can improve R&D performance.[47]

> . . . the evidence suggests that government has the power to increase desirable and important emissions-reducing research. First, . . . review of the NCRA ventures before and after the CAAA [Clean Air Act Amendments] supports the view that companies will turn their cooperative research toward emissions problems that have become the focus of government concern. Second, . . . results about emissions-reducing R & D support the view that the companies will invest in research in order to reduce the probability of failing to meet the emissions standards imposed by government. My earlier (Scott, 1988) study at the industry level of observation of NCRA cooperative ventures concluded that there was evidence that such ventures might reduce desirable competitive pressures and hence eliminate socially desirable R & D investments. The present study was able to use primary data at a highly disaggregated level of observation—namely, observations for individual companies of research efforts of a particular kind. For that particular type of research, these new "below the company level" data do not suggest that cooperation reduces desirable competitive pressures. Instead, cooperation appears to foster new research that would not have been initiated without cooperation among companies. Although the discussion of the other variables offers additional evidence consistent with that conclusion, the principal supporting evidence is simply that companies that do both cooperative and independent emissions-reducing research invest more, ceteris paribus, than those companies that do just independent research. Further, the companies in concentrated markets invest more than those in less concentrated markets and they are also less likely to join in cooperative emissions-reducing ventures. It does not, therefore, appear that cooperative R & D ventures are a way for companies to avoid Schumpeterian competitive pressures that stimulate R & D investment, although certainly that could be because of effective screening of research joint ventures by the U.S. Department of Justice and the U.S. Federal Trade Commission. These new, primary data at the disaggregated level of a particular type of R & D for particular companies support the belief that cooperative R & D ventures among manufacturing companies may well promote economic efficiency. (Scott, 1996, p. 675)

Overall, empirical evidence on cooperative R&D suggests that research joint ventures, with and without public involvement, have different effects in different circumstances (Scott, 1996, p. 672). Such variation in effects is wholly consistent with

[47] Link and Bauer (1989) provide an important evaluation of and support for the usefulness of infrastructure that takes the form of laws to facilitate cooperative R&D.

economic theory, which clearly suggests that the amount of underinvestment in R&D and the prospects for stimulating desirable R&D differ with the extent of and the source of market failure.

III. Institutional Design

A. General considerations

Public support for private R&D aims to correct equilibrium underinvestment in R&D in a market system by increasing the rate of return on the private firm's R&D investment and thereby giving the private firm a greater incentive to carry out the investment project. Public funding directly addresses the problems of appropriability difficulties and risk by changing the probability distribution over the outcomes for the private firm's investment in the project.

Public funding would typically shift the distribution of rate of return on the private firm's own investment in the project to the right over higher returns, increasing the company's expected return. The increase in expected value directly counteracts the effect of appropriability difficulties, which is to reduce the expected value of the firm's return.

For risk-averse companies, the rightward shift in the distribution can lower the concern about downside potential because of variance in returns given the concavity of the utility function over outcomes. Further, for a firm's decision makers, greater variance triggers concerns about bankruptcy costs and loss of firm-specific human capital. Given the variance of the potential outcome, a higher expected outcome because of the public funding will reduce the probability of the outcome falling below a

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Scott (1998b) provides additional evidence supporting the positive effects of public provision of technology infrastructure in the form of regulations and laws.

minimally acceptable value. Thus, even if variance in return were unchanged, risk is lowered by the public funding.[48]

The contribution of public resources can take many forms, and we will offer below a typology of promotional measures matching public action to sectoral sources of innovation market failure.

We argue that if circumstances rise in which policy makers face a choice between promoting the diffusion of knowledge and promoting the private appropriability of knowledge, the general preference should be for diffusion. Learning curve and scale economy advantages, lead time, and control of complementary assets normally afford incumbent firms sufficient protection for their innovative investments. Excessive appropriability raises entry barriers and impedes both product-market rivalry and cumulative innovation.

Main mode of innovation	**Main Sources of Market Failure**	**Typical sectors**	**Policy instrument**
Development of inputs for using industries	Financial market transactions costs facing SMEs; risk associated with standards for new technology	Software, equipment, instruments	Support for venture capital markets; bridging institutions to facilitate standards adoption
Application of inputs developed in supplying industries	Small firm size, large external benefits; limited appropriability	Agriculture, light industry	Low-tech bridging institutions (extension services)
Development of complex systems	High cost, risk (particularly for infrastructure technology)	Aerospace, electrical technology, semi-conductors	R&D cooperation, subsidies; bridging institutions to facilitate development of infra-structure technology

48 Scott (1980) discusses the coefficient of variation as a natural hybrid measure of both return and risk and provides evidence of the importance of the measure for investors' required rates of return. Tassey (1997) defines risk in terms of the downside potential for project failure; variance in return per se is not the key, but the probability of the downside deviations from expected value placing the return so low that the project is deemed a failure. Hence, he implicitly uses a hybrid measure of risk that combines expected return and the variance in the return. Given the variance, a higher expected return can — using the hybrid view of risk — lower risk, because it lowers the probability of failure.

Applications of high-science-content technology	Public nature of knowledge base	Biotechnology, chemistry, materials science, pharmaceuticals	High-tech bridging institutions

Table 1: Innovation Modes, Sources of Market Failure, and Policy Responses

B. A Typology of Innovation Modes and Innovation Market Failures

Our review of the theoretical and empirical literature on innovations suggests three overall conclusions. First, a market system will underinvest in innovation, from a public point of view. Second, public sector intervention can ameliorate this underinvestment. Third, the forces leading to such underinvestment differ from sector to sector across the economy, and policy design should take these differences into account.

Table 1 outlines a typology of innovation modes and innovation market failures.[49] Any such classification must be both crude and approximate. The categories in the table are not mutually exclusive, and the policy measures cited in the table are indicative rather than exhaustive.

Markets differ in terms of the mixture of basic and applied knowledge that contributes to their knowledge base, in the degree of appropriability of technology, in the extent to which commercially applicable knowledge is tacit, and in the importance of complementary assets to the commercialization of knowledge. Table 1 carves what is really a continuous spectrum of variation across these categories into four broad categories, based on the main mode of innovation. We argue that the nature of the main mode of innovation has implications for the most important sources of market failure in each category, and consequently, for the appropriate form of public-private sector partnership.

1. Innovating input suppliers

In intermediate good industries, the predominant form of innovation is the development of higher quality products that will be used as inputs in vertically related industries. The software industry is one example, as might be equipment-producing industries. In such sectors (Dosi, 1988, p. 1149)

> opportunities for innovation are generally abundant, but are likely to be exploited through "informal" activities of design improvement... Idiosyncratic and cumulative skills make for a relatively high appropriability of innovation.

Relatively high appropriability means there are large private incentives to innovate in such sectors. However, the idiosyncratic and cumulative nature of the skills involved means that financial market transaction costs of the kind emphasized by Oliver Williamson (rooted in imperfect and impacted information combined with moral hazard considerations) will be high and will make the cost of capital facing innovator firms high, if indeed capital can be obtained at all.

In these circumstances, an effective role for public support is to find a mechanism to make capital funding available to small- and medium-size firms, including start-up firms.[50] This will allow innovative new firms to bring their products to market. The lowering of entry barriers implied by such a policy will maintain competitive pressure on larger incumbent firms to maintain their own innovative momentum.

Because governments have a notoriously poor record of identifying ultimately successful lines of technological development in advance, we suggest that public

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[49] This is based on Pavitt (1984) and influenced by Dosi (1988), Nelson and Rosenberg (1993), and Tassey (1997).

[50] Such support is especially warranted early in an industry life cycle (Gemser et al., 1996).

support for innovating SMEs should not take the form of direct grants. Nor should it take the form of direct government debt or equity financing.

Debt financing, which yields pre-specified interest payments in the absence of bankruptcy, is not well suited for the financing of risky investments. When used to finance risky investment, there is a substantial moral hazard problem because the returns to the lender and to the borrower are asymmetric. The borrower will have an incentive to take big risks, since only the borrower participates in any up-side returns, but both the borrower and the creditor share the downside risk, and the possibility of bankruptcy means that the lender will bear even more downside risk than the borrower. Equity financing then, is the suitable means for financing such risky investment; with equity financing, the investor shares in the up-side profits of the risky venture.

However, the equity approach requires a hands-on approach to managing the investment, because if absentee owners place the equity funds in the control of the company investing in R&D, there is an agency problem. Whether those who have operating control are entrepreneurs who have obtained venture capital or simply the company's managers, not gaining all of the investment's upside returns, those with operational control have an incentive to undertake less risk than the equity owners would prefer. Those with operating control will not, in general, have an incentive to work in the best interests of the absentee equity investors without some sort of extra incentive mechanism.

"Venture Capital in OECD Countries," (OECD, 1996), emphasizes the "hands-on" aspect of venture capital for investments in companies in the early stages of development.[51] The survey also emphasizes that venture capital is the key source of

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[51]Harris and Bovaird (1996) also emphasize the need for hands-on management of venture capital investments by studying the successful investments of companies

long-term funds to small and medium size enterprises (SMEs), and it provides a description of the venture capital market and how it works. The extent and success of venture capital markets vary across countries, and there are many government programs to stimulate venture capital provision. The survey observes that there are differences in opinions about benefits of government involvement. Some believe that excessive public intervention will lower returns on the early stage investments to the point where venture capitalists would not be attracted. There are two reasons: (1) in the context of a limited number of such projects, the public-private partnership might take the more attractive projects, crowding out private investors; (2) the bidding for a limited number of projects can increase the price of the initial public offerings by the start-up companies and reduce the expected rate of return on the investment of the venture capital.[52] These critics then argue that government should limit its role to assistance in setting up the market infrastructure and in creating an environment conducive to entrepreneurship. However, new, technologically intensive firms may not receive sufficient capital in such a setup, and such capital constraints limit R&D investment especially for small firms.[53]

Lerner (1996) and Gompers and Lerner (1997) observe that the pool of funds committed to venture capital investments has recently grown rapidly. The relaxation of restrictions on the investment activities of pension funds has fueled this growth (Fenn, Liang, and Prowse, 1995). In addition to a rapid increase in the venture capital funds, there is the pervasive belief that private venture capital firms will do a better job

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offering funds to young businesses. Rather than simply providing capital, investors need to ensure that early-stage companies address other capability gaps — inadequate management skills, inadequate understanding of the market, inadequate relations with suppliers, and inadequate financial control (1996, p. 197).

[52] See Gompers and Lerner (1997).

than the government in monitoring the ventured equity positions in risky companies making R&D investments. But despite a surge in private funds for the venture capital market, and despite the capability of the private market for managing the investment of such funds, it remains the case that because of appropriability problems and risk the private sector on its own will typically underinvest in technology and R&D.

For example, the *Financial Times* (Campbell, 1997, p. I) reports that there is currently great momentum gathering behind private equity across Europe, observing that "Private equity encompasses everything from large leveraged buy-out deals to the more traditional venture capital channeled into start-up or early stage businesses. While there are some signs of a revival of interest in emerging businesses, particularly in the technology sector, today's flood of money is directed primarily toward buy-out opportunities." Detailed evidence on the new interest in venture capital for technology investments emphasizes that the increase in interest in providing venture capital to the high-tech sector is starting from a low base because of the poor performance of venture funds over the last decade and because of the difficulties of successfully managing such funds (Houlder, 1997; Price, 1997).

Lerner (1996, p. 3) observes that if the capital constraints literature is correct, then public funding of early-stage high-technology firms would stimulate significant growth for such firms because they would be able to invest in high-return projects that they could not have accepted without the government funding. The question, then, is how to deliver the necessary public funding to provide sufficient investment funds in such a risky environment without losing the monitoring ability of private venture capital firms and without trying to ensure such monitoring with clumsy and costly

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[53] See Lerner, 1996; Hubbard, 1996; Hall, 1992; Hao and Jaffe, 1993; and Himmelberg and Petersen, 1994.

contracts. He provides an excellent review of the literature suggesting the problems faced by government when it provides venture capital. Most early-stage, high-technology, high-growth firms are financed with venture capital, and Freear and Wetzel (1990) report that venture capital constitutes about two-thirds of private external equity financing for technology-intensive businesses. As Lerner (1996) explains, the venture investors typically spread the provision of funds out over time; thus, the young, early-stage firm's managers must return periodically to the suppliers of their funds in order to get additional financing, and that process can help to ensure that the investors' capital is not wasted. Managers of these venture-backed firms are forced to repeatedly return to their financiers for additional capital, in order to ensure that money is not squandered on unprofitable projects. The venture capitalists intensively monitor managers, Lerner (1996, p. 3) observes, and the investors demand financial instruments giving flexibility to exercise ownership options in the event that the investments pay big returns. Further, they typically have representation on the board of directors. Descriptions of the monitoring of early-stage firms by venture capitalists is given by Gompers (1995), Lerner (1995), and Sahlman (1990, with a review of the theoretical literature provided by Barry (1994).

Lerner (1996, p. 4) summarizes the force of the literature about the difficulties government faces in playing the role of venture capitalist by observing that if the expertise and resources required to monitor the early-stage firms are not available to government, then public funding of public-private partnership will at best just stimulate short-run productivity gains. Support for the view that public provision of venture capital will not work well is provided by the work of Dyck and Wruck (1996), who study German government-owned privatization agencies that own portfolios of eight to ten eastern German firms. Dyck and Wruck hypothesize that private companies are more reliable contracting partners than a government. As a result, governments must use more intricate and hence more costly contracts than private firms would use. To use these contracts most effectively, Dyck and Wruck emphasize the importance of defining objectives, using incentive-based rewards, and accepting restricted intervention rights. The reason that Dyck and Wruck expect governments to be less reliable partners and to require more costly contracts spelling out contingencies and responsibilities is their hypothesis that government organizations as political organizations need to please diverse constituencies and therefore will be reluctant to make economically painful or controversial decisions.

Although Brewer, Genay, Jackson, and Worthington (1997) provide a complementary view consistent with the need for contracts between investors and early-stage companies, they explain the sorts of designs for securities that help resolve the conflicts of interest between investors and the entrepreneurs seeking venture capital funds. Further, their explanations are in the context of the venture capital investments of small business investment companies (SBICs) — financial intermediaries that fund small business activities. These SBIC channel public funds to small businesses, although unlike the Small Business Innovation Research (SBIR) program discussed next, the SBICs do not make outright awards, but instead have debt and equity claims on the small businesses in which they invest. Importantly, these SBICs are chartered and regulated by the U.S. Small Business Administration (SBA) and can receive subsidized government funding in the form of loans from the SBA for up to three times their private capital. Nonetheless, as Brewer et al. (1997) make clear, such organizations can successfully invest public funds; the key is appropriate design of securities that address contracting costs. The mixture of debt and equity claims should be designed to minimize the conflicts of interest that arise between the owners and the managers on the one hand and the owners and the lenders on the other. Brewer, et al. explain that in general investments where tangible assets provide considerable collateral tend to be financed with debt, while the absence of tangible assets requires equity finance. Most private funding for early stage firms therefore will require securities emphasizing equity positions, and certainly Brewer et al. find that SBICs use relatively more equity, and debt with equity features, and less debt in the securities used to provide investment funds for small businesses when intangible assets such as R&D are involved.[54]

In his own original empirical work studying the impact of public provision of venture capital, Lerner (1996) provides evidence in support of a positive view of the prospects for public funding of private investments in innovation. Lerner (1996, p. 1)

> examines the impact of the largest U.S. public venture capital initiative, the Small Business Innovation Research (SBIR) program, which has provided over $6 billion to small high-technology firms between 1983 and 1995. ...SBIR awardees grew significantly faster than a matched set of firms over a ten-year period. The positive effects of SBIR awards were confined to firms based in zip codes with substantial venture capital activity. The findings are consistent with both the corporate finance literature on capital constraints and the growth literature on the importance of localization effects.

Thus, he tests the hypotheses that the private sector provides too little capital to new firms and that the government can identify companies where investments will yield high social and private returns, and his evidence supports the hypotheses. He also observes (Lerner, 1996, p. 2) that among the companies that received public support from the SBIR or its forerunner the Small Business Investment Company (SBIC) program were some of the most dynamic technology companies in the U.S. Receiving support while still private companies were Apple Computer, Chiron, Compaq, Federal Express, and Intel. Further, he observes (1996, p. 2) that public venture capital firms have had a big

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[54]Brewer, et al. (1996) and Brewer and Genay (1994) provide more details about the SBIC program.

impact in other countries, for example accounting for more than half the recent investments in new German technology-intensive firms (Wupperfeld, 1992).

Wallsten (1997) reexamines the SBIR Program and finds that the SBIR grants crowd-out private firm R&D dollar-for-dollar. He hypothesizes that the grants fund research that would have been funded privately because politicians judge the success of technology programs by the commercial success the projects they fund, and then of course the managers of the grant programs choose promising commercially viable projects that would have been funded privately and needed no subsidy. Wallsten observes (1997, p. 10) that although “Lerner included a control group, he did not deal with the issue of ‘picking winners’ — the possibility that agencies fund commercially attractive projects that could have been funded privately.”

The mechanism design for delivering public funding that we propose below actually solves this problem, to the extent that it does exist, because for such projects our design results in the private sector completely reimbursing the government for the cost of the publicly funded project. Some transactions costs would remain unreimbursed, but over time as experience with choosing of projects and use of the new financing principle grew, the mechanism would allow identification and weeding out of such projects that should not have been publicly funded.

Venture capital investments tend to be concentrated in particular regions and sectors — in U.S., for example, venture capital has been concentrated in California and Massachusetts and in the computer hardware and software sectors. On one hand, the concentration could reflect a “herding” of investors that could yield poor performance by too many similar investments (Devenow and Welch, 1996; Sahlman and Stevenson, 1986). In that case, public investments in sectors and regions overlooked by venture capitalists might generate benefits. On the other hand, successful high-tech firms may cluster in particular regions to take advantage of knowledge spillovers, and pools of specialized resources — specialized labor and specialized intermediate goods (Krugman, 1991; Saxenian, 1994). In that case, the public funds would most profitably be invested in the same industries and regions where private venture capital funds are invested. Lerner's important findings are consistent with the hypothesis that the clustering reflects the productive exploitation of complementarities of research assets and intermediate goods and services uses by high-technology firms. The implication for the targeting of public funds to support private innovation is clear, and further it fits with the general thrust of our recommendation to let the private sector direct the delivery of such public funds, insofar as this is possible.

Another observation about the venture capital market is also important for our proposal below for a new mechanism for public support of innovation where the source of market failure is financial market transaction costs. Gompers and Lerner (1997) find a very robust relationship between the valuation of early-stage firms and the volume of venture capital funds that are bidding for the equity of companies seeking venture capital. In particular, a greater volume of commitments to venture capital funds increases the valuation of new investments. Apparently, a larger volume of venture fund commitments translates into more competition for, and hence higher prices for, the type of risky asset provided by entrepreneurs seeking venture funds. There are implications of their finding for the bidding mechanism that we propose below. First, the most propitious time to invite bidding from private venture funds for the right to manage public funds will be when outstanding venture capital commitments are high. Second, the need for public funds may be greatest when such commitments are relatively low.

The venture capital literature also emphasizes the importance of a means of "exit" from the venture capital stage. Although exit can be provided by acquisition or merger, anticipated rewards can be increased by the capability of successfully trading the company on an exchange such as the NASDAQ. Several new stockmarkets for small, fast-growing firms have emerged in Europe recently (*Economist*, 1997). Gilson and Black (1996) and MacIntosh (1996) emphasize the importance of stock markets as a means for venture capitalists to dispose of their investments. One simple recommendation for technology and innovation policy is then for governments to take steps to increase the availability and ease of use of stock markets for small, rapidly growing firms.

A contingent valuation method to bid for the right to be the private partner can establish the desired incentives for the private sector to choose the best private partner, for that private partner to carry out the desired amount of investment at the least cost to the public, and for avoiding opportunistic behavior by either the public or the private partner.[55]

Such a scheme would involve a hybrid bidding mechanism that combines an up-front bid, a periodic payment bid, and finally a royalty bid. Private firms would bid for the right to be the private partner in a project that the government would fund. Alternatively, private venture capital companies that would manage projects receiving public support would bid for the rights to manage the projects, as opposed to having bids be accepted directly from companies that would carry out the R&D.

Broadly, suppose that the government wants to provide support for an R&D project.[56] The government would announce that it would provide an up-front payment F to support the R&D investment project to be conducted by the winning bidder in an auction to determine the private partner in the project. Further, the government would pledge to provide a periodic flow of funds c throughout the project's life to support the flow costs of the R&D project.[57]

Bidders then bid for the right to be the private partner in the project by submitting a three-part bid:

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[55] For a detailed discussion of the proposed mechanism, see Scott (1998c), and for the formal development of the proposed mechanism see Martin and Scott (1998b), where the mechanism is placed in the context of a taxonomy of innovation modes, sources of market failure, and appropriate policy responses to explain where it is likely to be a useful policy, is further illustrated by juxtaposing the proposed mechanism with primary data about the barriers to developing information technology in the health care sector, and is formalized by addressing the issues of mechanism design in a formal economic model.

[56] See McAfee and McMillan (1987) for a review of bidding mechanisms, as well as Hansen (1985) and Samuelson (1983, 1986).

[57] Note that the fixed cost F and the flow cost c correspond to the typical abstraction of the structure of costs for R&D investment projects (Lee and Wilde, 1980).

- first a bid for how much the private firm will pay the government up-front;
- second a bid on the periodic flow payment during the life of the R&D project;
- finally a bid on the royalty rate that it would pay the government on the innovation produced by the public-private partnership and licensed (perhaps exclusively) to the private partner.

There are nontrivial choices to be made about the exact nature of the auction. Apart from the usual choices for auctions in general, there would be choices specific to the new institutional use of auctions to determine the private partner for the publicly supported project. For example, institutional arrangements must be designed to insure that the governments payments of F and c go solely for the purchase of R&D investments; the private partner's profits from the R&D investment project must come after the innovation is introduced. However, for this paper, full details of the ideal auction in different circumstances will not be developed. Instead, we shall present the basic idea and observe that the three-part bidding mechanism we propose has the potential for effectively addressing the innovation market failure arising from transaction costs in financial markets.

- First, with a well designed auction, a partner that is likely to be viable will be chosen. Intuitively, the company that can (or at least *thinks* it can) produce the best results at the least cost will gain more value from winning the bid to be the private partner in the public-private partnership; therefore, it will bid higher and win.

- Second, the government's investment cost will be minimized. Intuitively, since that cost is the present value of (1) the up-front investment F minus the up-front bid and (2) the flow cost c minus the periodic flow payment, the firm with the best capabilities for producing the research at lowest costs will submit the highest bid for the up-front payment and the periodic flow payment. The government's net costs are reduced further by the royalty payments it will receive. Those royalty payments, however, serve other specific roles in the mechanism design.

- Third, the royalty payments are the contingent payment option that mitigate the effects of uncertainty by tying the private firm's actual payment to the government to the actual performance of the R&D investment and the innovation it produces. The contingent payment mechanism then increases the willingness for private firms to bid and increases the winning bid and reduces the expected cost to the government. Greater uncertainty about value implies a lower expected price at the auction, and using royalty bidding as a type of contingent pricing mechanism gets around that problem, giving in effect *ex post* pricing, whereas without contingency pricing less is bid because no one knows what to pay for the right to be the private partner in the public-private partnership. However, as we note below, with royalties there is an agency problem that changes the way the winning bidder will exploit the innovation resulting from the public-private partnership, and we address this issue below.

- Fourth, the royalty payments give the government an equity stake in the project and reduce the likelihood of opportunistic behavior on the part of the government.[58] Suppose that the project is one for which public support — not only funds but also the energy and talents of the government's employees such as those in public laboratories and technology policy departments — will be needed for many fiscal years. The government's equity position in the project is a way to ensure the credibility of the public support throughout those early investment years despite changes in administration or changes in public sentiment otherwise. The equity position could help to ensure that the government did not abandon a project midstream, and thus make private participation and investment more attractive.

- Fifth, the likelihood of opportunistic behavior by the private investors is reduced because the private firm or firms will have invested with up front and periodic payments, and good faith behavior would be required to keep the public funds c for the flow costs coming to protect that investment and to keep the prospect of the private share of the project's earnings.

- Clearly, though, the royalties to the government in return for use of the technology must be low enough so that the problem of reduced incentives for the private firm to promote the innovation does not outweigh the gains because the royalty mechanism mitigates risks and ensures continued public support. With diminishing returns and hence rising marginal costs of exploiting the innovation, the royalty payments to the government will reduce the private company's use of the innovation below the optimal amount.

Our proposed mechanism, broadly, is that private firms bid for such partnerships using a three part bid reflecting the up-front, fixed costs of the R&D project, its flow costs, and the stream of profits from the resulting innovation. Government wants the right firms to win the bid, and it wants to pay the optimal amount but not too much to get the innovations. The three-part bidding mechanism that we propose would provide the desired properties. By having private venture-capital companies, as contrasted with the early-stage companies performing the

[58]Of course, the government is not a profit-maximizing firm, and one must be concerned then, that incentive problems will occur because a bureaucrat will be deciding what to do based on his or her own preferences. However, governments do have constituencies to be satisfied who potentially can play a role analogous to that of stockholders in a for-profit firm if a good mechanism for delivering the public funding to the public-private partnership is in place.

government-supported research and technology investment, bid for the contract, the bidding mechanism could even incorporate private venture-capital-market supervision of the public investments in early stage firms or joint ventures.

2. Innovative Input Users

Dual to the category of sectors that innovate by developing higher-quality inputs that are used in vertically related industries is the category of firms that innovate by adapting products and processes developed in vertically related industries to their own commercial needs.

One example comes from north-central Italy (Best, 1990, p. 218):

> The strength of the Third Italy is in the flexibility and innovation that come from decentralized and autonomous design capabilities. But competing on the basis of product design, quality, or customization depends upon integrating marketing capabilities and competitors analysis with production flexibility which, in turn, depends upon staying abreast of technological developments. Here again small firms are faced with the need to undertake activities characterized by substantial economies of scale.

Agricultural sectors share many of these characteristics: small operating units, able to benefit from adopting state-of-the-art techniques, but ill able to afford the expense of keeping abreast of such techniques, and able to internalize only a fraction of the overall benefits that flow from keeping the sector as a whole on the technological frontier.

Public support for innovation in such sectors can take the form of extension services that service as an open technical repository to which private firms can turn for the solution of specific problems. Such a system has been used in U.S. agriculture since 1862 (Adams and Martin, 1986; Nelson and Rosenberg, 1993, p. 12; Mowery and Rosenberg, 1993, p. 37).

Burton and Hansen (1993) discuss a functionally equivalent German mechanism to support industrial innovation: the Fraunhofer Gesellschaften, which (1993, p. 39)

> conduct applied research for industry on a contract basis, using the facilities and personnel of regional polytechnics or technical universities.

The cooperative industrial research associations are organized by industry and identify the research needs of small and medium sized enterprises (SMEs) and actually carry out the research themselves or hire others to perform contract research. They identify five specific advantages of such cooperative research associations, which (p. 39)

- encourage industrially relevant research;
- promote the exchange of information between industrial and academic communities;
- assist commercialization and marketing;
- socialize university students with respect to commercial application of technology;
- promote the diffusion of research.

Such associations will be of greatest assistance to SMEs, and the benefits seem mostly to be related to knowledge dissemination rather than increasing the private appropriability of knowledge.

3. Complex Systems Innovation

Only a few sectors, although it is possible to argue that they are vital ones, fall in this category. Firms in these sectors are typically large in an absolute sense, and well able to maintain their own firm-specific pools of technical competence. Innovation market failures arise because the R&D projects carry a cost proportionally as large or larger than the absolute size of innovating firms, and because of the risk associated with failure to stay on the technological frontier. The risk that is in question is the risk of extinction if a firm is not in the first round of innovators — drastic innovation, in the vocabulary of the theoretical economics literature — because a steep learning curve implies that second-movers fall rapidly behind.

One part of policy in this area should be adoption of a competition policy that permits R&D cooperation. It should not be anticipated that the incidence of operating entity joint ventures will increase very much in response to such a policy, because firms will typically be risk-averse about divulging proprietary information.

Policy should also be open to the possibility of direct subsidies, at least early in the life of cooperative activity.[59] A condition of such subsidies should be acceptance of arrangements to diffuse knowledge generated by the joint venture to all comers on reasonable terms (perhaps after a certain delay). Learning-by-doing advantages will normally allow incumbents to profit from exploiting an innovation; the availability of the innovation to outsiders at reasonable cost will prevent first-innovators from extracting excessive economic profits.

Innovative market failure may also arise in these sectors when innovation involves the development of common standards for infrastructure technology. Such innovations involve network externalities and carry a substantial risk if a firm enters into a technological trajectory (Dosi, 1988) that ultimately fails to be selected as the market standard. Public bridging institutions would fill an essential gap in these cases. In the United States, Federal Laboratories at the National Institute of Standards and Technology are examples.

4. High Science-content Technology

[59] What Dosi (1988) calls technological trajectories are likely to be fairly well defined in these sectors, and the problems associated with government selection of projects to back are less likely to arise than for sectors populated by innovating input suppliers.

Where innovation relies on a technology base with a high science content (biotechnology, pharmaceuticals), there is also a need for bridging institutions. Firms in such sectors will often be large in an absolute sense, and will typically maintain their own formal R&D laboratories. The role of bridging institutions in this case is to facilitate diffusion of advances in basic research from academic research operations to the private sector. Commercial application of such advances will typically best be carried out at private laboratories, which will be able to use information from marketing and distribution channels to direct development in the most effective direction. The bridging institutions here could be university-industry research parks or government laboratories such as those operated in the U.S. by the National Institute of Standards and Technology (Tassey, 1997; Scott, 1998a).

IV. Conclusions

We have sought to distill the specific knowledge that economists have developed about the sources of innovation market failure use it to inform policy makers about the design of mechanisms for public support of private investment in technology and innovation. To that end we have examined a large body of literature ranging over the theoretical and empirical work of industrial organization economists studying equilibria in game theoretic models of R&D and production, the work of microeconomic theorists studying auctions markets, and the work of financial economists studying venture capital markets. We conclude our study with a list of recommendations for the public financing of private R&D.

One of the propositions that industrial economics has made its own in the last 20 years is that general analytical frameworks are generally inappropriate. Industries differ enough and in important aspects that these differences must be taken into account in explaining market performance. This is true for technological performance as well as product market performance. With respect to the appropriate institutional framework for public support to investment in innovation, it is important to distinguish

- incremental innovations and fundamental technological breakthroughs;
- markets where information flows easily on the supply side, so that appropriability of the profits that result from successful innovation is low, and markets where information does not flow easily — for example, extent of public funding needed will vary with the effectiveness of patents;
- markets where the extent of noncooperative rivalry or cooperation implies underinvestment from markets where the state of competition results in satisfactory investments in technology and innovation;
- markets where learning-by-doing is important, so that carrying out R&D is a necessary ticket to enter the product market.

The prevalence of market failure and underinvestment in technology and innovation implies the importance of establishing a long-term institutional framework for the support of commercialization as well as basic research and generic-enabling research. Further, the institutional structure to support applied and developmental work should aim to mitigate market failures wherever they may occur.

The distinction between "high tech" and "low tech" sectors may not be useful: some aspects of agriculture would often be thought of as "low tech,"[60] yet cumulative technological advance in US agriculture has been great, and the potential payoff to such advance in LDCs may well be enormous.

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[60] Of course, with universities and publicly funded research stations focused on agricultural R&D, and with the large equipment and materials agricultural businesses as well as the farms themselves, the agricultural sector is well-endowed with important and evolving technology — even exotic high-technology such as genetic manipulation of plant and animal materials.

A considerable amount of theory and evidence supports the view that public support for R&D should be directed toward sectors where small firms would not otherwise be able to compete, and to "infrastructure" sectors, from which technological advance will spill over to benefit the whole economy.

The evidence suggests that a general relaxation of competition policy vis-à-vis R&D cooperation will not have much effect on the level of private investment in innovation, since the fear of competition policy prosecution does not appear to be a factor that discourages individual or joint R&D. In a similar vein, a requirement to license research output, thereby increasing competition, is a reasonable quid pro quo for public support; this would improve post-innovation product market performance without significantly affecting incentives to innovate.

Serious consideration should be given to developing appropriate bidding mechanisms to allow private-market decisions to flexibly tailor the amount and timing and delivery of public funding to private innovation projects involving SMEs and start-up firms. We have sketched a prototype three-part bidding mechanism and explained why it can potentially provide the desired traits for delivering the public funds to public-private partnership. Such a mechanism would address sources of innovation market failure that arise in financial markets. By having private venture-capital companies bid for the contract, the bidding mechanism could even incorporate private venture-capital-market supervision of the public investments in early-stage firms or joint ventures.

Such a bidding mechanism should be evaluated and compared with other mechanisms to ensure that it performs well. A good mechanism should not only have the desirable traits — choosing a good private partner, achieving desired investment while minimizing the expenditure of public funds, and so forth — that we have associated with the bidding mechanism, but should also have relatively low administrative costs.

In the context of their evaluation of alternative tax incentives for R&D, Bozeman and Link (1983) list and critically discuss several criteria by which alternative mechanisms should be evaluated. We expect that bidding mechanisms have the potential to return far more than they cost administratively because they will minimize the public funds needed to support the projects of public-private partnerships. But that expectation must be tested. To our list of recommendations, then, we add that government should engage in ongoing evaluation and development of the mechanisms for identifying projects for public funding and for delivering the public funds to such projects.

Finally, problems with incentives, unintended consequences, interest groups lobbying for concentrated benefits that have diffuse costs, and inconsistencies of group decision-making suggest that the makers of technology policy should continually look for ways to remove government-induced obstacles to R&D investment and ways to make private investment more effective even while implementing new mechanisms to make the government's actions more effective. The survival of capitalism and democracy in the 21st century will require governments to implement programs to promote innovation that address specific sources of market failure while avoiding government failure.

V. References

Acs, Zoltan J., Audretsch B., and Feldman, Maryann P., "R&D Spillovers and Innovative Activity," *Managerial and Decision Economics*, Volume 15, Number 2, March-April 1994a, pp. 131-8.

Acs, Zoltan J., Audretsch B., and Feldman, Maryann P., "R&D Spillovers and Recipient Firm Size," *Review of Economics and Statistics,* Volume 126, Number 2, May 1994b, pp. 336-40.

Adams, Walter and Martin, Stephen "Public Support of Innovative Activity: Lessons From U. S. Industrial Policy," in H. W. de Jong and W. G. Shepherd, editors, *Mainstreams in Industrial Organization* Dordrecht: Martinus Nijhoff, Publishers, 1986, pp. 413-39.

Anderson, Simon P., Goeree, Jacob K., and Holt, Charles A. "Rent Seeking with Bounded Rationality: An Analysis of the All-Pay Auction," Thomas Jefferson Center Discussion Paper 283, University of Virginia, February 1997.

Antonelli, Cristiano, Guest Editor. Special Issue on "The Economics of Standards." *Information Economics and Policy*, 6 (3,4), December 1994.

Arrow, Kenneth J. "Economic Welfare and the Allocation of Resources for Invention," in *The Rate and Direction of Inventive Activity: Economic and Social Factors*, NBER, Princeton: Princeton University Press, 1962, pp. 609-625.

Audretsch, David B. and Vivarelli, Marco, "Small Firms and R&D Spillovers: Evidence from Italy," Discussion Paper FS IV 93-21, September 1993, Wissenschaftszentrum Berlin.

Baldwin, William L., *The Impact of Department of Defense Procurement on Competition in Commercial Markets: Case Studies of the Electronics and Helicopter Industries*, Monograph prepared for Office of Policy Planning, Federal Trade Commission, December 1980. Washington, D.C.: U. S. Government Printing Office, 1981.

Baldwin, William L. and Childs, Gerald L. "The Fast Second and Rivalry in Research and Development," *Southern Economic Journal,* Volume 36, Number 1, July 1969, pp. 18-24.

Baldwin, William L., and Scott, John T., *Market Structure and Technological Change*, in the series *Fundamentals of Pure and Applied Economics*, vol. 17. Chur; London; Paris; New York: Harwood Academic Publishers, 1987.

Barry, Christopher B., "New Directions in Research on Venture Capital Finance," *Financial Management*, vol. 23, no. 3 Autumn 1994, pp. 3-15.

Barzel, Y., “Optimal Timing of Innovations,” *Review of Economics and Statistics*, vol. 50, 1968, pp. 348-355.

Bernstein, Jeffrey I. “The Structure of Canadian Interindustry R&D Spillovers and the Rates of Return to R&D,” *Journal of Industrial Economics*, Volume 21, 1989, pp. 324-47.

Bernstein, Jeffrey I. and Nadiri, M. Ishaq “Interindustry R&D Spillovers, Rates of Return, and Production in High-Tech Industries,” *American Economic Review*, Volume 78, Number 2, May 1988, pp. 429-34.

Best, Michael H. *The New Competition*. Cambridge, Massachusetts: Harvard University Press, 1990.

Bozeman, Barry, and Link, Albert N., “Tax Incentives for R &D: A Critical Evaluation,” *Research Policy*, vol. 13 (1984), pp. 21-31.

Brewer, Elijah, III, and Hesna Genay, “Funding Small Businesses through the SBIC Program,” *Economic Perspectives*, Federal Reserve Bank of Chicago, May/June 1994, pp. 22-34.

Brewer, Elijah, III, Hesna Genay, William E. Jackson III, and Paula R. Worthington, “How Are Small Firms Financed? Evidence from Small Business Investment Companies,” *Economic Perspectives*, Federal Reserve Bank of Chicago, Volume 20, No. 6, November/December 1996, pp. 2-17.

Brewer, Elijah, III, Hesna Genay, William E. Jackson III, and Paula R. Worthington, “Issues in Funding the Activities of Small Firms through SBICs,” *Chicago Fed Letter*, Federal Reserve Bank of Chicago, Number 113, January 1997, pp. 1-3.

Burton, Daniel F. and Hansen, Kathleen “German Technological Policy: Incentive for Industrial Innovation,” *Challenge*, Volume 36, Number 1, January-February 1993, pp. 37-47.

Caballero, Ricardo J. and Jaffe, Adam B, “How High Are the Giants’ Shoulders: An Empirical Assessment of Knowledge Spillovers and Creative Destruction in a Model of Economic Growth,” *NBER Macroeconomics Annual*, 1993, pp. 15-74.

Callon, Scott, *Divided Sun: MITI and the Breakdown of Japanese High-Tech Industrial Policy, 1975-1993* Stanford, California: Stanford University Press, 1995.

Campbell, Katharine, “Funds Flood Across the Channel,” *Financial Times Survey*, October 10, 1997, p. I.

Chesnais, François “The French national system of innovation,” in Nelson, Richard R., editor. *National Innovation Systems*. Oxford: Oxford University Press, 1993.

Cockburn, Iain and Griliches, Zvi "Industry effects and appropriability measures in the stock market's evaluation of R&D and patents," *American Economic Review* Volume 78, Number 2, May 1988, pp. 419-423.

Cohen, W. M. and Levinthal, D. A. "Innovation and Learning: The Two Faces of R&D," *Economic Journal* Volume 99, no. 397, September 1989, pp. 569-596.

Cremer, Jacques and Scotchmer, Suzanne "Optimal R&D procurement: why patents?," mimeo, revised October 1997.

Cusumano, Michael A., Mylonadis, Yiorgos, and Rosenbloom, Richard S. "Strategic maneuvering and mass-market dynamics: the triumph of VHS over Beta," *Business History Review* Volume 66, Number 1, Spring 1992, pp. 51-94.

Dasgupta, Partha, and Stiglitz, Joseph, "Industrial Structure and the Nature of Innovative Activity," *European Economic Review* Volume 15, 1981, pp. 137-158.

d'Aspremont, Claude and Jacquemin, Alexis, "Cooperative and noncooperative R&D in duopoly with spillovers," *American Economic Review* Volume 78, Number 5, December 1988, pp. 1133-7.

d'Aspremont, Claude and Jacquemin, Alexis, "Cooperative and noncooperative R&D in duopoly with spillovers: erratum," *American Economic Review* Volume 80, Number 3, June 1990, pp. 641-2.

Demsetz, Harold "Information and Efficiency: Another Viewpoint," *Journal of Law and Economics* Volume 12, Number 1, April 1969, pp. 1-22.

Devenow, Andrea, and Ivo Welch, "Rational Herding in Financial Economics," *European Economic Review*, 40 1996, forthcoming.

Dixit, Avinash K. "Optimal trade and industrial policies for the U.S. automobile industry," in Robert Feenstra, editor, *Empirical Methods for International Trade*. Cambridge, Massachusetts: MIT Press, 1988.

Dosi, Giovanni "Sources, procedures, and microeconomic effects of innovation," *Journal of Economic Literature* Volume 26, September 1988, pp. 1120-71.

Duysters, Geert and Hagedoorn, John "Convergence and divergence in the international information technology industry," in Hagedoorn, John, editor *Technical change and the world economy*. Aldershot: Edward Elgar, 1995, pp. 205-234.

Dyck, I. J. Alexander, and Karen H. Wruck, "The Government as Venture Capitalist? Organizational Solutions to Contracting Problems in German Privatization," Harvard Business School, Working Paper 97-007, July 22, 1996.

EC Commission, *Panorama of EU Industry 94*. Luxembourg: Office for Official Publications of the European Communities, 1994.

The Economist, "Small-Company Stockmarkets: Europe's Growth Industry," (March 15, 1997), p. 78.

Fenn, George W., Nellie Liang, and Stephen Prowse, 1995. *The Economics of the Private Equity Market*, Washington, Board of Governors of the Federal Reserve System.

Fisher, F. M. and Temin, Peter, "Returns to Scale in Research and Development," *Journal of Political Economy* Volume 81, 1973, pp. 56-70.

Fölster, Stefan *The Art of Encouraging Innovation*. Stockholm: Almqvist & Wiksell International, 1991.

— "Should cooperative R&D be subsidized? An empirical analysis," in Witteloostuijn, Arjen van, editor, *Market Evolution: Competition and Cooperation*. Dordrecht: Kluwer Academic Publishers, 1995, pp. 53-68.

Freear, John, and William E. Wetzel, Jr., 1990, "Who Bankrolls High-Tech Entrepreneurs?" *Journal of Business Venturing,* 5, 77-89.

Freeman, Christopher *The economics of industrial innovation*. Second edition. London: Francis Pinter, 1982.

Fudenberg, Drew, Gilbert, Richard, Stiglitz, Joseph, and Tirole, Jean "Preemption, leapfrogging and competition in patent races," *European Economic Review* Volume 22, 1983, pp. 3-31.

Fudenberg, Drew and Tirole, Jean "Understanding rent dissipation: on the use of game theory in industrial organization," *American Economic Review* Volume 77, Number 2, May 1987, pp. 176-83.

Futia, C. A., "Schumpeterian Competition," *Quarterly Journal of Economics,* 94 1980, pp. 675-695.

Gemser, Gerda, Leenders, Mark A. A. M. and Wijnberg, Nachoem M. "The dynamics of inter-firm networks in the course of the industry life cycle: the role of appropriability," *Technology Analysis & Strategic Management* Volume 8, Number 4, December 1996, pp. 439-53.

Geroski, Paul A., "Innovation and the Sectoral Sources of UK Productivity Growth," *Economic Journal*, 101 November 1991, pp. 1438-1451.

Gilbert, Richard J. and Newbery, David M. G., "Preemptive patenting and the persistence of monopoly," *American Economic Review* Volume 72, Number 3, June 1982, pp. 514-26.

— "Uncertain innovation and the persistence of monopoly: comment," *American Economic Review* Volume 74, Number 1, March 1984, pp. 238-242.

Gilson, Ronald J., and Black, Bernard S., "Venture Capital and the Structure of Capital Markets: Banks versus Stock Markets," Working Paper No. 135, John M. Olin Program in Law and Economics, Stanford Law School, July 1996.

Gompers, Paul A., "Optimal Investment, Monitoring, and the Staging of Venture Capital," *Journal of Finance*, 50 1995, pp. 1461-1489.

Gompers, Paul, and Josh Lerner, "Money Chasing Deals?: The Impact of Fund Inflows on Private Equity Valuations," Harvard University and National Bureau of Economics Research, manuscript, August 1997.

Griliches, Zvi, "Productivity, R&D, and Basic Research at the Firm Level in the 1970s," *American Economic Review*, 76 1986, pp. 141-154.

Griliches, Zvi "The Search for R&D Spillovers," *Scandinavian Journal of Economics* Volume 94, 1992, pp. 29-47.

Griliches, Zvi, and Lichtenberg, Frank, "Interindustry Technology Flows and Productivity Growth: A Reexamination," *Review of Economics and Statistics*, 66 May 1984, pp. 324-329.

Hagedoorn, John "Organizational modes of inter-firm co-operation and technology transfer," *Innovation* Volume 10, Number 1, 1990, pp. 17-30.

Hall, Bronwyn H., 1992, "Investment and Research and Development: Does the Source of Financing Matter?," Working Paper No. 92-194, Department of Economics, University of California at Berkeley.

Hansen, Robert G., "Auctions with Contingent Payments," *The American Economic Review*, volume 74, no. 4 September 1985, pp. 862-865.

Hao, Kenneth Y., and Adam B. Jaffe, 1993, "Effect of Liquidity on Firms' R&D Spending," *Economics of Innovation and New Technology*, 2, 275-282.

Harhoff, Dietmar, F. M. Scherer, and Katrin Vopel, "Exploring the Tail of Patent Value Distributions," Center for European Economic Research, Mannheim, and Harvard University. Manuscript, July 1997 Revision.

Harris, Simon, and Bovaird, Chris, *Enterprising Capital: A Study of Enterprise Development and the Institutions which Finance It* Aldershot, England; Brookfield, Vermont, U.S.A.: Avebury, 1996.

Henderson, Rebecca and Cockburn, Iain "Scale, scope and spillovers: the determinants of research productivity in drug discovery," *Rand Journal of Economics* Volume 27, Number 1, Spring 1996, pp. 32-59.

Henriques, Irene "Cooperative and noncooperative R&D in duopoly with spillovers: comment," *American Economic Review* Volume 80, Number 3, June 1990, pp. 638-640.

Himmelberg, Charles P., and Bruce C. Petersen, 1994, "R&D and Internal Finance: A Panel Study of Small Firms in High-Tech Industries," *Review of Economics and Statistics*, 76, 38-51.

Hinloopen, Jeroen "Subsidizing cooperative and noncooperative R&D in duopoly with spillovers," *Journal of Economics*, forthcoming, 1998.

Houlder, Vanessa, "The High-Technology Sector: New Funds Focus on IT Companies," *Financial Times Survey*, October 10, 1997 p. V.

Hubbard, R. Glen, "Capital-Market Imperfections and Investment," *Journal of Economic Literature*, 1996, forthcoming.

Irwin, Douglas A., and Peter J. Klenow, "High-tech R&D Subsidies Estimating the Effects of Sematech," *Journal of International Economics*, vol. 40 1996, pp. 323-344.

Jaffe, Adam B., "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value," *American Economic Review*, Volume 76, Number 5 December 1986, pp. 984-1001.

Jones, Charles I. and Williams, John C. "Measuring the social return to R&D," Finance and Economics Discussion Series Staff Working Paper 1997-12, Federal Reserve Board, Washington, D.C., February 1997.

Kamien, Morton I., Muller, Eitan, and Zang, Israel "Research joint ventures and R&D cartels," *American Economic Review* Volume 82, Number 5, December 1992, pp. 1293-1306.

Kamien, Morton I. and Schwartz, Nancy L. "Timing of innovations under rivalry," *Econometrica* Volume 40, Number 1, January 1972, pp. 43-60.

Kamien, Morton I. and Zang, Israel "Competing research joint ventures," *Journal of Economics & Management Strategy* Volume 2, Number 1, Spring 1993, pp. 23-40.

Kash, Don E. and Rycroft, Robert W. "Nurturing winners with Federal R & D," *Technology Review* Volume 96, Number 8, November/December 1993, pp. 58-64.

Katz, Michael L. "An analysis of cooperative research and development," *Rand Journal of Economics* Volume 17, Number 4, Winter 1986, pp. 527-43.

Katz, Michael L. and Ordover, Janusz A. “R&D cooperation and competition,” *Brookings Papers on Economic Activity* Microeconomics 1990 pp. 139-203.

Khanna, Jyoti “Cooperative versus noncooperative behavior: the case of agricultural research,” *Review of Economics and Statistics* Volume 75, Number 2, May 1993, pp. 346-352.

Kleinknecht, Alfred and Reijnen, Jeroen O. N. “Why do firms cooperate on R&D? An empirical study,” undated.

Kocka, Jurgen “Germany: cooperation and competition,” *Business History Review* Volume 64, Number 4, Winter 1990, pp. 711-16.

Kohn, Meir and Scott, John T. “Scale economies in research and development,” *Journal of Industrial Economics* Volume 30, Number 3, March 1982, pp. 239-249.

Krugman, Paul R., *Geography and Trade.* Cambridge, Mass.: MIT Press, 1991.

La Manna, Manfredi, Macleod, Ross, and de Meza, David “The case for permissive patents,” *European Economic Review* Volume 33, Number 7, September 1989, pp. 1427-33.

Lee, Tom and Wilde, Louis L. “Market Structure and Innovation: A Reformulation,” *Quarterly Journal of Economics* Volume 94, Number 2, March 1980, pp. 429-436.

Lerner, Josh, “Venture Capitalists and the Oversight of Private Firms,” *Journal of Finance*, 50 1995, pp. 301-318.

Lerner, Josh, “The Government as Venture Capitalist: The Long-Run Impact of the SBIR Program,” NBER Working Paper 5753, September 1996.

Levin, R. C., A. K. Klevorick, R. R. Nelson, and S. G. Winter “Survey Research on R & D Appropriability and Technological Opportunity: Part 1, “ Working Paper, Yale University, 1984.

Levin, Richard C., Klevorick, A. K., Nelson, R. R. and Winter, S. G. “Appropriating the returns from industrial research and development,” *Brookings Papers on Economic Activity* Microeconomics 1987, pp. 783-820.

Leyden, Dennis Patrick, and Link, Albert N., *Government’s Role in Innovation* Boston; London: Kluwer Academic Publishers, 1992.

Leyden, Dennis Patrick, and Link, Albert N., “Federal Laboratories as research partners,” *International Journal of Industrial Organization,* forthcoming, 1998.

Lichtenberg, F. R., "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment," *Journal of Industrial Economics*, 36 September 1987, pp. 97-104.

Link, Albert N., Technological Change and Productivity Growth, in the Series *Fundamentals of Pure and Applied Economics*, vol. 13 Chur; London; Paris; New York: Harwood Academic Publishers, 1987.

Link, Albert N., "Public/Private Partnerships as a Tool to Support Industrial R&D: Experiences in the United States," Report prepared for the Working Group on Innovation and Technology Policy, OECD. Draft, October 1997.

Link, Albert N., and Bauer, Laura L., *Cooperative Research in U.S. Manufacturing* Lexington, Mass.: Lexington Books, D. C. Heath and Company, 1989.

Link, Albert N., and Scott, John T. "Evaluating Technology-Based Public Institutions: Lessons from the National Institute of Standards and Technology," in *Policy Evaluation in Innovation and Technology: Towards Best Practices*, OECD Proceedings from a conference on 26-27 June 1997, edited by George Papaconstantinou and Wolfgang Polt. Paris: OECD, 1997, pp. 255-277.

Link, Albert N., David J. Teece, and William F. Finan, "Estimating the Benefits from Collaboration: The Case of SEMATECH," *Review of Industrial Organization*, Vol. 11, No. 5 October 1996, pp. 737-751.

Loury, Glenn C. "Market Structure and Innovation," *Quarterly Journal of Economics* Volume 93, Number 3, No. 372, August 1979, pp. 395-410.

MacIntosh, Jeffrey G., "Venture Capital Exits in Canada and the U.S.," manuscript, Faculty of Law, University of Toronto, June 27, 1996.

Malerba, Franco and Orsenigo, Luigi "Schumpeterian patterns of innovation," *Cambridge Journal of Economics* Volume 19, Number 1, February 1995, pp. 47-65.

Mansfield, Edwin, John Rapoport, Anthony Romeo, Samuel Wagner, and George Beardsley, "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics* Volume 91, No. 2, May 1977, pp. 221-240.

Mansfield, Edwin "How rapidly does new industrial technology leak out?" *Journal of Industrial Economics* Volume 34, Number 2, December 1985, pp. 217-23.

— "R&D and Innovation: Some Empirical Findings," in *R&D, Patents, and Productivity*, ed. Zvi Griliches, chapter 6, pp. 127-48 Chicago: University of Chicago Press for the National Bureau of Economic Research, 1984.

Mansfield, Edwin, Schwartz, Mark and Wagner, Samuel "Imitation costs and patents: an empirical study," *Economic Journal* Volume 91, No. 364, December 1981, pp. 907-18.

Martin, Stephen, “Private and Social Incentives to Form R&D Joint Ventures,” *Review of Industrial Organization* Volume 9, 1994, pp. 157-171.

— “R&D Joint Ventures and Tacit Product Market Collusion,” *European Journal of Political Economy* Volume 11, Number 4, April 1996a, pp. 733-741.

— “Protection, promotion and cooperation in the European semiconductor industry,” *Review of Industrial Organization* Volume 11, Number 5, October 1996b, pp. 721-735.

— “Public Policies Toward Cooperation in Research and Development: the European Union, Japan, the United States,” in Leonard Waverman, William Comanor, and Akira Goto, editors, *Competition Policy in the Global Economy*. London: Routledge, 1997a, pp. 245-288.

— “Product market competition policy and technological performance,” paper presented at the meetings of the Industrial Organization Society, Chicago, 3 January 1998 (http://www.econ.ku.dk/CIE/lpchap2.pdf).

Martin, Stephen and Scott, John T. “Financing and Leveraging Public/Private Partnerships,” report prepared for the Working Group on Technology and Innovation Policy, Division of Science and Technology, OECD, mimeo, January 1998a (http://www.econ.ku.dk/CIE/flppp.pdf).

— “Financial Market Transaction Costs and R&D Policy,” mimeo, in process, 1998b.

Matutes, Carmen, Regibeau, Pierre, and Rockett, Katherine “Optimal Patent Design and the Diffusion of Innovations,” *Rand Journal of Economics* Volume 27, Number 1, Spring 1996, pp. 60-83.

McAfee, R. Preston, and McMillan, John, “Auctions and Bidding,” *The Journal of Economic Literature*, volume 25, no. 2 June 1987, pp. 699-738.

Mowery, David “The practice of technology policy,” in Stoneman, Paul, editor *Handbook of the Economics of Innovation and Technological Change*. Oxford: Blackwell Publishers Ltd., 1995.

Mowery, David C. and Rosenberg, Nathan “The U.S. national innovation system,” in Nelson, Richard R., editor. *National Innovation Systems*. Oxford: Oxford University Press, 1993.

Nelson, Richard R. “Uncertainty, learning, and the economics of parallel research and development efforts,” *Review of Economics and Statistics* Volume 43, Number 4, November 1961, pp. 351-64.

— “Government Stimulus of Technological Progress: Lessons from American History,” edited by R. R. Nelson, *Government and Technical Progress* New York: Pergamon, 1982, pp. 451-482.

Nelson, Richard R. and Rosenberg, Nathan "Technical innovation and national systems," in Nelson, Richard R., editor. *National Innovation Systems*. Oxford: Oxford University Press, 1993.

Odagiri, Hiroyuki "Industrial policy in theory and reality," in H. W. de Jong and W. G. Shepherd, editors, *Mainstreams in Industrial Organization* Dordrecht: Martinus Nijhoff, Publishers, 1986, pp. 387-412.

Odagiri, Hiroyuki and Goto, Akira "The Japanese system of innovation: past, present, and future," in Nelson, Richard R., editor. *National Innovation Systems*. Oxford: Oxford University Press, 1993.

OECD, "Venture Capital in OECD Countries," Special Features section of *Financial Market Trends*, vol. 63 February 1996, OECD, pp. 15-38, based on a paper by Margaret O'Shea, consultant to the Financial Affairs Division of the OECD.

Ouchi, W. G. "The new joint R&D," Proceedings of the IEEE Volume 77, no. 9, 1989, pp. 1318-1326.

Ordover, J. A. "A patent system for both diffusion and exclusion," *Journal of Economic Perspectives* Volume 5, 1991, pp. 43-60.

Pavitt, Keith "Patterns of technical change: towards a taxonomy and a theory," *Research Policy* Volume 13, Number 6, 1984, pp. 343-73.

Peck, Merton J. "Joint R&D: the case of Microelectronics and Computer Technology Corporation," *Research Policy* Volume 15, Number 5, October 1986, pp. 219-31.

Price, Christopher, "Early-Stage Investing Across Europe: Fresh Interest in Technology Funds," *Financial Times Survey*, (October 10, 1997) p. IV.

Reinganum, Jennifer F., "Uncertain innovation and the persistence of monopoly," *American Economic Review* Volume 73, Number 4, September 1983, pp. 741-8.

Reinganum, Jennifer F., "Preemptive patenting and the persistence of monopoly: reply," *American Economic Review* Volume 74, Number 1, March 1984, pp. 251-3.

Röller, Lars-Hendrik, Tombak, Mihkel M., and Siebert, Ralph "Why firms form research joint ventures: theory and evidence," mimeo, May 21, 1997

Romano, Richard E. "Aspects of R&D subsidization," *Quarterly Journal of Economics* Volume 104, No. 419, Issue 4, November 1989, pp. 863-73.

Sahlman, William A., 1990, "The Structure and Governance of Venture-Capital Organizations," *Journal of Financial Economics*, 27, 473-521.

Sahlman, William A., and Howard Stevenson, "Capital Market Myopia," *Journal of Business Venturing*, 1 1986, pp. 7-30.

Salus, Peter H. *A Quarter Century of UNIX*. Reading, Massachusetts: Addison-Wesley Publishing Company, 1994.

Samuelson, William F., "Bidding for Contracts," *Management Science*, volume 32, no. 12 December 1986, pp. 1533-1550.

— "Competitive bidding in defense contracting," in R. Engelbrecht-Wiggins et al., editors, *Auctions, Bidding, and Contracting: Uses and Theory*. New York University Press, 1983.

Saxenian, Annalee, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* Cambridge, Harvard University Press, 1994.

Scherer, F. M. "Research and development resource allocation under rivalry," *Quarterly Journal of Economics* Volume 81, Number 3, August 1967, pp. 359-94.

— "Inter-industry Technology Flows and Productivity Growth," *Review of Economics and Statistics*, 64 November 1982, pp. 627-634.

— "New Perspectives on Economic Growth and Technological Innovation," manuscript, July 1997a.

Schumpeter, Joseph A. *The Theory of Economic Development*. Oxford: Oxford University Press, 1961 [reprint of 1934 edition]

— *Capitalism, Socialism and Democracy*. New York: Harper & Row, 1942; Colophon edition, 1975.

Scotchmer, Suzanne "Standing on the shoulders of giants: cumulative research and the patent law," *Journal of Economic Perspectives* Volume 5, 1991, pp. 29-41.

Scott, John T., "Corporate Finance and Market Structure," Chapter 13 of *Competition in the Open Economy: A Model Applied to Canada*, by Richard E. Caves, et al. Cambridge: Harvard University Press, 1980, pp. 325-359.

— "Diversification versus co-operation in R&D investment," *Managerial and Decision Economics* Volume 9, no. 3 September 1988, pp. 173-86.

— "Firm Versus Industry Variability in R&D Intensity," in *R&D, Patents, and Productivity*, ed. Zvi Griliches, chapter 10, pp. 233-245 Chicago: University of Chicago Press for the National Bureau of Economic Research, 1984.

— *Purposive Diversification and Economic Performance* Cambridge: Cambridge University Press, 1993.

— "The Damoclean Tax and Innovation," *Journal of Evolutionary Economics*, vol. 5, no. 1 February 1995, pp. 71-89.

— "Environmental Research Joint Ventures among Manufacturers," *Review of Industrial Organization*, Volume 11, No. 5 October 1996, pp. 655-679.

— "The Service Sector's Acquisition and Development of Information Technology," *Journal of Technology Transfer*, 1998a, forthcoming.

—"Schumpeterian Competition and Environmental R&D," *Managerial and Decision Economics*, 1998b, forthcoming.

— "The Hurdle-Lowering Auction: A Mechanism for Financing and Leveraging Public/Private Partnerships," *STI Review*, Paris, OECD, forthcoming, 1998c.

Scott, John T., and Pascoe, George, "Purposive Diversification of R&D in Manufacturing," *Journal of Industrial Economics*, vol. 36, no. 2 December 1987, pp. 193-205.

Sigurdson, Jon, *Industry and State Partnership in Japan: the Very Large Scale Integrated (VLSI) Project* Lund: Swedish Research Policy Institute, University of Lund, 1986.

Spence, A. Michael "Cost Reduction, Competition, and Industry Performance," *Econometrica* Volume 52, Number 1, January 1984, pp. 101-121.

Steinmueller, W. Edward "International joint ventures in the integrated circuit industry," CEPR Publication No. 104, September 1987.

— "Industry structure and government policies in the U.S. and Japanese integrated-circuit industries," in Shoven, John B., editor. *Government policy towards industry in the United States and Japan*. Cambridge: Cambridge University Press, 1988, pp. 319-354.

Suzuki, K. "R&D spillovers and technology transfer among and within vertical keiretsu groups: evidence from the Japanese electrical machinery industry," *International Journal of Industrial Organization* Volume 11, Number 4, December 1993, pp. 573-591.

Suzumura, Kotaro "Cooperative and noncooperative R&D in an oligopoly with spillovers," *American Economic Review* Volume 82, Number 5, December 1992, pp. 1307-1320.

Tassey, Gregory, *The Economics of R&D Policy* Westport, Connecticut; London: Quorum Books, 1997.

Von Weizsäcker, C. C., *Barriers to Entry: A Theoretical Treatment* Berlin: Springer-Verlag, 1980.

Vonortas, Nicholas S. “Inter-firm cooperation with imperfectly appropriable research,” *International Journal of Industrial Organization* Volume 12, Number 3, September 1994, pp. 413-35.

Wallsten, Scott “Can Government-Industry R&D Programs Increase Private R&D? The Case of the Small Business Innovation Research Program,” manuscript, November 1997, Stanford University.

Wegberg, Marc van and Witteloostuijn, Arjen van “Multimarket collusion in product markets and joint R&D ventures: the case of the information technology industry in an integrating Europe,” in Hagedoorn, John, editor *Technical change and the world economy*. Aldershot: Edward Elgar, 1995, pp. 83-108.

Wright, Brian “The economics of invention incentives,” *American Economic Review* Volume 73, 1983, pp. 691-707.

Wupperfeld, Udo, *The Role of Various Types of German Investment Companies for the Financing of New Technology-Based Firms* Karlsruhe, Franhofer-Institut fur Systemtechnik and Innovationsforschung, 1992.

Yi, Sang-Seung, “Endogenous Formation of Joint Ventures with Efficiency Gains,” *Rand Journal of Economics*, 1998, forthcoming.

Yi, Sang-Seung, and Shin, Hyukseung, “Endogenous Formation of Research Coalitions with Spillovers,” Manuscript, May 15, 1997.

Ziss, Steffen “Strategic R&D with spillovers, collusion and welfare,” *Journal of Industrial Economics* Volume 42, Number 4, December 1994, pp. 375-93.