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The challenge of contracting for technological information

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ABSTRACT Contracting to provide technological information (TI) is a significant challenge. TI is an unusual commodity in five ways. (*i*) TI is difficult to count and value; conventional indicators, such as patents and citations, hardly indicate value. TI is often sold at different prices to different parties. (*ii*) To value TI, it may be necessary to "give away the secret." This danger, despite nondisclosure agreements, inhibits efforts to market TI. (*iii*) To prove its value, TI is often bundled into complete products, such as a computer chip or pharmaceutical product. Efficient exchange, by contrast, would involve merely the raw information. (*iv*) Sellers' superior knowledge about TI's value make buyers wary of overpaying. (*v*) Inefficient contracts are often designed to secure rents from TI. For example, licensing agreements charge more than marginal cost. These contracting difficulties affect the way TI is produced, encouraging self-reliance. This should be an advantage to large firms. However, small research and development firms spend more per employee than large firms, and nonprofit universities are major producers. Networks of organizational relationships, particularly between universities and industry, are critical in transmitting TI. Implicit barter—money for guidance—is common. Property rights for TI are hard to establish. Patents, quite suitable for better mousetraps, are inadequate for an era when we design better mice. Much TI is not patented, and what is patented sets fuzzy demarcations. New organizational forms are a promising approach to contracting difficulties for TI. Webs of relationships, formal and informal, involving universities, start-up firms, corporate giants, and venture capitalists play a major role in facilitating the production and spread of TI.

Information is often described as a public good.[a] This assumes that there is nonrivalry in consumption and that, once information is made available to one party, it is readily available to another. For some types of information, particularly consumptive information such as the scores of sporting events, this may be an adequate description. But if our concern is with information affecting technology and the economy, it almost certainly is not. I argue below that the public good classification can be misleading in two respects: (*i*) for much information, many of the usual characteristics of public goods are not satisfied,[b] and (*ii*) focusing on the public good aspect of information has deterred economists and policy analysts from delving more deeply into the distinctive properties of information, including most particularly the challenge of contracting for technological information (TI).

Even if there is no restriction on access to information, it may be extremely costly to acquire. The basics of physics or molecular biology are contained in textbooks, yet people spend years learning to master them. Corporations become tied to a given technology and have vast difficulties changing when a superior one becomes available. Often the physical costs of change, for example to new machines, are small relative to the costs of changing procedures and training personnel. Looking across corporations within the same industry, we often see significantly different levels of productivity. In the classical economic formulation, technological advance merely drops into the production function, boosting levels of outputs or factors. In the real world, improved technology, as represented, say, by new information, may be extremely costly to adopt. Many of the factors that limit the public good status of TI also make it difficult to buy and sell, even as a private good.

Economics has addressed the challenges of contracting, particularly in the context of agency relationships. Inefficiencies arise because it is not possible to observe the agent's effort, or to verify the state of the world, or because potential outcomes are so numerous (due to uncertainty) that it is not possible to prespecify contingent payments (see refs. 3 and 4).[c] All these problems arise in contracting for TI. For example, because effort is difficult to monitor, contracts for TI usually pay for outputs (e.g., a royalty), not inputs, even in circumstances where the buyer is much less risk averse than the seller.

The Peculiar Properties of Technological Information

The primary challenge in contracting for information stems from the bizarre properties of information as a commodity, which are discussed below under five headings: counting and valuation, giving away the secret, bundling and economies of scale, asymmetric knowledge of value, and patterns of rents. For the moment, we focus discussion on TI, a category that is predominantly produced by what we call R&D. TI enters the production function to expand the opportunity set, to get more output, or value of output, for any level of input.

Counting and Valuation. Theorists have proposed a variety of measures for information, which may involve counting bits or considering changes in odds ratios, but such measures could hardly be applied with meaning to information contained in the formulation of a new pharmaceutical or the design of a computer chip. (Tallies of papers, patents, and citations are frequently used as surrogate measures for technological advance.) Even if an unambiguous quantity measure were available for information, we need a metric that indicates the importance of the area to which it is applied. Price plays this

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Abbreviations: R&D, research and development; TI, technological information; JG, Johnson–Grace, Inc.

[a]The attendant policy concern is that too little inventive activity will take place when private rates of return fall below public rates. Pakes and Schankerman (1) find private rates to be "disappointing," suggesting a divergence is a concern.

[b]Were research and development (R&D) a public good, with consumption of the good provided free of charge, the largest economy should spend the most, with smaller countries riding free. In 1993, in fact, Sweden had the highest national R&D intensity. Leaving defense aside, the United States trailed its major competitors, Japan and Germany (2).

[c]See also the extensive literature on research contracting (e.g., ref. 5).

role when apples are compared with oranges, but information is sold in markets that are both thin and highly specialized. We do not have price equivalents for units; we even lack clear ways to identify the relative importance of different information arenas.

Given such difficulties, we do not tally quantities of information. Rather, we combine the quantity and importance issues, and, at best, talk of information's value. That value is most likely to be revealed in contracts between two parties engaged in bilateral bargaining, suggesting that there will be substantial instability in the outcomes. To be sure, there are information services, trade journals and the like, sold at a price. But when TI is sold in raw form, rarely is the same package sold to multiple parties at the same price. Below we observe that information is usually sold in a package with other components; for example, a modern PC chip contains numerous technological innovations. And when patents or licenses are sold, often the buyer already knows the information; the commodity purchased is the right to use it.

Giving Away the Secret. The benefit of TI is extremely difficult to judge. First, it may be difficult to know whether it will work or whether it will expand production capabilities. Second, if it does work, will it facilitate new products? What products will be wanted, and how widespread will be the demand? These questions are exceedingly difficult to answer, as contemplation of the wonders of the Internet makes clear.

This suggests that if some potentially valuable information were displayed on a shelf, it would be a challenge for the seller to price it, or for the buyer to know whether to purchase. However, unless information is securely protected, it rarely gets the equivalent of shelf display. Merely informing a potential buyer about one's product gives away a great deal of the benefit. Hence, information is shared alongside sheaves of nondisclosure agreements, and, even then, there is selective hiding of critical components. Frequently prototypes are demonstrated, but inner workings may be hidden, much as magic stores demonstrate an illusion but not its working mechanism. But even to make it clear that something is technologically feasible is to give away a great deal; it reveals that innovation is feasible, and someone thought the effort to produce it was worth making.[d]

When TI is the product, fears of inappropriate use may cause both customers and technology providers to clam up. The experience of Johnson–Grace, Inc. (JG), a small firm located no more than 1 mile from this conference, is instructive. For 2 years, it has had a superior image compression algorithm, which has been prominently employed by America Online. Some potential customers (online services) have been reluctant to provide information that would enable JG to operate on their system. JG has resisted giving out source code, which would permit customers to understand better how their system worked but would also facilitate legal or illegal theft. For a period, for example, JG refused to discuss with Microsoft its product that interleaves compressed sound and video. Knowing such a product could be developed might spur Microsoft to do so.[e]

For most products, such as cars or television sets, the more consumers the merrier. The early consumers of such products gain as they become more widely used, say because repair facilities will be more convenient. With much TI, however, additional users diminish the value to current users. When the TI is targeted to a particular industry or product, the loss is likely to be great.

Such losses imply that those in possession of TI will be vitally concerned whether it is made available to others and, if so, how widely it will be employed. Here contracting encounters another hurdle. More than being difficult to count, information is impossible to meter; it is often beyond anyone's capability to state how widely a technology has been disseminated. (To be sure, in some circumstances it can be licensed on a per-unit basis for a limited set of products.)

Firms that utilize their own R&D frequently do not license it to competitors, which leads to inefficiency, since, from a resource standpoint, the marginal cost of use is zero.[f] The consumers who benefit from the increased competition cannot be charged for their gains. Moreover, it may be impossible to limit the potential licensee to particular noncompetitive uses. Given this difficulty, firms developing TI often sell it to a single entity.

The logical extension of the single entity concept is to create a new firm to produce a particular form of TI. That is why we see so many start-up firms in the high-tech arena. Start-ups have the additional advantage of securing the majority of their benefits for the individuals who actually provide and develop the innovative ideas. Such individuals may be forced to break off from an old, larger firm because they are unable to demonstrate the extraordinary value of their ideas or because compensation policies simply can't reward the innovators sufficiently.

Finally, R&D cannot be taken to the bank as an asset to be mortgaged. Explaining the product to the bank would be difficult and potentially disadvantageous competitively. Moreover, given the tremendous uncertainties about value, a default is not unlikely, and when there is one the asset is likely to have little salvage value.

Bundling and Economies of Scale. TI has many of the characteristics of an acquired taste. The buyer has to try it before buying. With exotic ice creams or Icelandic sagas, also acquired tastes, a relatively cheap small test can guide us about a potential lifetime of consumption. With information, by contrast, we may have to acquire a significant portion or all of the total product before we know whether we want it. A good idea packaged alone is not enough, since its merits are hard to establish. What is usually required to convince a party to purchase TI is a demonstrated concept or completed product. In effect, there are significantly increasing returns to scale with respect to investment in innovation, and if patent protection is required, there is possibly an indivisibility.

This increasing returns aspect of TI compounds contracting difficulties.[g] Even if there were no charge for the information, the costs of evaluating it would discourage acquisition, however desirable that would prove *ex post*. Much information that might be sold is not even displayed for sale. When it is, elaborate legal documents relating to such matters as nondisclosure are required (at times with lawsuits to follow). Finally, the information may be bundled into products, which can be

[d]Arrow (ref. 6, pp. 5–6) makes this point with respect to the development of the atomic bomb. There were severe concerns about espionage leaks when the Soviet Union produced its own bomb. However, the primary "leak" may have come from the public knowledge that the United States was able to produce a successful weapon.

[e]In January of 1996, JG was sold to America Online, its major customer. Moving to common ownership of the buyer and seller of TI is a frequent solution to the problem of contracting for TI. Before the acquisition, as they became increasingly entwined, both JG and America Online became vulnerable to "holdup"—i.e., exploitation because its value can be destroyed—by the other party.

[f]When there are significant network externalities, or other gains from extending the market, licensing is desirable. Witness the recent agreement with Phillips, Toshiba, etc., relating to the next generation of compact disk technology, and the subsidized sales of software products seeking to become the standard. Many commentators believe Apple Computer made a major mistake not licensing its superior Macintosh technologies, which it has only begun to do recently.

[g]This increasing returns feature relates to another contentious issue in technology policy. It suggests that government subsidies to R&D, in some circumstances, may enhance and not crowd out private efforts.

demonstrated and purchased whole, though the unbundled information may be the commodity truly sought.

Beyond this, the very nature of information makes it difficult to peruse the landscape to find out what is available. Despite the miracles of the Internet, Nexis–Lexis, and the like, there is no index of technologies that one might acquire. Much valuable TI, such as trade secrets, is not even recorded. As a consequence, many technologies sit on the shelf; valuable resources lie dormant.

What information is contracted, not surprisingly, often comes in completed bits. A superior video compression algorithm may be placed into an applications program specialized for the information provider. A fledgling biotech firm sells its expertise to the pharmaceutical company as a formulated product. And venture capitalists package their special expertise and connections along with a capital investment. Michael Ovitz, whose pre-Disney monopoly returns derived from his information network, made his money through deal-making, not the direct sale of information.

Such packaging can play a number of useful roles, for example: (*i*) it may assure the buyer that the information is really valuable, since it works in the product;[h] and (*ii*) it may facilitate price discrimination. Such discrimination trades off the inefficiency of a positive charge for a zero cost service against the incentive gain of letting the information developer secure more for his output.

TI may be bundled as one component in a product, or it may be a process or item that is licensed with the protection of patent. The need for a patent before information is readily sold, though understandable, incurs significant liabilities. To begin, it limits and delays what can be sold. (The parallel in the physical product world would require a hard disk manufacturer to produce a whole computer before making a sale.)

Given the difficulties of contracting for information on an arm's-length basis, frequently it is secured as part of some long-term, often contractual relationship.[i] One firm provides TI, the other offers complementary products, say, manufacturing or marketing capability. This could be a joint venture, with say a manufacturer joining with a technology firm, with some agreed-upon division of profits. Alternatively, to secure a long-term relationship, one firm—more commonly the complement—makes an equity investment in the other, possibly a complete acquisition. Even one-time contractual relationships may specify an enduring connection.[j]

Asymmetric Knowledge of Value. However packaged, asymmetries in knowledge will remain when information is sold. Even if the technology is well understood, the parties may differ on valuation. The winner's curse—when a knowledgeable party allows you to buy something that is worth less than you thought—will (appropriately) inhibit contracting. Consider the possible purchase of a patent that is worth 1.5 times as much to B as to A, its owner. B's subjective distribution on the value is uniformly distributed on the interval [0,1]; A knows the true value. Any positive bid by B will lose money on expectation; hence (inefficiently), the patent will not be sold.[k] A parallel argument applies when the acquirer, say a large company with well-developed markets, has more knowledge of the value of a technology than its seller, perhaps a start-up firm. When the patent is sold, it will be sold for too little, a phenomenon that inhibits a potential sale.

Given difficulties of contracting for information outside the firm, TI may be of greater value in a larger firm, where it can be deployed for a larger volume of products, where marketing skills are superior, brand names are better known, etc. When a small firm possesses TI, or has superior abilities to develop it, a larger firm may seek to acquire the small one so as to reap its technology and capabilities.[l] Such acquisitions are common, but they are reduced in frequency because of information asymmetries. Small firms may have difficulty demonstrating the superiority of technology they already possess, much less their future ability to generate new knowledge. Moreover, a willingness to contemplate sale hints at self-doubts.

R&D races, a favorite subject for economics study,[m] are also affected by asymmetries in knowledge of value. The greater is your opponent's assessment of the payoff from winning, the more likely he is to stay in and the more resources he will devote. Hence, when you win the race, the prize is less valuable. Assuming the participants understand this phenomenon, R&D races will be less profligate.

On the other side, failures of contract exacerbate the costs of R&D races. The challenge of demonstrating a workable technology (e.g., the phenomena that call for bundling) makes it difficult or unwise for the leader to demonstrate her advantage, hoping to induce her opponent(s) to drop out. For example, journal publication, which may deter competitors by demonstrating one's lead in a race, also reveals secrets.

Patterns of Rents. The use of capital, a stock of resources, earns a rent. Machines thus have a rental price; risk capital earns a return, and skilled humans receive a premium wage. The rent is equal to the increment in output per period offered by the resource, which we can think of broadly as capital.

Information and knowledge are often labeled intellectual capital. But the services of such capital, say, how to conduct a physical process or design a circuit, does not offer a level benefits stream over time. It often offers its primary benefits almost immediately, subject only to constraints such as time to process and understand. The story is told of the great Charles Steinmetz, called to repair a giant General Electric generator after many others had failed. Steinmetz marched around the colossus a couple of times and called for a screwdriver. He turned a single screw, then said: "Turn it on," and the machine sprang to life. When Steinmetz was questioned about his $10,000 bill, he responded: "10 cents to turn the screw, $9999.90 to know which screw to turn."

Those who possess intellectual capital, like scientists or lawyers, may even be rewarded with per-period excess wages. However, this arrangement may not reflect the true pattern of productivity, which is extraordinarily high during a brief period of distillation—the colloquial brain picking interlude—and then falls to ordinary levels when the capital is applied to totally new problems. To be sure, firms offer technologies on a per-period basis, but not the information contained in that technology. If they did, 1 day's purchase would offer an eternal license.[n]

[h]Even seeing a successful product may be insufficient. If a product is sufficiently innovative, sales to other parties often serve as the best evidence that it is worthwhile. This may offer protective cover to the purchasing decision maker. Interestingly, even venture capital firms, the touted sleuths of product discovery, often seek confirmation from peers. On average, 2.2 venture capitalists are involved in first-round financing of companies (7). When positive decisions depend on the positive decisions of others, herding is a likely result.

[i]Kogut (8) finds that long-term relationships induce and stabilize joint ventures for R&D, since they create the potential to penalize and reward behavior among partners.

[j]S. Nichtberger (personal communication), who does product development for Merck, reports that when a pharmaceutical firm contracts for a drug or technique, it traditionally requires exclusive rights to all drugs using the same technique for a category of disease.

[k]Let us say you bid 0.6. When the seller lets you have it, it will be worth on average 0.3 to the seller; hence, 0.45 to you. In expectation you will lose 0.15. This example is adapted from ref. 9.

[l]In effect, this raises bundling to a higher level, with the small firm's capabilities and personnel ties sold as a unit. Favorable employment contracts are employed to stem leakage.

[m]See ref. 10 for a recent treatment.

[n]This suggests that architects and technological consultants should offer their services at an initial rapidly declining hourly rate. The first

Bundling is a second-best approach to the 1-day-tells-all problem. Even information possessed by a single individual may be unfolded as part of a larger package, where, say, he custom-designs a process or device for a particular company. He can't merely tell the secret and let the company do the development, because he can't assure the company in advance that his information will be valuable.

The Production and Transmission of TI

The difficulties in contracting for R&D profoundly affect the way it is produced. Some firms have R&D as their stock in trade; their related activities simply encapsulate the knowledge they produce. But for the vast majority of firms, R&D is not a central activity. Rather, they produce steel, manufacture cars, or sell securities. Superficially, it might seem that those in securities or steel would contract out for R&D. The care and nurturing of engineers and scientists may require a distinctive culture, not well-suited to bartering bonds or churning out ingots. Moreover, if research universities are indicative, there are significant economies of scale in conducting research. Many firms would seem to have R&D divisions below efficient scale.

Surprisingly, a vast range of firms run their own R&D operations. This reflects, I believe, the difficulties of contracting for information. Even if a firm wanted to buy R&D from outside, it would have a difficult time doing so. Moreover, in going to the market for R&D, it would be exposing internal information it would rather keep proprietary.[o] Cohen and Levinthal (12), highlighting difficulties in transferring TI, talk of a dual role for R&D: generating new information and enhancing "absorptive capacity." The latter—the ability to identify, assimilate, and exploit information—helps explain why firms undertake basic research and why some ill-equipped firms do R&D at all.

Assuming that contracting challenges foster a tendency to self-reliance, what is lost? In theory, large firms should be able to spread knowledge and information over a much wider base. Hence, other factors equal, they should have higher R&D intensity than small firms. This proves not to be the case. In 1991, firms undertaking R&D with fewer than 500 employees spent $6021 per employee on R&D (excluding federal support), the most for any size category.[p] The largest firms, those with more than 25,000 employees, were second at $5169, presumably reflecting the public good nature of information (ref. 13, p. 33), at least within the firm.[q] The high R&D expenditure levels of small firms suggest that whatever disadvantages they have in deploying information is compensated by their advantages in producing it.

Universities, of course, are major producers of TI. Given their nonprofit and public-oriented mission, it might naively be thought that TI might flow more smoothly from them. Van de Ven (16) argues that there is a "stickiness" of such knowledge or, as Zucker *et al.* (17) phrase it, a "natural excludability." Specific pieces of information may be less critical than insights and experience; moreover, universities and their researchers have gotten into the business of selling their TI.

Blumenthal *et al.* (18) report that, for biotechnology companies, university–industry relationships help 83% of them keep abreast of important research (promoting their absorptive capacity), whereas 53% secure licenses for products. Some knowledge may flow in the opposite direction, with 58% of companies suggesting such arrangements "risk a loss of proprietary information."

Powell *et al.* (19) document that, in a field of rapid technological advance (biotechnology is their prime example), learning occurs within "networks of inter-organizational relationships." Firms use ties to learn from each other. They conclude that "much of the relevant know-how is neither located inside an organization nor readily available for purchase."

Together these authors paint a picture of information exchanged on a nonexplicit basis, in the form of implicit barter arrangements. Companies sponsor university research and receive in return subtle information about what fields and researchers are promising and on what types of technologies might prove feasible. More explicit agreements might give the sponsor privileged access to license technology. Professors train students; at a later date, they work together in a private sector venture. Favors are reciprocated, insights and experiences are exchanged, and information gets passed along webs of relationships. The exchanges may be between employees of different companies, or even within a company, who make each other look good.[r] Though some information is paid for explicitly, much that could not possibly be contracted—perhaps an opinion on what research areas will prove promising—is offered gratis. Informational gifts may be part of a commercial courtship ritual, perhaps demonstrating one's capabilities or hoping to start an escalating exchange of valuable knowledge.

Assuming contracting challenges, there are two inefficiencies in R&D locale: it is produced inefficiently, and what is produced is substantially underutilized. The latter problem may not be extreme, since only 17% of R&D is spent in firms with fewer than 5000 employees.[s]

Implications

Economic analyses of TI usually start with the observation that such information is a public good. Excessive focus on this feature, I argue here, has led us to slight the major class of market failures associated with TI that stems from its amorphous quality. This quality makes information hard to count, value, trade, or contract on in market or nonmarket transactions. The critical features of these two conceptions of TI are summarized in Table 1.

A thought experiment might ask what would happen if information remained a public good but were susceptible to contract. Fortunately, there are public goods that offer relatively easy contracting, such as songs or novels, which offer an interesting contrast with information. Such goods appear to be well-supplied to the market, with easy entry by skilled low-cost songwriters and novelists.

few hours call primarily on their intellectual capital on hand, subsequent hours on their time. Most such professionals design their introductory meetings to establish long-term relationships, and they experience the tension between displaying their capabilities and revealing too much too soon. To be sure, English and economics professors spill their intellectual capital on a per-hour basis, but an engineering professor would hardly do so with commercially valuable proprietary knowledge.

[o]This in-house bias even extends across oceans. Hines (ref. 11, p. 92) reports that for foreign affiliates of U.S. multinationals, 93% of their royalty payments to American companies went to their parents.

[p]This result is biased; because a much smaller proportion of small firms undertake R&D, the relative R&D of small firms is overstated.

[q]Perhaps surprisingly, small manufacturing firms do not do more R&D as a percent of net sales than large; both are at 4.1% (ref. 13, p. 19). Mansfield (14) finds that a 1% increase in a firm's sales is associated with a 1.65% increase in its basic research expenditures and a 0.78% increase in R&D expenditures for process or product innovation. Scherer and Ross (ref. 15, pp. 654–656), in an overview, find R&D outlays are slightly less than proportional to sales, a longstanding phenomenon in the United States. In terms of productivity, they observe: "the largest manufacturers derived fewer patents and significant technological advances from their R&D money than smaller firms."

[r]von Hippel (20) assesses "know-how" trading as a benefit to firms and/or their trading employees.

[s]Figure for latest year available 1989 (ref. 13, p. 17).

Table 1. Two conceptions of technological information

	Public goods	Challenge to contract
Rivalry	• Nonrivalrous	• Strong rivalry
Excludability	• Nonexcludable	• Exclusion mechanisms Sticky to begin Secrecy Patents Lawsuits • Transmission through relationships
Good produced	• Nuggets of knowledge	• Bundled products
Locus of production	• Most efficient knowledge producer	• Inefficient internal reliance • Absorptive capacity investment • Webs of relationships
Transmission	• Open literature • Forums and seminars • Internet and mass media	• Human mules • Raiding and defection of personnel • Academic–industry relationships • Personal relationships
Critical concerns	• Underprovision • For second best world, tension between intellectual property and pricing above marginal cost best world	• Underprovision • Inefficient production • Underexploitation • Protection of intellectual property • Facilitating contracts for information • Backward impact on university (secrecy, conflicts of interest) • Private benefits from government research expenditures
Policy measures	• Substantial government subsidy • Required dissemination of government-sponsored results • Patents recognizing second best	• Government subsidy proportional to leakage • Direct government provision to avoid appropriation • Government–industry proprietary research relationships • Patents recognizing second best • Antitrust policy recognizing second best

Given contracting difficulties, information is likely to be produced in the wrong locale, by big firms rather than small, and in duplicative fashion rather than singly by the most efficient producer. These inefficiencies in production, moreover, may significantly reduce the output of TI.[t] These problems do not arise with songs or novels.

If the public good nature of TI were the sole concern, government could merely secure it from the private sector, as it does with weapons or social science research. To deal with contracting issues, research is undertaken directly by government laboratories, say the National Institutes of Health campus, in preference to the private or nonprofit sector.[u] Government-funded collaborative research facilities, such as Sematech, are designed to overcome duplicative research efforts. Such ventures are rare, in large part because it is hard to contract even for the production of R&D, say, to get companies to send their best scientists. If the collective inputs were merely dollars and if it were hard to claim private benefits from the output, collaborative efforts would be much easier to organize. That is why trade associations, which for the most part possess these characteristics, are common.

Recognizing that contracting difficulties are a principal impediment to the effective production and exchange of TI should shift our policy attention. The effective definition of property rights becomes a central concern. Our patent system was developed for the era of the better mousetrap and its predominantly physical products, whereas today we are designing better mice. Today's TI is less contractible because it is less tangible, perhaps an understanding of how computers or genes deal with information. Much TI is not patented, due to both expense and inadequate protection (perhaps a half-million dollars to fight a patent infringement case in front of an ill-informed jury). What is patented sets fuzzy demarcations, as an explosion of litigation attests. Related policies for the protection of intellectual property (e.g., trade secrets and copyright law) also persist from an outdated era.

Market structure significantly affects both the level and deployment of R&D activity. (The two most salient antitrust cases of the modern era—IBM and AT&T—involved the nation's two technological giants.) Our mainline antitrust policies do not explicitly recognize the R&D link. However, the Department of Justice and Federal Trade Commission (DOJ–FTC) Horizontal Merger Guidelines (April 2, 1992) do allow for an efficiency defense,[v] and cooperative research efforts receive favored treatment. More important, the general tenor of the contemporary antitrust policy arena, including the DOJ–FTC 1994 guidelines on Intellectual Property Licensing, reflects a high sensitivity to R&D production. The TI explosion has given birth to new organizational forms for confronting contracting difficulties. They range from the traditional—vertical mergers involving media and information companies—to the highly innovative—webs of relationships, formal and informal, involving universities, start-up firms, corporate

[t]However, if demand is inelastic, more may be spent than in a perfect world.

[u]Over the past decade, government laboratories have undertaken collaborative research and development agreements with private entities, which receive proprietary TI in exchange for their own R&D efforts. This approach, in effect, sacrifices public good benefits to enhance productivity. See ref. 21 for a discussion of contracting difficulties that remain.

[v]In relation to TI, probably the most relevant defense cited is achieving economies of scale.

giants, and venture capitalists—and play a major role in facilitating the production and spread of TI. The twenty-first century merits policies affecting a range of organizational forms, that explicitly take account of the effects of these structures on the production, dissemination, and utilization of TI.

Recognizing the importance of webs of relationships (8, 19) to R&D development suggests that regions, or industries, blessed with social capital (22)—trust, norms, and networks—will have substantial advantages, as Silicon Valley and Route 128 make evident. In recent years, Europe has made explicit efforts to build cooperative approaches to R&D among natural competitors, relying on substantial government subsidies and coordination on research directions (23).

The R&D problem is often framed as one of providing public goods, with Federal funding as the implicit solution. Yet federal funding as a proportion of industrial R&D has fallen precipitously from the 1960s, when it exceeded company spending, to the 1990s, when it has been <40% as large.[w] Given contemporary political and budget realities, generosity in government funding, whatever its theoretical merits, is unlikely to guarantee the efficient production of R&D.

The second major government function in R&D production is its accepted role as definer and enforcer of property rights. However, bold new frontiers are being crossed in defining technological realities—witness the Internet and genetic engineering. In such unfamiliar territory, appropriate property delineations are much harder to define. This is particularly true since other salient values, such as freedom of speech, privacy, and the sanctity of life, are deeply involved with technological advance.

The nature of TI, I have argued here, severely impedes its purchase and sale. When such inefficiencies are great, the struggle for second best outcomes will lead to new organizational forms to facilitate contracting. This implies that the vast increase in the role of TI, beyond any direct effects in expanding production possibilities, will transform the structure of industry in developed nations, dramatically altering patterns of competition and cooperation.

[w]In 1991, excluding aircraft and missiles, Federal funds comprised 18% (671/3807) of basic research and 22% [(4918-471)/(24,084-3248)] of applied research (ref. 13, pp. 3, 24–25).

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