Parallel Research, Multiple Intellectual Property Right Protection Instruments, and the Correlation among R&D Projects

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Abstract

The choice of a research path in attacking scientific and technological problems is a significant component of firms' R&D strategy. One of the findings of the patent races literature is that, in a competitive market setting, firms' noncooperative choices of research projects display an excessive degree of correlation, as compared to the socially optimal level. The paper revisits this question in a context in which firms have access to trade secrets, in addition to patents, to assert intellectual property rights (IPR) over their discoveries. We find that the availability of multiple IPR protection instruments can move the paths chosen by firms engaged in an R&D race toward the social optimum.

Keywords*:* intellectual property rights, parallel R&D, patent races.

JEL Classification: O3, L0

1. Introduction

By endowing inventors with exclusive property rights over their discoveries, patents can be a powerful incentive for undertaking new research and development (R&D) projects in a market economy, thereby promoting the flow of innovation that is at the root of modern economic growth. Ancillary benefits that are often cited include the patent system's role in disseminating new knowledge and in helping technology transfer and commercialization of new inventions. But patents are a quintessential second-best solution to very real market failures that affect the provision of innovations in a competitive setting. Whereas they solve some incentive problems, the monopoly positions engineered by patent rights can create other inefficiencies (see Scotchmer, 2004, or Langinier and Moschini, 2002, for an overview). The economic issues raised by patent races are a case in point. The competition for the economic rents secured by a patent provides incentive for parallel research (Dasgupta, 1990). Given that R&D projects have uncertain outcomes, some parallel research may be desirable from the social point of view because it increases the probability of success. But because the reward to firms engaged in a patent race is in the form of winner takes all, too much parallel research is also possible in a competitive setting, an example of the rent dissipation postulate (Tirole, 1988).

In addition to providing a possibly inefficient *amount* of R&D investment, parallel research also may fail to provide the correct *type* of R&D efforts. Specifically, competitors in a patent race may choose strategies that are too risky from society's viewpoint (Klette and de Meza, 1986). More subtly, R&D competitors may choose projects that are excessively correlated relative to what is socially desirable. Expanding on earlier work by Bhattacharya and Mookherjee (1986), Dasgupta and Maskin (1987) showed that projects selected by firms engaged in a patent race are in fact excessively correlated. Cabral (1994) showed that the excess risk result is sensitive to the specification of the winner-takes-all assumption, and a model allowing for post-R&D oligopoly market sharing may actually induce the opposite bias (too little risk-taking in R&D). However, excess correlation of R&D still obtains in his model. Cabral (2002) studied the strategic choice of covariance in a dynamic R&D model and showed that, in equilibrium, laggards may want to diversify from leaders, thereby choosing less-promising paths.

In this paper we revisit the issue of excessive correlation in a parallel research setting by investigating the impact of a more realistic institutional setting. Specifically, it is known that firms rely on multiple modes of protection for their discoveries. Trade secrets, lead time, and manufacturing capabilities not only complement patents in helping firms appropriate returns from R&D activities but are often considered more important (Cohen, Nelson, and Walsh, 2000). Indeed, the reported importance of trade secrecy increased dramatically compared with earlier industry surveys (Arundel, 2001). Trade secrets are particularly attractive to inventors when a discovery is difficult and costly to reverse-engineer and/or discover independently (Daizadeh et al., 2002). In agricultural innovations, for example, this has been the case for proprietary germplasm. Pioneer Hi-Bred International successfully used trade secrets to protect its germplasm in at least two high-profile cases (against Holden Foundation Seeds, Inc. in 1991, for a judgment worth $46.7 million, and against Cargill, Inc. in 2000, for a settlement worth $100 million). More generally, Lerner (1995) finds that trade secret disputes captured 43% of intellectual property litigations.

The impact of alternative modes of intellectual property protection has been the object of a number of studies. In line with the strategic patenting hypothesis discussed in the empirical literature, Horstmann, MacDonald, and Slivinski (1985) consider the relative advantage of the explicit choice not to patent. In a signaling model, Scotchmer and Green (1990) consider not patenting as an alternative to patenting intermediate discoveries in a multistage innovation race. Anton and Yao (2004) study the choice between patenting and trade secrets to process innovation in a Cournot competition setting. Denicolò and Franzoni (2004) explicitly model multiple modes of protection available to innovators in studying the ability of patents to exclude prior users. Note that these studies have focused on the choice of research intensity. However, the choice of research path in attacking scientific and technological problems is a significant component of firms' R&D strategy (Cabral, 2003).

Does the availability of alternative modes of protection affect the research path chosen by R&D competitors? That is essentially the question that we propose to analyze in this paper, and we do so by developing a simple model that combines features of the analyses of Dasgupta and Maskin (1987) and

Denicolò and Franzoni (2004). In particular, we model the strategic interaction between firms both at the stage of project selection and at the stage of intellectual property (IP) choice.[1] By linking research and IP game stages, we are able to analyze how the availability of intellectual property right (IPR) protection instruments affects some relevant research choices in a parallel R&D contest. We find that the availability of additional modes of protection (trade secrets in our model) may in fact lead R&D competitors to choose less-correlated projects. The root of our finding is that the presence of an additional IPR instrument introduces an asymmetry on how firms are rewarded in the event of success. Specifically, when there is a single winner in the R&D contest, the availability of trade secrets (in addition to patents) means that the firm has the option of selecting a possibly more profitable IPR protection. But when both firms are successful, the strategic game between firms makes the additional IPR protection instruments less useful. Thus, the presence of trade secrets in addition to patents provides an additional incentive to be the sole winner, thereby driving firms' R&D choices closer to the social optimum for a range of parameter values. We conclude that modeling parallel research with just one winner-takes-all instrument (i.e., patents) may exaggerate the concerns about the insufficient diversification of privately chosen research portfolios. Our model is also useful in recovering a role for patent length as a policy tool in this context, shedding perhaps a novel light on the interaction among alternative IPR protection modes.

2. The Modeling Framework

The starting point of our model is the two-point distribution approach introduced in Dasgupta and Maskin (1987). The R&D contest is represented as a one-shot game in which two firms (firm 1 and firm 2) simultaneously pursue a research project, the outcome of which is either "success" (denoted with S) or

[1] The competition in the research stage is often suppressed in the literature studying strategic patenting, whereby it is usually assumed that one of the firms is the winner of the research contest, and a leader-follower situation arises at the patenting stage (e.g., Horstmann, MacDonald, and Slivinski, 1985; Denicolò and Franzoni, 2004; and Bessen, 2004). On the other hand, studies focusing on the research stage competition typically do not model the strategic interaction in the choices concerning IP protection (e.g., Dasgupta and Maskin, 1987).

“failure” (denoted with F). Let $X_i \in \{S,F\}$ denote the random outcome for the i^{th} firm ($i=1,2$), such that four events (X_1,X_2) are possible: (S,S), (S,F), (F,S), and (F,F). If p_i denotes the i^{th} firm’s unconditional probability of success, and ρ represents the coefficient of correlation of the dichotomous variables X_i (e.g., Hays and Winkler, 1970, pp. 206-208), the probabilities of the four possible events are as follows:

$$prob(S,S) = p_1 p_2 + \rho\sqrt{p_1(1-p_1)p_2(1-p_2)} \tag{1.a}$$

$$prob(S,F) = p_1(1-p_2) - \rho\sqrt{p_1(1-p_1)p_2(1-p_2)} \tag{1.b}$$

$$prob(F,S) = (1-p_1)p_2 - \rho\sqrt{p_1(1-p_1)p_2(1-p_2)} \tag{1.c}$$

$$prob(F,F) = (1-p_1)(1-p_2) + \rho\sqrt{p_1(1-p_1)p_2(1-p_2)} \tag{1.d}$$

where $\rho\sqrt{p_1(1-p_1)p_2(1-p_2)} = Cov(X_1,X_2)$ is the covariance term.

As in Dasgupta and Maskin (1987), in this setting the presumption is that a firm can unilaterally diversify from its rival (thereby reducing the correlation of outcomes) at the expense of decreasing its own unconditional probability of success. Thus, we assume that each firm can choose an action $a_i \in [0,1]$ that affects both the unconditional probability of success p_i as well as the correlation/covariance of outcomes, where $a_i = 0$ represents no diversification effort of firm i and $a_i = 1$ represents firm i ’s maximum diversification.[2] Specifically, we write $p_i = p(a_i)$, $i=1,2$, and $Cov(X_1,X_2) = C(a_1,a_2)$.[3] In the analysis that follows we rely on the following.

[2] Note that our specification differs slightly from that adopted by Dasgupta and Maskin (1987). In particular, they consider the project space to be $[1/2\,,1]$ for firm 1 and $[0\,,1/2]$ for firm 2. Also, their parameterization of the covariance structure differs from the canonical form given previously.

[3] Because the success probability function $p(\cdot)$ is the same for both firms, the covariance function is symmetric in project choices, that is, $C(a_1,a_2) = C(a_2,a_1)$, $\forall\,(a_1,a_2) \in [0,1]\times[0,1]$.

Assumption 1. (i) The unconditional probability function $p(a_i)$ is strictly decreasing and strictly concave in its domain, with maximum at $a_i = 0$ and minimum at $a_i = 1$. (ii) The covariance function $C(a_1, a_2)$ is strictly decreasing in a_i ($i = 1,2$). (iii) The probability of event (F, F), that is $[1 - p(a_1)][1 - p(a_2)] + C(a_1, a_2)$, is strictly convex in a_i ($i = 1,2$).

As in Dasgupta and Maskin (1987), moreover, it may also be desirable to restrict attention to the case of nonnegative covariance, such that maximum diversification choices entail $C(1,1) = 0$.

2.1. Social Optimum

In this setting, the question of interest concerns what the noncooperative choices of the two firms are, and how that compares with the desirable choices from society's viewpoint. To address this in the simplest case, following Dasgupta and Maskin (1987) we assume that the payoff to society of at least one project being successful is $B > 0$, and we abstract from cost considerations. Thus, expected social welfare can be written as $E[W] = B \cdot [1 - prob(F, F)]$, where $E[\cdot]$ is the expectation operator, so that the social planner's problem is

$$\underset{a_1, a_2}{\text{Max}} \quad E[W] = B \cdot [1 - prob(F, F)] \quad . \tag{2}$$

Therefore, the social planner maximizes the total probability of success. The objective function in equation (2) is strictly concave by Assumption 1, and thus we have a unique solution to the welfare maximization problem.

Given our formulation, the solution to the problem in (2) is symmetric and it is labeled (a^*, a^*). Note that, because $prob(F, F) = 1 - prob(S, F) - p(a_2) = 1 - prob(F, S) - p(a_1)$, from equation (1) the optimality conditions for an interior solution are equivalent to

$$\frac{\partial prob(S, F)}{\partial a_1} = \frac{\partial p(a_1)}{\partial a_1}[1 - p(a_2)] - \frac{\partial C(a_1, a_2)}{\partial a_1} = 0 \quad , \tag{3.a}$$

$$\frac{\partial prob(F,S)}{\partial a_2}=\frac{\partial p(a_2)}{\partial a_2}[1-p(a_1)]-\frac{\partial C(a_1,a_2)}{\partial a_2}=0 \quad . \tag{3.b}$$

That is, the social planner effectively maximizes the probabilities that each firm is the single winner. In doing this, it weighs the loss of the unconditional probability of success against the (optimal) diversification gain through the covariance term.

2.2. Noncooperative Solution

In contrast, in a competitive R&D setting, firms simultaneously choose research projects in a non-cooperative fashion. Let U_{SS} denote the expected payoff to each firm when both firms are successful, let U_S denote the payoff to a single successful firm, and let U_F be the payoff to the firm that fails (whether alone or jointly with the other firm). It is assumed that $U_S \geq 2U_{SS} > U_F = 0$.[4] Then, the firms' optimization problems (conditional on the other firm choice) are

$$\underset{a_1}{\text{Max}} \quad V_1(a_1,a_2) \equiv U_{SS} \cdot prob(S,S) + U_S \cdot prob(S,F) \ , \tag{4.1}$$

$$\underset{a_2}{\text{Max}} \quad V_2(a_1,a_2) \equiv U_{SS} \cdot prob(S,S) + U_S \cdot prob(F,S) \ , \tag{4.2}$$

with first-order conditions (FOCs) for an interior solution being

$$U_{SS}\frac{\partial prob(S,S)}{\partial a_1}+U_S\frac{\partial prob(S,F)}{\partial a_1}=0 \ , \tag{5.1}$$

$$U_{SS}\frac{\partial prob(S,S)}{\partial a_2}+U_S\frac{\partial prob(F,S)}{\partial a_2}=0 \ , \tag{5.2}$$

which yield the firms' best-response functions. Note that, because by Assumption (1) $prob(F,F)$ is convex in (a_1,a_2) and $p(a_i)$ is concave, then $prob(F,S)$ and $prob(S,F)$ are concave in (a_1,a_2) . Furthermore, in view of (1), the firms' objective functions can alternatively be written as

[4] The condition $U_{SS} > 0$ presumes that competition between successful innovators does not dissipate the rent created by the innovation, an outcome that is likely under a variety of market conditions (Cabral, 1994). The condition $U_S \geq 2U_{SS}$ simply means that a monopoly is at least as profitable as a duopoly.

$V_1(a_1,a_2) = U_{SS} \cdot p(a_1) + \left(U_S - U_{SS}\right) \cdot prob(S,F)$ and $V_2(a_1,a_2) = U_{SS} \cdot p(a_2) + \left(U_S - U_{SS}\right) \cdot prob(F,S)$,

and therefore they are concave in the decision variables. Hence, the FOCs in (5) are both necessary and sufficient for a maximum. The (symmetric) competitive market portfolio—the Nash equilibrium, denoted by (a^c, a^c)—satisfies the best-response functions of both firms, i.e., it solves equations (5). We shall further restrict our analysis as follows.

Assumption 2. The problems in (2) and (4) admit solutions that lie in the interior of $[0,1]\times[0,1]$.

The following result (Proposition 3 in Dasgupta and Maskin, 1987) then follows.

Proposition 1. *The noncooperative solution consists of projects that are too highly correlated, relative to the social optimum. That is,* $a^c < a^*$.

Proof. By assumption $U_{SS} > 0$ and, given Assumption 1, $\partial prob(S,S)/\partial a_i < 0$, $i = 1,2$. Hence, if equation (3) holds, equation (5) cannot hold. Specifically, the FOCs for the social optimum, when evaluated at the noncooperative equilibrium solution, are positive. Because the second-order conditions for the planner's problem hold globally, the result of Proposition 1 follows.■

The intuition for this result is as follows. Whereas society does not care about the identity of the winner (i.e., society is indifferent between the outcomes (S,S), (S,F) and (F,S)), the firms of course do care. If, starting from the market equilibrium, a firm were to move away from the rival, toward the social optimum, it would create a positive externality for the opponent because it increases the probability that the opponent is successful when the firm in question is not. Although desirable for society because it increases the total probability of success, this effect is not taken into account in the firms' problem.

2.3. Comparative Statics

To extend the analysis of Dasgupta and Maskin (1987) with the aim of considering multiple modes of protection, we first note that the competitive (Nash equilibrium) solution depends on the relative magnitude of the payoffs U_{SS} and U_S. More specifically, the following preliminary result will be useful in what follows.

Lemma 1. *Let* (a^c, a^c) *denote the symmetric Nash equilibrium of the noncooperative (interior) solution. Then* a^c *is increasing in* U_S *(the payoff to a single successful firm) and it is decreasing in* U_{SS} *(the payoff when both firms are successful). Furthermore, if* $R \equiv U_{SS}/U_S$ *, then* a^c *is decreasing in* R *.*

Proof. Let $\phi_i(a_1, a_2; U_S, U_{SS}) = 0$ denote the FOC in equation (5) ($i = 1,2$), such that the symmetric Nash equilibrium is the solution to $\phi_i(a^c, a^c; U_S, U_{SS}) = 0$. From standard comparative statics one can then establish that $sign\left(\partial a^c/\partial U_S\right) = sign\left(\partial \phi_i/\partial U_S\right)$ and $sign\left(\partial a^c/\partial U_{SS}\right) = sign\left(\partial \phi_i/\partial U_{SS}\right)$. Furthermore, $\partial \phi_i/\partial U_{SS} = \partial prob(S,S)/\partial a_i\big|_{a_1=a^c, a_2=a^c} < 0$ and $\partial \phi_i/\partial U_S = \partial prob(S,F)/\partial a_i\big|_{a_1=a^c, a_2=a^c} > 0$. The first inequality follows directly from Assumption 1, and the second inequality follows from the fact that equation (5) holds. Similarly, $sign\left(\partial a^c/\partial R\right) = sign\left(\partial \phi_i/\partial R\right)$ and $\partial \phi_i/\partial R =$

$\partial prob(S,S)/\partial a_i\big|_{(a_1=a^c, a_2=a^c)} < 0$. ■

The important implication here is that anything that increases the payoffs in the event of a single successful firm without changing the payoff in the event of both firms succeeding will tend to decrease the correlation of the firms' equilibrium choices. Similarly, decreasing the payoff when both firms succeed while keeping the payoffs in other events constant decreases the correlation of choices as well. This will be the basis for proving our main conclusion—that having different modes of IPR protection may lead to a more desirable outcome vis-à-vis the differentiation of firms' research projects.

3. The Model with Patents and Trade Secrets

To add an explicit consideration of alternative modes of protection, we continue to assume that research outcomes are common knowledge. The game tree is depicted in Figure 1. Note that this extends the one-shot game discussed earlier by the addition of an IP subgame. What were exogenous payoffs in Dasgupta and Maskin (1987) are made a function of IP choices along the lines of Denicolò and Franzoni (2004). Specifically, the winner of the research stage chooses between a patent and trade secret protection. The patent provides $T < \infty$ periods of absolute monopoly. If we were to interpret the social payoff B as the present value of a perpetual flow of benefits, then $B = \int_0^\infty be^{-rt}dt = \frac{b}{r}$, where b is the per-period benefit and r is the discount rate. Assuming, for simplicity, that the patentee can capture the entire social surplus while the patent is valid, a patent lasting T periods provides a return of $\int_0^T be^{-rt}dt$. The reward from the patent protection can therefore be written as $\delta(T)B$, where

$$\delta(T) \equiv (1 - e^{-rT}) \tag{6}$$

denotes the fraction of total social surplus captured by the patentee.[5] We write $\delta(T)$ to emphasize that the reward offered by patents depends on a policy variable, the patent length T.

The protection offered by trade secrets, rooted in civil law, can provide an alternative way to secure a temporary monopoly. Unlike the case of patents, the monopoly is of random duration and ends whenever other firms independently invent or reverse-engineer the invention, i.e., when the secret leaks out (Friedman, Landes, and Posner, 1991). Assuming an exponential distribution for the duration of the trade secret, the payoff in this case can be written as $\int_0^\infty be^{-(z+r)t}dt$, where the hazard rate z indexes the difficulty of concealing the invention (that is, e^{-zt} is the probability that the secret will not leak out by time t). Thus, the reward from trade secret protection can be written as $\gamma(z)B$, where

$$\gamma(z) \equiv \frac{r}{r+z} \tag{7}$$

represents the fraction of total social surplus that can be captured under trade secrecy protection. We write $\gamma(z)$ to emphasize that the strength of protection offered by trade secrets depends on the hazard rate $z \geq 0$. Furthermore, the value of trade secrets as an IPR protection instrument depends on the provisions established by law (mostly state law in the United States). Thus, in this setting the parameter z also can be considered a policy instrument.[6]

The loser of the R&D race gets zero payoff from its research activity. Furthermore, without loss of generality, in what follows we normalize the social benefit of success to $B = 1$.

3.1. Equilibria in the IP Subgame

To find the subgame perfect Nash equilibrium of the game depicted in Figure 1, we begin with the subgames that start when R&D outcomes become known. Once the equilibrium payoffs from the IP subgames are determined, the game reduces to the one in Dasgupta and Maskin (1987) discussed earlier. For three of the possible four outcomes the situation is trivial. For the event (F, F), where both firms fail to innovate, the game ends with both firms obtaining a zero payoff. For the events (S, F) and (F, S), on the other hand, only one firm succeeds. The successful firm can obtain payoff $\delta(T)$ with patenting and payoff $\gamma(z)$ with trade secrecy, and thus the IP choice revolves around $\max\{\gamma(z), \delta(T)\}$. The unsuccessful firm gets zero payoff.

For event (S, S), when both firms are successful with the invention, we have a simultaneous-move game for the firms' choice of IP protection mode. We assume that if both firms try to patent, each has an equal chance of getting priority. If both choose trade secret protection, they will engage in a

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[5] We assume that the social and private discount rates are identical, but this condition could easily be relaxed.

[6] As in Denicolò and Franzoni (2004), the parameter r could also account for the arrival rate of an alternative discovery that supersedes the technology. Under this interpretation, one may expect r to be higher under the patent choice than under secrecy, because the information disclosure required by patents may be useful in the research for a superior innovation. Here we abstract from such generalizations.

duopoly competition as long as the secret does not leak out.[7] If one of the firms decides to keep secret, it can of course be excluded whenever the other inventor decides to patent (the patenting firm would get the full reward). Finally, the parameter $\mu \in (0,1)$ captures the profit dissipation due to the competition that arises when both firms elect to use trade secrets (e.g., the joint profit of duopolists is lower than that of a monopolist).

Note that if $\delta(T) > \frac{\mu}{2}\gamma(z)$, the profile (Patent, Patent) is the unique Nash equilibrium. In particular, if $\mu\gamma(z) \leq \delta(T)$, this equilibrium is Pareto efficient. If $\frac{\mu}{2}\gamma(z) < \delta(T) < \mu\gamma(z)$, the IP game is of the prisoner's dilemma type and the unique Nash equilibrium (Patent, Patent) yields a lower payoff (to both firms) than the profile (Secret, Secret). If $\delta(T) \leq \frac{\mu}{2}\gamma(z)$, on the other hand, we have a coordination game that admits two pure-strategy Nash equilibria, i.e., the profiles in which both firms patent and that in which both firms choose the trade secret. In this case, we also have a mixed-strategy Nash equilibrium. Specifically, whenever $\delta(T) < \frac{\mu}{2}\gamma(z)$, the (symmetric) non-degenerate mixed-strategy equilibrium is defined by $\sigma^* = \left[\delta(T)/\left(\mu\gamma(z) - \delta(T)\right)\right]$ for both players, where σ^* denotes the probability assigned to the pure-strategy "secret" (such that $1-\sigma^*$ is the probability assigned to the pure-strategy "patent").[8] We can summarize the foregoing analysis in the following.

Lemma 2. *In the IP subgame that follows the event (S,S): (i) For $\delta(T) \geq \mu\gamma(z)$ there is a unique Nash equilibrium where both firms patent, and this equilibrium is Pareto efficient. (ii) For $\mu\gamma(z) > \delta(T) > \mu\gamma(z)/2$ there is a unique Nash equilibrium where both firms patent, and this equilibrium*

[7] We are implicitly assuming that the probability distribution of the trade secret duration does not depend on the number of secret holders.

[8] The mixed-strategy solution is somewhat unappealing in our context because it implies that as the strategy profile in which both firms patent becomes less and less attractive, in equilibrium each firm puts more probability mass on the "patent" strategy.

is of the prisoner's dilemma type. (iii) For $\mu\gamma(z)/2 \geq \delta(T)$ *there are two pure-strategy equilibria—(Patent, Patent) and (Secret, Secret)—and a mixed-strategy equilibrium.*

Table 1 summarizes the equilibrium outcomes of the IP subgame. Note that, as μ decreases towards 0 (i.e., the market competition between firms when both hold the trade secret dissipates profits more and more), the range of the parameter where (Patent, Patent) is the unique Nash equilibrium increases (in particular, the range for UNE-1 increases and that for UNE-2 decreases). Furthermore, the range of parameters where multiple equilibria arise also shrinks.

3.2. Impact on Firms' Research Paths

By introducing alternative modes of protection, we have made otherwise exogenous payoffs a function of IP choices. Once the payoffs associated with the equilibria discussed in Lemma 2 are obtained, the reduced game has the same structure as the one in Dasgupta and Maskin (1987). We can then exploit the comparative statics analysis that we discussed in Lemma 1 to obtain comparisons of alternative IP environments. Specifically, we can conclude the following.

Proposition 2. *Whenever* $\mu \in (0,1)$ *and* $\delta(T) < \gamma(z)$, *the availability of trade secret protection, in addition to patents, leads firms to select actions that decrease the correlation of R&D outcomes, as compared with the patent-only environment, although the correlation level still remains higher than the socially optimal level.*

Proof. The equilibrium payoffs of the IP subgame, under the patents-plus-trade-secret environment, are summarized in the last two columns of Table 1. In contrast, recall that, in the patents-only environment, the expected payoff to the firms for the event (S,S) is $U_{SS}^{P} = \frac{1}{2}\delta(T)$ and the payoff to the successful firm for events (S,F) and (F,S) is $U_{S}^{P} = \delta(T)$. Hence, for the parameter range $\gamma(z) > \delta(T) > \mu\gamma(z)/2$, the availability of trade secret protection (in addition to patents) increases the winner's payoff for the events with only one successful firm while it leaves unchanged the payoff for the event when both firms succeed. By Lemma 1, therefore, the equilibrium correlation level must decline (i.e., the Nash equilibrium action a^c increases. For the parameter range $\mu\gamma(z)/2 \geq \delta(T)$ the payoff associated with the event (S,S) depends on which particular equilibrium one considers. For the (Patent, Patent) equilibrium the outcome is exactly as for the $\gamma(z) > \delta(T) > \mu\gamma(z)/2$ parameter range. For the (Secret, Secret) equilibrium, the equilibrium payoffs under patent-plus-trade-secret environment is $U_{SS}^{P+S} = \frac{\mu}{2}\gamma(z)$ for event (S,S) and $U_S^{P+S} = \gamma(z)$ for the events with a single successful firm. Then, $\left(U_{SS}^{P+S} / U_S^{P+S}\right) = \frac{\mu}{2} < \left(U_{SS}^P / U_S^P\right) = \frac{1}{2}$ because $\mu \in (0,1)$, and hence the results of Lemma 1 apply to this domain as well. Finally, the mixed-strategy equilibrium payoff under event (S,S) cannot exceed that of the equilibrium (Secret, Secret), and therefore we again conclude that $\left(U_{SS}^{P+S} / U_S^{P+S}\right) < \left(U_{SS}^P / U_S^P\right)$. By Lemma 1, therefore, the equilibrium correlation level must decline.■

The equilibrium R&D choices of the firms, for the various regions of the parameter space that we discussed, are illustrated in Figure 2. Note that whenever $\delta(T) < \gamma(z)$, (Patent, Patent) is a Nash equilibrium of the IP subgame. For this equilibrium the ratio U_{SS}^{P+S} / U_S^{P+S} is monotonically increasing in $\delta(T)$, and so the equilibrium competitive action for this environment, labeled a_{P+S}^c, is decreasing (i.e., R&D projects are more and more correlated). For the subset $\left(\mu\gamma(z)/2\right) < \delta(T) < \gamma(z)$ of this parameter range, the profile (Patent, Patent) is actually the unique Nash equilibrium, and the associated graph of a_{P+S}^c is represented by the green segment in Figure 2. When $\delta(T) = \gamma(z)$ the payoff ratio reaches its maximum value of $\frac{1}{2}$; this is the same as the patent-only environment, and thus $a_{P+S}^c = a_P^c$ for $\delta(T) \geq \gamma(z)$. For the domain $\delta(T) \leq \mu\gamma(z)/2$ we have two Nash equilibria in pure strategies. If the firms could coordinate on the (Secret, Secret) equilibrium, the payoff ratio would be $\left(U_{SS}^{P+S} / U_{S}^{P+S}\right) = \frac{\mu}{2} < \frac{1}{2}$, leading to the equilibrium outcome that equals the value of the solution in a hypothetical trade-secret-only environment, labeled a_S^c in Figure 2. Note that the trade-secret-only environment would lead to an equilibrium correlation level that is lower than the patent-only environment. In fact, it is even lower than the equilibrium correlation level under the patent-plus-secrecy environment whenever $\delta(T) > \mu\gamma(z)$. For the parameter range $\delta(T) \le \mu\gamma(z)/2$ we also have a mixed-strategy Nash equilibrium, the equilibrium outcome of which is depicted by the red segment.

We should stress that the main point of Proposition 2 does not rely on the assumption that $\mu < 1$. Indeed, were one to make the (questionable) assumption that $\mu = 1$, the parameter range $\left(\gamma(z)/2\right) < \delta(T) < \gamma(z)$ would still support our conclusion (see Figure 2). The parameter space associated with a unique equilibrium in the IP subgame could be extended by appealing to notions that select among pure-strategy Nash equilibria. Particularly attractive, in our case, is the notion of risk-dominant equilibrium (RDE) introduced by Harsanyi and Selten (1988). In our 2×2 symmetric game, if both players strictly prefer the same action when each assumes that the opponent randomizes evenly between the two available actions, then the profile in which they play that action is the RDE (Fudenberg and Tirole, 1991).[9] It follows that, if $\frac{\mu}{3}\gamma(z) < \delta(T) \le \frac{\mu}{2}\gamma(z)$, then the profile (Patent, Patent) is the (unique) RDE, thereby extending the parameter range whereby the competitively chosen diversification efforts are decreasing in $\gamma(z)$ (i.e., the green segment in Figure 2). Conversely, if $\delta(T) < \frac{\mu}{3}\gamma(z)$, the RDE profile is (Secret, Secret) and, for the case $\delta(T) = \frac{\mu}{3}\gamma(z)$, neither pure-strategy equilibrium is dominating (which makes the mixed-strategy equilibrium perhaps more meaningful at this point).

[9] The basic idea is that, when a player does not know which equilibrium is selected by the other player, she will play the strategy of the less risky equilibrium. Risk-dominance as an equilibrium selection criterion in 2×2 games also is supported by the global games analysis of Carlsson and van Damme (1993), the results of which are extended to supermodular games by Frankel, Morris, and Pauzner (2003).

An additional result that is worth emphasizing in this model concerns the ability of the social planner to affect firms' choices by altering the parameters T and z that index the strength of IPR protection.

Proposition 3. *In the patent-only environment the social planner cannot affect the firms' R&D diversification choices by choosing the patent length T. In the patent-plus-trade-secret environment, on the other hand, the social planner may be able to induce firms to diversify toward the social optimum by providing a relatively weaker protection to patents (or stronger protection to trade secrets).*

Proof. The first part of the proposition follows directly from observing that, in the patent-only environment, the payoff ratio $\left(U_{SS}^{P} / U_{S}^{P}\right) = \frac{1}{2}$ is independent of patent length T. In the patent-plus-secrecy environment, on the other hand, a_{P+S}^{c} monotonically increases as T decreases for the unique Nash equilibrium of the parameter range $\gamma(z) > \delta(T) > \mu\gamma(z)/2$. ■

For a similar argument, the social planner cannot affect R&D correlation in the other polar case, the trade-secret-only environment, by choosing the strength of trade secret protection (as indexed by the leak parameter z). Hence, in our setting, the strength of IPR protection can be an effective policy instrument, to affect the firms' equilibrium R&D correlation level, only if multiple protection instruments are available. Thus, our analysis provides another justification for the optimality of a finite patent length, distinct from the classic trade-off between dynamic incentive benefits and static efficiency losses analyzed by Nordhaus (1969) and others.

4. An Example

The relationship between the equilibrium correlation levels, the different values of the leak parameter, and the behavior of the correlation level under different solution concepts as patent length varies can be illustrated with the following example. First, we parameterize the correlation coefficient as $\rho \equiv 1-\frac{1}{2}(a_1+a_2)$. Thus, as in Dasgupta and Maskin (1987), we consider the case of non-negative correlation only. Next, the unconditional probability functions are specified as $p_i(a_i)=\frac{1}{4}-\frac{1}{8}a_i^2$. Note that this implies $p_i(a_i)\in[0,\frac{1}{2}]$ and, given our parameterization of correlation, the condition $p_i(a_i)\in[0,\frac{1}{2}]$ is sufficient to ensure that the covariance term is decreasing in the actions a_1 and a_2. Thus, this parameterization satisfies the basic assumptions of our model. The resulting social planner's objective function, equation (2), is in fact concave for the domain of interest. To solve for the firms' noncooperative choices, we set $r=0.04$ and, consistent with the assumed normalization $B=1$, set $b=r$. Finally, we set $\mu=8/9$ (as would result, for example, from a textbook example of Cournot competition with linear demands).

Having computed the optimal R&D choices, in Figure 3 we report the implied correlation coefficient ρ under various conditions regarding $\gamma(z)$ and $\delta(T)$. Specifically, here we fix the patent length as $T=20$ years (as is the case in virtually all jurisdictions), so that the fraction of social surplus that is offered by patent protection is $\delta(20)=0.55$, and then consider various levels of the trade secret parameter $\gamma(z)$. The socially optimal correlation level for this example turns out to be $\rho^*=0.48$. If IPR protection were available only through patents, the firms' noncooperative action choices would result in $\rho^P=0.76$. When trade secrets are available, in addition to patents, then we need to differentiate according to the parameter space. For values of z such that $\gamma(z)\le\delta(20)$, trade secret protection is not effective and the correlation level is calculated as $\rho^{P+S}=\rho^P=0.76$. When $\gamma(z)$ exceeds $\delta(20)$, trade secret protection becomes relevant and the Nash equilibrium correlation level decreases, reaching a minimum of 0.63 (when $\gamma(z)=1$). For the range $\delta(20)<\gamma(z)\le 1$, the profile in which both firms patent is actually the unique Nash equilibrium. In fact, given the chosen levels of the parameters, here it is always the case that $\frac{\mu}{2}\gamma(z)<\delta(20)$, $\forall z\in[0,\infty)$ and $\forall\mu\in(0,1)$, and thus the case of multiple equilibria for the IP subgame does not arise. This equilibrium is of the prisoner's dilemma type for $\gamma(z) > \delta(20)/\mu$, that is, for $\gamma(z) > 0.62$. Thus, the profit-dissipation parameter $\mu \in (0,1)$ does not affect ρ^{P+S} in Figure 3 but affects only the hypothetical correlation level that would attain in the trade-secret-only environment, say, ρ^S and, from the foregoing, $\rho^S = 0.73 < \rho^P$.

5. Conclusion

We have shown that the availability of multiple modes of protection—specifically trade secrets and patents—can affect the equilibrium outcome of competitively chosen diversification efforts in a parallel research contest. In particular, the availability of trade secrets in addition to patents can push the market outcome toward the social optimum as far as the choice of correlation among R&D projects is concerned. Therefore, considering a generic winner-takes-all contest (with an implicit single mode of protection) in studying the correlation level of firms' R&D activities may miss an important institutional feature and may overestimate the bias inherent in competitive parallel research contests.

Another implication of the model that we have studied is that it is only when multiple modes of protection are present that the competitively chosen R&D diversification efforts can be affected by the patent length. In reality, of course, patent length is fixed by law and, following the implementation of the TRIPS agreement of the World Trade Organization, it is the same (20 years) for all signatory countries. But what matters here is the strength of IPR protection offered by patents relative to that of trade secrets, and the latter are quite a bit more variable because they are rooted in civil law. Furthermore, the strength of trade secret protection may vary across technology fields because it depends crucially on the feasibility of reverse engineering (admissible under trade secret protection). Hence, in some fields at least, the availability of trade secret protection may be critical for the nature of competitively chosen R&D activities and may beneficially affect firms' R&D diversification efforts.

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Table 1. Parametric Domain, Equilibrium IP Strategies, and Outcomes with Both Patents and Trade Secrets

Parametric domain	Event (S,S): both firms are successful			Events (S,F) or (F,S)
	Equilibrium profile(s)	Type of equilibrium	Equilibrium payoff(s)	Winner's payoff
$\delta(T) \geq \gamma(z)$	(Patent , Patent)	UNE-1	$\frac{1}{2}\delta(T)$	$\delta(T)$
$\gamma(z) > \delta(T) \geq \mu\gamma(z)$	(Patent , Patent)	UNE-1	$\frac{1}{2}\delta(T)$	$\gamma(z)$
$\mu\gamma(z) > \delta(T) > \mu\gamma(z)/2$	(Patent , Patent)	UNE-2	$\frac{1}{2}\delta(T)$	$\gamma(z)$
$\mu\gamma(z)/2 \geq \delta(T)$	(Patent , Patent) (Secret , Secret) $(\sigma^*, 1-\sigma^*)$	MNE	$\frac{1}{2}\delta(T)$ $\frac{\mu}{2}\gamma(z)$ $\frac{\mu\gamma(z)\delta(T)}{2(\mu\gamma(z)-\delta(T))}$	$\gamma(z)$

Notes: UNE-1 = Unique Nash equilibrium (Pareto efficient);
UNE-2 = Unique Nash equilibrium (prisoner's dilemma);
MNE = Multiple Nash equilibria, where the mixed-strategy equilibrium is $\sigma^* = \frac{\delta(T)}{\mu\gamma(z)-\delta(T)}$.

Figure 1.The Model with Patents and Trade Secrets

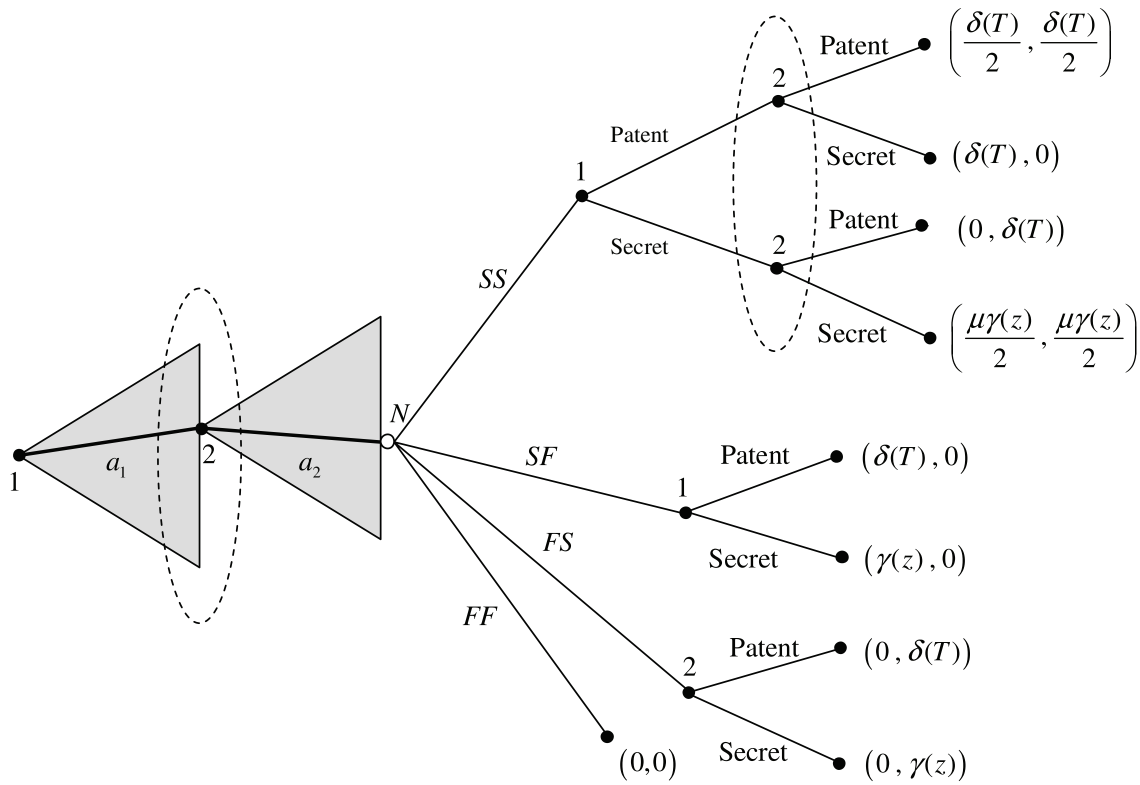

Figure 2. Correlation of R&D Projects and Solution Concepts

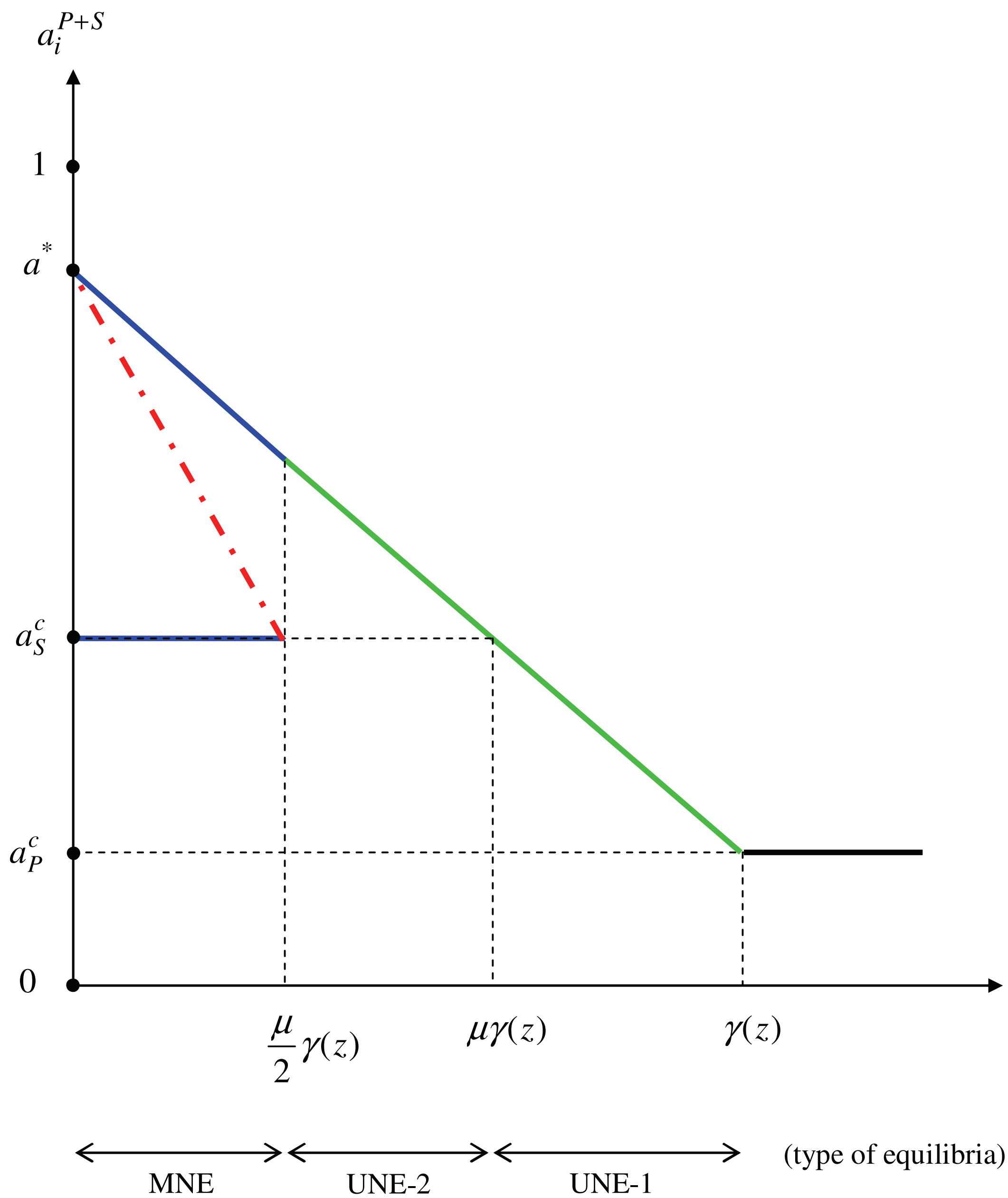

Figure 3. R&D Correlation with Patents and Trade Secrets