Strategies for pairwise competitions in markets and organizations

Bradford Cornell*

and

Richard Roll**

Biologists' models of competition among animals are useful for understanding human conflict. Such models are explained and applied here to examples of market and organizational behavior. An equilibrium strategy for securities trading, for instance, can consist of accepting the market price on some occasions while investing resources in security analysis on others. An organizational example involves seniority. As a device for settling conflicts within an organization, seniority can be adopted voluntarily by all participants, even if it is wholly unrelated to ability.

1. Introduction

■ Maynard Smith, in a series of papers on animal conflicts (1973, 1974, 1976), developed the concept of an evolutionary stable strategy, or ESS. Evolutionary stable strategies are equilibrium "solutions" to gaming problems akin to the Nash solution. Though stable strategies can be studied in a general setting, closed form solutions have been derived only for specific cases.[1] Fortunately, solutions do exist for a class of games of potential interest to economists and organizational theorists.

In this paper we focus on pairwise competitions which are two-person games with an added wrinkle. Instead of knowing who his opponent will be, a contestant knows only that his opponent will be randomly selected from a given population. Examples are two male antelopes competing for a mating ground or two Congressmen competing for a committee chairmanship.

We formally define an ESS in the next section and apply the solution concept to a simple problem. The model is expanded in Section 3 by the introduction of uncorrelated asymmetries. With this addition we investigate the role

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* University of California, Los Angeles.

** University of California, Los Angeles.

The suggestions and comments of Nai-fu Chen, Robert Geske, Jack Hirshleifer, and John Riley are gratefully acknowledged. We also benefited from the opportunity to present these results at the Virginia Polytechnic Institute and State University and at the University of Oregon. Although the individuals and participants above were most generous in their encouragement and should be partly credited with anything herein that pleases the reader, the authors alone are to be blamed for anything that elicits an opposite reaction.

[1] See Haigh (1974) and Riley (1979) for further discussion of the general properties of an ESS.

of seniority in organizations and the role of security analysis in competitive capital markets. A summary of our results is presented in the final section and possible extensions to other applications are discussed.

2. Evolutionary stable strategies

■ A strategy is a specification of individual behavior in a contest. If, for example, the decision variable is the time an employee spends seeking a promotion, his strategy would specify the number of hours he invests against any particular opponent. If the population of potential competitors is homogeneous, the contests are said to be symmetrical, and each individual will behave identically in all contests. If the population is heterogeneous, then a strategy must specify what a contestant would do against every possible opponent. For instance, if members of an organization are ranked according to their seniority, a strategy would then state the hours invested in contests against an opponent with any particular amount of seniority.

Let I denote the strategy of one player and J denote the strategy of his opponent. The expected utility, or payoff, of playing I against J is denoted by $E(I|J)$. Maynard Smith defined a stable strategy as one for which either

$$\text{(i)} \qquad E(I|I) > E(J|I) \qquad \text{for all } J, \text{ or} \tag{1}$$

$$\text{(ii)} \qquad \text{if } E(I|I) = E(J|I) \qquad \text{for some } J, \qquad \text{then} \qquad E(I|J) > E(J|J). \tag{2}$$

Recently, Hirshliefer and Riley (1978) have shown that there is a third situation in which a strategy can be stable. They prove that a population using I will still be dynamically stable, even when $E(I|I) = E(J|I)$ and $E(I|J) = E(J|J)$ if there exists a third strategy K such that

$$\text{(iii)} \qquad \begin{cases} E(I|K) > E(J|K) \\ E(K|J) > E(J|J). \end{cases} \tag{3}$$

Hirshleifer and Riley call (iii) a "roundabout" ESS.

If an agent is facing competitors from a population whose members employ strategy I, then the condition,

$$E(I|I) \geq E(J|I) \qquad \forall J, \tag{4}$$

is the familiar Nash equilibrium. If (4) holds, no agent has a motive for employing any strategy other than I. Maynard Smith's addition of the criterion that $E(I|J) > E(J|J)$ when $E(I|I) = E(J|I)$ selects those Nash equilibria that are "secure from invasion."

Consider, for instance, a population in which all members employ strategy I. If a "mutant" appears and employs strategy J, he will not be at a selective disadvantage as long as $E(I|I) = E(J|I)$. Once a second mutant appears, however, Maynard Smith's condition, given by (2), implies that the mutant strategy is now inferior. The more numerous the mutants, the greater the selective pressure against them.

This property of an ESS is illustrated by a simple example. Imagine a large homogeneous population whose members compete pairwise for a prize with a present value of v. The individual's strategy is defined by a maximum amount of resources, t, that he budgets for the competition. The victor in any contest is the participant who is willing to make the largest investment. Thus, if two contestants are willing to invest up to t_1 and t_2, respectively, where $t_1 > t_2$, the payoff to the first contestant will be $v - t_2$, while to the second it will be $-t_2$. The contest ends when one contestant refuses to continue,[2] at which point his opponent wins the prize without having to make any further investment. (For this reason, the winner's cost is $-t_2$, not $-t_1$.)

In equilibrium, all agents will select the randomized strategy described by an exponential probability distribution,

$$I = \left\{ p(t) = \frac{1}{v} e^{-t/v} \right\}, \tag{5}$$

where $p(t)$ is the probability in a given contest of choosing to invest a maximum of t. (See Hines (1977) for a proof.) Suppose that all members of the population are employing I. For any competing strategy J, simple integration shows that $E(J|I) = 0$. Thus, there would be no selective pressure against a mutant who appeared in the population and employed some alternative strategy. However, I dominates J in contests against any other mutants because $E(I|J) > E(J|J)$ for all J. (Again see Hines (1977) for the proof.) Thus, I is an ESS.

The equilibrium strategy given by (5) can be interpreted in two ways. Either all individuals employ the randomized strategy, or the strategies employed by different individuals must be cross sectionally distributed according to (5).[3] Because opponents are randomly drawn from the population, a contestant would view both situations identically. In terms of social theory, however, the second interpretation is probably more relevant. Individuals are likely to fix a maximum time they are willing to spend seeking promotion or a similar reward, rather than to employ a randomized strategy. The system as a whole will then come into equilibrium when the cross sectional distribution of effort is exponential.

The equilibrium given by (5) also implies a "zero profit" condition. Since $E(J|I) = 0 \ \forall J$, the expected gain from playing any strategy against I (including I itself) is zero. By raising his level of investment, a contestant can increase his probability of winning, but he also increases the net cost if he loses. In equilibrium, the two effects are offsetting, leading to an expected gain of zero, independent of the strategy. This also implies that the total expected expenditure of resources by both competitors is equal to the value of the prize or

$$2E(t) = v.$$

If conflicts could be resolved without this cost, the welfare of everyone would be improved. Furthermore, since the population is homogeneous, settling disputes by flipping a coin, or using any similar randomized technique, would be superior. As we shall see, it is possible that mechanisms analogous to coin flipping can evolve naturally, but it is first necessary to assume that members of the population can be distinguished.

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[2] For obvious reasons Maynard Smith (1974) called such a contest a "war of attrition."

[3] Strictly speaking, a continuous mixed strategy followed by each individual contestant can be equivalent to the population's being cross sectionally distributed according to the same probability distribution only if the population is infinite. For finite populations, some conceptual, and perhaps practically relevant, problems are associated with stable equilibria. Cf. Riley (1979).

3. Uncorrelated asymmetries

■ We begin by introducing a particular type of heterogeneity into the population. It is assumed that the two contestants in every conflict can be distinguished by a given characteristic. The characteristic is such that one contestant, and only one, possesses it. Furthermore, the characteristic is assumed to provide no direct benefits to its bearer. It affects neither the payoffs nor the probability of victory if a struggle ensues. For this reason, biologists have called such characteristics uncorrelated asymmetries. A good example is first arrival at a location. Two competitors can be distinguished by who arrived first, even though arrival time may be uncorrelated with both the payoff for victory and competitive skill.

Despite its apparent irrelevance, the existence of an uncorrelated asymmetry changes fundamentally the stable strategy. As an example, consider the case where the characteristic is equally likely to be conferred on either contestant. Let S be the strategy defined by:

$$S = \begin{Bmatrix} \text{(i)} & \text{if your opponent has characteristic } s \text{ (and thus you do not), play } 0; \\ \text{(ii)} & \text{otherwise, play } T > v. \end{Bmatrix}.$$

Clearly, $E(S|S) = v/2)$. If the alternative to S is to disregard the characteristic and play a fixed value of t, then denoting this alternative strategy by J,

$$\text{if} \quad t < T, \quad \text{then} \quad E(J|S) = (v - t)/2$$

$$\text{if} \quad t > T, \quad \text{then} \quad E(J|S) = v - T/2.$$

Since $T > v$, $E(S|S) > E(J|S)$ for all pure strategies, and hence $E(S|S) > E(K|S)$ for any randomized strategy K. In particular, for the strategy I defined by (5), which disregards the characteristic,

$$E(I|S) = v/2 + (2ve^{-T/v} - v)/2 < v/2 = E(S|S),$$

so that the old strategy I is no longer stable. The new equilibrium strategy is not necessarily S; consider an alternative S' which is the same as S, except that $T' < v$ is played when the opponent does not possess the characteristic s. Using the "roundabout" definition of an ESS, it can be shown that S beats S' with the intermediate (pure) strategy, $\{\text{play } T' + \epsilon\}$, but there may be other alternatives which we have not yet discovered that are stable against S.[4]

If the characteristic, s, is arrival time, then the stable strategy reduces to first come, first served. It is not surprising that biologists are interested in this form of the model, because a large number of animal conflicts, involving issues as important as mate selection via territorial rights, are settled on the basis of arrival time. In human society, the use of queues to allocate resources can be interpreted analogously. The next place in line is the reward, and the two contestants are the first and second arrivals. The equilibrium strategy is for the latecomer to defer. Such a strategy may be justified because it is regarded as equitable. The model demonstrates, however, that a first-come, first-served mechanism will be self-sustaining even if the population is composed of selfish

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[4] We are indebted to John Riley for bringing the S' alternative to our attention and to Jack Hirshleifer for showing that the "roundabout" definition would save S against S' after all.

individuals (selfish in the sense that the well-being of others does not enter anyone's utility function).[5]

When conflict resolution is based on arrival time, or on any other uncorrelated asymmetry, the costs of conflict are eliminated. Based on the signal provided by the uncorrelated asymmetry, one of the contestants withdraws without an investment of resources. Such a mechanism will not produce an inefficient allocation of rewards because all members of the population are assumed to be equally talented.

Finally, it should be noted that the symmetry of the problem implies that there will always be two equilibrium strategies. In the case where s is arrival time, for instance, the characteristic can denote either first or second arrival. This last-come, first-served will also be a stable strategy. The fact that such an allocation mechanism is rarely observed indicates that other factors, not included in this simple model, influence the equilibrium toward which the system converges.[6]

These conclusions about an uncorrelated asymmetry depend critically on a strong ordering of individuals in every conflict. Any characteristic which ranks the two individuals could serve; but a critical element is the impossibility of ties. In every conflict, both individuals cannot possess the characteristic and both cannot be without it.

To demonstrate the difference that obtains when ties are possible, suppose that the characteristic "belongs" to the individual (e.g., s = male, or brown eyes, or registered voter, or full professor); but again, assume that it provides no benefit in the conflict. For simplicity, suppose also that s is possessed by exactly half the population, and that individuals are selected randomly for each contest. In this case, and when both contestants employ the previously defined strategy, the payoff matrix to contestant "a" is shown in Table 1. Since each of the four outcomes is equally likely, $E(S|S) = v/2 - T/4$. The old strategy I defined by (5) now becomes relatively attractive. In fact, we find that $f(T) \equiv E(I|S) - E(S|S) = (2ve^{-T/v} - v)/2 + T/4$. It is easy to show that the minimum of $f(T)$ occurs for $T/v = \log_e (4)$ and that $f[v \log_e (4)] > 0$. This proves that I remains stable against S.

We might have predicted this result because I was previously shown to be stable against any randomized strategy. When both contestants have some probability of possessing the characteristic, strategy S in effect becomes randomized. When the characteristic can be possessed by only one player, however, the two players' actions are perfectly (negatively) correlated in every conflict. This is, of course, just the opposite of a randomized strategy.

Strategy I will itself *not* be the equilibrium stable strategy if mixtures of I and S are permitted. For instance, consider the strategy $K \equiv$ {play S if only one of the two contestants possesses the characteristic s, otherwise play I}. It is

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[5] It could be argued that the first-come, first-served strategy is regarded as equitable *because* it is stable. Once the system is entrenched, moral explanations may be concocted to rationalize it.

[6] One such mechanism, suggested to us by Robert Geske, is a cost of reshuffling the established hierarchy. If deference is to the latecomer, every old member of the queue must be moved downward one position; but if the newcomer ranks last, the relative positions of previous arrivals are unaltered. Reshuffling could be very costly, especially where upward movement is infrequent such as in organizational job hierarchies.

TABLE 1

		CONTESTANT b	
		s	NO s
CONTESTANT a	s	$\frac{1}{2}$v	v
	NO s	0	$\frac{1}{2}$v − T

easy to show that $E(K|K) = v/4$ and that $E(I|K) = ve^{-T/v}/2$. Thus, K dominates I (since $T > v$). Similarly, $E(S|K) = v/4$ but $E(K|S) - E(S|S) = e^{-T/v}/2 + (T - v)/4 > 0$, and thus K dominates S. Again, however, K will be dominated if strategies are permitted which entail further rules. For example, if instead of playing I when both contestants possess the characteristic, a coin were flipped to determine the winner, conflict costs would be eliminated. This reverts the contest to the case of a pure uncorrelated asymmetry.

The uncorrelated asymmetry model can be generalized easily. Assume that s can take on a range of values and that all individuals can be ordered according to their level of s. Defining $P(s_0)$ to be the fraction of individuals in the population for whom $s < s_0$, the strategy S^* for an individual possessing level s_0 is defined by

$$S^* = \begin{Bmatrix} \text{(i)} & \text{if your opponent has } s > s_0, \text{ play zero;} \\ \text{(ii)} & \text{otherwise, play } T > v. \end{Bmatrix}$$

S^* will be an equilibrium strategy. To see this, consider the result of playing S^* against S^*:

$$E(S^*|S^*) = P(s_0)v.$$

An individual of level s_0 who employs strategy $J \equiv$ {play a fixed level t} will have the following payoffs,

$$\text{if} \quad t < T, \quad \text{then} \quad E(J|S^*) = P(s_0)v - (1 - P(s_0))t$$

$$\text{if} \quad t > T, \quad \text{then} \quad E(J|S^*) = v - (1 - P(s_0))T.$$

For $t < T$, S^* clearly dominates, while for $t > T$,

$$E(S^*|S^*) - E(J|S^*) = (1 - P(s_0))(T - v) > 0. \tag{6}$$

Since (6) holds for arbitrary values of s_0, and for any pure strategy J, we have proved that S^* is an equilibrium strategy. It should be noted that symmetry considerations again imply that the dual strategy of deferring to individuals with lower s is also stable.

When s is interpreted to be seniority, the model offers some interesting insights into the role of seniority systems in institutions like the United States Congress. First, it demonstrates that seniority systems may be the natural result of competition among otherwise homogeneous individuals. Secondly, it rebuts the view that a seniority system should be scrapped if seniority is found to be uncorrelated with performance. The benefits of conflict resolution on the basis of uncorrelated asymmetries come not from the fact that the appropriate individuals are selected for promotion (with a homogeneous population, this question is irrelevant), but from the fact that conflicts are settled at zero cost.

This supports the often stated view that the seniority system has facilitated the operation of Congress by reducing internal strife.

It may seem implausible that individuals who have low seniority, and hence know that they will lose the great majority of the contests, would continue to employ strategy S^*. A closer look at the derivation leading to (6), however, reveals that they have no choice. A contestant who accepts his low seniority will rarely be selected for advancement, but if he employs S^*, at least his costs will be zero. If he employs any other strategy which invests less than T, he will simply be squandering resources without winning any additional contests. By investing more than T, he will win every contest, but each victory results in a net loss because of the large required investment. Thus, there is no way that the low seniority individual can improve his position as long as other members of the population employ S^*. Only by forming a coalition with other low seniority people and attacking the rationality of S^* could he increase expected utility. Unfortunately, the dynamics of coalition formation cannot be analyzed in the context of the pairwise model.

☐ **Differential qualifications.** In situations where abilities differ and the differences are observable, the obvious strategy of deferring to more talented individuals proves to be stable. To model differences in productivity, we assume that to invest t units in a contest, an individual must expend γt, where $\gamma \geq 1$.

Consider the strategy G given by:

$$G \equiv \left\{ \begin{array}{ll} \text{(i)} & \text{if your opponent has a smaller } \gamma \text{ (is more productive), play zero;} \\ \text{(ii)} & \text{if your opponent has a larger } \gamma \text{, play } T \text{ such that } \gamma_0 T > v, \\ & \text{where } \gamma_0 \text{ is your productivity level.} \end{array} \right\}$$

Letting $P(\gamma_0)$ be the fraction of individuals in the population for whom $\gamma < \gamma_0$, the payoffs to playing G against itself and against pure strategies J which ignore productivity differences are,

$$E(G|G) = (1 - P(\gamma_0))v,$$

$$\text{if} \quad t < T \quad E(J|G) = (1 - P(\gamma_0))v - P(\gamma_0)\gamma_0 t,$$

$$\text{if} \quad t > T \quad E(J|G) = v - P(\gamma_0)\gamma_0 T.$$

For $t > T$,

$$E(G|G) - E(J|G) = P(\gamma_0)(\gamma_0 T - v) > 0. \tag{7}$$

since $\gamma_0 T > \gamma T > v$. Thus G is a stable strategy against any pure alternative.

The existence of productivity differences resolves an ambiguity in the previous problem: the dual strategy of deferring to less productive competitors is not stable. Repeating the calculations that led to (7) for the dual strategy, G', yields

$$E(G'|G') - E(J|G') = (1 - P(\gamma_0))(\gamma_0 T - v) \gtrless 0, \tag{8}$$

because

$$\gamma_0 T < \gamma T > v, \qquad \text{so that} \quad \gamma T \gtrless v.$$

(Note that $\gamma_0 T$ can be less than v even though $\gamma T > v$.) Therefore, a stable equilibrium requires the more productive individuals to win every contest.

Productivity differences play two roles in this model. Like uncorrelated asymmetries, they act as a distinguishing characteristic on which strategies can be based. This leads to conflict resolution at low aggregate cost. Unlike uncorrelated asymmetries, however, productivity differences result in one, rather than two equilibrium solutions; because, given the level of investment, differences in productivity can influence the outcome of contests, whereas uncorrelated asymmetries cannot.

□ **Uncorrelated asymmetries and uncertainty about ability.** Throughout the previous section, we assumed that competitors had perfect information. Either the population was homogeneous or differences between individuals were known to all. One means of generalizing the model, therefore, is to relax the assumption of complete information. For example, it could be assumed that productivity differences exist, but that these differences are costly to measure. In such a model, information could be acquired during the course of a contest. Maynard Smith and Parker (1976) have analyzed this problem, but have been able to find a stable strategy only for a unique numerical example.

Given the presence of uncertainty about ability, it seems natural to conjecture that an equilibrium stable strategy would contain at least two mechanisms for conflict resolution: both uncorrelated asymmetry and perceived or estimated ability. When abilities were perceived by both contestants as vastly different, the perception alone could resolve the conflict. If perceived abilities were close, however, or if both contestants believed themselves very superior (or inferior), then an uncorrelated asymmetry could be employed to determine the winner. The exact occasions to employ each mechanism would, of course, depend on the net payoffs. One could imagine a mixed mechanism, a "score" calculated as a weighted average of asymmetries and abilities.

It is not hard to find examples in human conflict that seem to fit this mold. Obviously, strict seniority might be employed even when experience directly increases ability. We conjecture that a strict seniority system would be most likely at the two extremes, either when job experience is perfectly related to ability or when the two are entirely unrelated. In the middle range, where experience is only a mediocre predictor of ability, some combination of seniority and estimated ability would be more likely to emerge in determining advancement.

Another example would be admissions tests for graduate study. Reportedly, there is little predictive content in the test score. Among admitted students, the low scorers do just as well as the high scorers on the basis of any measure of subsequent performance (grade average, time to finish, publications). This implies that many nonadmitted students would have performed just as well. Why then do universities insist on such tests? One reason may be that information about the true abilities of applicants is so imperfect that the test score serves as an uncorrelated asymmetry, resolving conflicts at minimal social cost. Casting lots for admission might serve just as well, but it might be hard to explain to the trustees and alumni.

It might be tempting to draw an analogy between uncorrelated asymmetries and market signals (in the sense of Spence (1974)). A closer examination, however, reveals two fundamental differences between these concepts. The differences are worth mentioning, because they could be used in practice to ascertain whether a particular device is a signal or an asymmetry, which, in turn, could have relevant policy implications.

First, the signal is a perfect predictor of ability. In Spence's labor market, for instance, a worker's marginal product can be inferred from his market signal, the level of education. By contrast, uncorrelated asymmetries have no predictive content for ability (although they *are* predictors of the outcomes of contests). Second, the signalling model takes the level of signal to be a decision variable of the contestant; and a signalling equilibrium requires that a given level is less costly to obtain for a contestant with greater ability. The level of an uncorrelated asymmetry, on the other hand, cannot be selected by either contestant. Instead, it is determined randomly in any given contest and it costs nothing to employ. Its use evolves as a device to eliminate the costs of engaging in conflict.

Devices such as admissions tests and seniority are frequently criticized, perhaps because they are interpreted incorrectly as signals. When they are found to have little correlation with ability, arguments arise for their forced elimination. We see, however, that such actions could increase social costs without any offsetting benefits.

4. Securities trading and securities analysis

■ Scholars of asset markets have long been puzzled by the apparent conflict between market efficiency and the widespread practice of "analyzing" securities. If the market is efficient,[7] then all information relevant to the future performance of a security is already impounded in the price. The expenditure of resources to forecast future prices is simply a waste. This has led some scholars to predict the demise of security analysts and portfolio managers. It has led to the advocacy of "index" funds[8] and similar devices whose owners do not even hope to "beat the market."

But as members of the investment community have always insisted in the face of these arguments, if *every* investor abandoned any attempt to forecast future events and instead relied entirely on the current market price to contain all relevant information, then the price would cease to contain *any* information. It could not be a reliable measure of the present worth of the asset.

Grossman and Stiglitz (1976) have shown that a sensible asset market equilibrium must leave room for analysis by some investors. They prove that the market price cannot be a sufficient statistic for all relevant information. In this section we show how a simple biological conflict model can give the same result. The illustration is very elementary, and yet it contains, we believe, most of the salient features of a realistic model of the securities markets including transactions and analysis costs. It will probably be necessary, however, to generalize the model before it can be successfully tested.

Consider a market place (where each entering investor meets another, his opponent). At this meeting, we assume that a trade must occur. (This is equivalent to assuming that the payoffs cannot be ascertained until after the trade.) Either trader can choose between two levels of "analysis," g_1 and $g_2 (g_2 > g_1)$. The first level, g_1, could be regarded as transactions costs, including the trouble and inconvenience of coming to the market plus perform-

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[7] See Fama (1970) for a detailed survey on the theory of efficient capital markets and the related empirical testing.

[8] An "index" fund is a mutual fund whose avowed goal is to form a portfolio that exactly mimics some particular stock market index such as the Dow-Jones industrial average. The managers of such funds do not purport to be able to detect undervalued stocks.

TABLE 2

		HIS OPPONENT ANALYZES?	
		YES	NO
THE TRADER ANALYZES?	YES	$r - g_2$	$rd - g_2$
	NO	$r/d - g_1$	$r - g_1$

ing a modest level of analysis such as buying a financial newspaper and picking an asset. The second level, g_2, includes all the costs of g_1 plus the expenditure of additional resources to buy advice or to generate an opinion privately. For convenience of illustration, both g_1 and g_2 are assumed to be constant and to be measured in units of return.

The payoffs to trading are assumed to have two components. There is a "normal" return, r, and a multiplicative premium, $d > 1$. If neither the trader nor his "opponent" does extended analysis, for example, the trader's return is $r - g_1$. But if analysis is done by the trader and not by his opponent, his payoff is $rd - g_2$. The complete payoff matrix appears in Table 2, which contains payoffs to the trader on the left. Notice that no premium is earned by either contestant when they have both taken the same action. This is sensible because no advantage would then accrue to either side. On the other hand, if one contestant had an advantage in the trade because he had garnered better information through analysis, he would earn rd (and his opponent would earn r/d). Of course, the analyst/trader would incur a larger cost, $g_2 > g_1$.

Given this simple structure, we now show (a) that a stable mixed strategy can exist with a positive level of security analysis and (b) that such an equilibrium is characterized by the zero-profit condition: investors have no incentive to enter or exit the market nor to alter their level of analysis.

A mixed stable strategy exists if

$$r(d - 1) > g_2 - g_1$$

and (9)

$$r(1 - 1/d) < g_2 - g_1.$$

To see that this is true, notice that *if* a mixed stable strategy exists with probability $p(0 < p < 1)$ of pursuing security analysis before trading, then

$$p(r - g_2) + (1 - p)(rd - g_2) = p\left(\frac{r}{d} - g_1\right) + (1 - p)(r - g_1), \qquad (10)$$

because when (10) holds for some p, every alternative strategy with probability $q \neq p$ has the same payoff played against p as does p itself. It is easy to show that such a p does exist, and that it is a mixed strategy (with $p > 0$ and $p < 1$), whenever (9) is satisfied. Furthermore, no other strategy $q \neq p$ has as high a payoff played against itself as does p played against q.[9]

The conditions (9) constitute an economically sensible set of payoffs and

[9] These results are easy to prove for the 2×2 payoff matrix in Table 2, which is a special case of a finite dimensional payoff matrix. In the working version of this paper, we analyzed the more general case in detail and a copy of the results can be obtained from the authors upon request.

penalties for acts of conflict. If the trader's opponent does not analyze, then the first condition in (9) requires that the benefit be much greater from analysis than from none. Notice from the payoff matrix that (9) is equivalent to a statement about the relative payoffs in the second column. Similarly, given that the trader's opponent has analyzed, the second condition in (9) implies that the best action is to avoid conflict and not to analyze.

If the cost and benefits of analysis satisfy (9), then either everyone will pursue a mixed strategy or else some investors will always do analysis and others never will (but they will still trade). For economic reasons, we would expect that a mixed strategy will prevail. The probability of analysis should not equal zero, because the market price would then contain *no* relevant information about the future. On the other hand, if analysis were always pursued, everyone would be expending resources at every trade; but there would be no advantage to the analysis since every opponent would have done just as much. Therefore, an economic contest such as this must achieve a stable equilibrium strategy wherein (9) is satisfied. It *can* achieve this result through market forces altering either the benefits from analysis (the premium d), or the incremental costs of analysis, $(g_2 - g_1)$.

If there is no economic profit when this equilibrium strategy finally evolves, then the expected marginal payoff will be zero to both analysis and no analysis. For the present payoff matrix this implies that

$$d = g_2/g_1 \tag{11}$$

and

$$p = (rd - g_2)/(rd - r).^{10} \tag{12}$$

The remarkable simplicity of the final result under competition is illustrated by these equations. The first (11) is simply a restatement of price equals marginal cost. In this case marginal cost is g_2/g_1, the incremental expenditure required when securities analysis is conducted. The price or marginal revenue from analysis is d, the multiplicative premium.

Technology will determine the costs of doing analysis, and competition will drive down the price until no further potential entrant will be attracted into the business of analysis. This happens, of course, whenever the incremental revenue is just offset by the incremental cost.

Unlike classical price theory, however, there is a second condition (12) imposed upon the competitive equilibrium and revealed by this biology-based model; the size of the industry is endogenously determined. Notice that (12) implies that a proportion p of all asset traders will be attracted into the business of securities analysis. Simple comparative statics show that the industry's size is negatively related to marginal costs (to g_2), positively related to price (d), and positively related to "normal" return (r).[11] The potential richness of this explicit second condition is, we feel, justification enough for further investigation into the use of evolutionary stable strategy models in economics.

Finally, and more specifically to the present application, we suggest that a better definition of an efficient capital market than has heretofore been em-

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[10] If the expected marginal payoff is zero, then both sides of (10) equal zero and thus $p = (rd - g_2)/(rd - r) = (r - g_1)/(r - r/d)$. The second equality can be simplified to $d = g_2/g_1$.

[11] The positive relation of industry size to "normal" return is probably just a result of the multiplicative nature of the premium rather than anything fundamental.

ployed would be a market displaying the characteristics above: no individual has an incentive to alter his current behavior, be it trade or not trade, and be it do security analysis or not, if he is trading. This is, of course, simply the classical economic competitive equilibrium in which every possible human activity has the same net marginal benefit; and it illustrates formally how the competitive equilibria obtain, even while individuals pursue persistently different (specialized) strategies.

5. Summary and possible extensions

■ This paper builds on the theory of pairwise competitions developed by mathematical biologists. After describing the basic model, the results are extended to cover problems related to organizations and markets.

Of particular interest is the role of "uncorrelated asymmetries" in conflict resolution. It is shown that utility maximizing individuals of equal ability may settle conflicts for power within an organization on the basis of characteristics which are uncorrelated with performance. Such a strategy turns out to be optimal for both the individual and the organization as a whole, because it permits the resolution of conflicts without the investment of resources. It is possible that seniority systems are the result of such strategies' being employed. The theory then explains the persistence of seniority systems and supports the intuitive argument that internal strife is reduced by settling disputes on the basis of seniority.

It is argued also that uncorrelated asymmetries may persist, even when there are differences in ability that could serve to resolve conflict on a seemingly more "rational" basis. If ability is detectable without error in the sense that every pair of contestants can be ranked unambiguously, then no uncorrelated asymmetry will be employed. However, if abilities are uncertain or hard to measure without error, the best strategy may be to use a combination of perceived (estimated) ability *and* an uncorrelated asymmetry. We predict, for example, that seniority will be employed to resolve conflict for promotion in organizations where there is no connection between experience and ability and in organizations where the connection is very strong more frequently than in organizations where there is medium degree of relatedness.

A biological conflict model was employed also in an asset market context to show how investors should adopt differing trading strategies. Some traders will expend resources in an effort to forecast prices, and others will simply trade without any attempt at "analysis." Given information processing costs, a stable proportion of the population will pursue each strategy. An economic equilibrium will result when the expected payoffs to both strategies are equal and when no individual not already trading has an incentive to begin with either strategy.

Many extensions of the simple models discussed here can be imagined. In the uncorrelated asymmetries model, a formal extension to uncertainties about ability would be desirable as such an extended model should apply to many varieties of human conflict.

The market application can be extended also. In principle, if multilevel securities analysis were permitted, instead of just the two levels used in the illustration here, a fairly realistic depiction of actual asset market operations should be obtained, and it might be tested with data about the distribution of actual expenditures on analysis.

Similar biology-based development might lead to insights and testable models for other markets where economists have had difficulty understanding the variety of behaviors exhibited by participants in the same basic activity. The biology-based models have a potential richness beyond those of classic competitive equilibrium because the size of a competitive industry is explicitly and endogenously determined.

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