Simulation & Gaming

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Simulation Gaming 2005; 36; 9
DOI: 10.1177/1046878104270471

Keynote article

In the long run: Biological versus economic rationality

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Eight computer simulations examined how long hypothetical gamblers could continue gambling without going broke in different games of chance. Gamblers began with a fixed amount of money and paid a fixed ante to play each game. Games had equal expected value but varied in their probability of winning and amount won. When the expected value was zero or positive, gamblers playing low ante, low-risk games (high chances of small wins) had longer runs than did gamblers playing high ante, high-risk games (low chances of big wins). When the expected value was negative, gamblers playing high-risk games had longer runs than gamblers playing low-risk games. The results extend Slobodkin and Rapoport's concept of biological rationality and explain why people with limited wealth are wise to avoid risks in winning situations and take risks in losing situations, a central principle of prospect theory.

KEYWORDS: *biology; economics; gambling; optimization; rationality; risk; survival*

One of the most notable achievements of the Age of Reason was the creation of rules for making decisions based on expected consequences of actions rather than on habit, law, or religious canon—rules now known as the *rational calculus*. Many of the creators of the rational calculus, including Descartes (1595-1650), Pascal (1623-1662), Halley (1656-1742), Huygens (1629-1695), and later the Bernoullis (circa 1650-1750) and Laplace (1749-1827), began their work in response to the practical problems of two nascent industries, insurance and gambling. To address these problems, they developed the concepts of randomness and probability, formalizing the counterintuitive notion that complex or unpredictable individual events can in the aggregate or the long run show simple and predictable patterns.

Examples of aggregated or long run order emerging from individual disorder are common. We cannot predict beyond chance next week's high temperature in our backyard, but aggregated over days of the season, we can predict quite accurately that the average backyard summer temperature will be higher than the average winter temperature. We cannot predict who will have an auto accident in our country next month, but

SIMULATION & GAMING, Vol. 36 No. 1, March 2005 9-26
DOI: 10.1177/1046878104270471

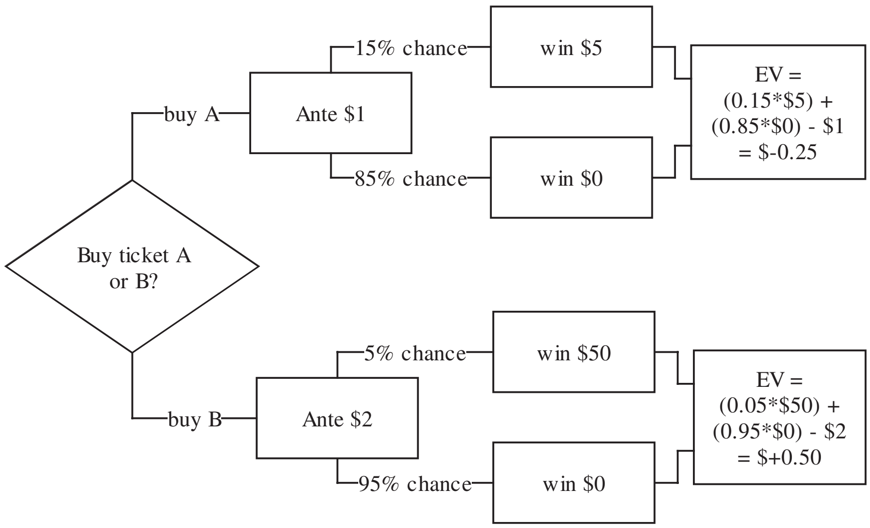

FIGURE 1: Calculating Expected Values for Buying Lottery Tickets A and B

we can predict with good accuracy the total number of accidents that will occur. We cannot predict whether a coin will turn up heads or tails on any one flip, but we can be confident that across many flips it will land heads up close to half the time. Just how close depends on the number of flips; the greater their number, the closer their aggregate approaches our expectations. Statisticians know this as the law of large numbers, and it forms one basis of rational calculus rules about making decisions that will be advantageous when repeated many times.

Central to the rational calculus is the concept of expected value (EV) based on aggregated, long run properties of repeated events, and it is perhaps best understood by example. Suppose you are given an opportunity to buy one or more lottery tickets, either tickets from Series A or tickets from Series B. An A ticket costs $1 and gives a 15% chance of winning $5 (+ an 85% chance of winning nothing). A B ticket costs $2 and gives a 5% chance of winning $50 (+ a 95% chance of winning nothing). Which ticket should you choose? The rational calculus prescribes that your decision should be based on a comparison of the expected value of each ticket, that is, on how much you could expect to win or lose on average if you bought hundreds or thousands of each. In this example, the EV of a ticket is given by a simple mathematical formula: the chances of winning times the amount won, plus the chances of losing times the amount lost, minus the cost of a ticket (the ante). The calculation is diagrammed in Figure 1.

Figure 1 indicates that the EV of buying ticket A is –$0.25. In other words, if you repeatedly bought A lottery tickets and averaged your wins and losses across your purchases, then in the long run, you could expect to lose an average of 25 cents per ticket. In contrast, Figure 1 indicates that the expected value of buying ticket B is +$0.50.

Thus, if you repeatedly bought B tickets and averaged your wins and losses across your purchases, then in the long run, you could expect to gain an average of 50 cents per ticket.

Is it better for you to choose an action that in the long run would cost you an average of about 25 cents per indulgence or to choose an action that in the long run would give you 50 cents per indulgence? The rational calculus prescribes that you should always make choices that maximize your expected value or gain in the long run. Thus, the rational calculus prescribes that you should buy ticket B. You will pay more for ticket B than for ticket A, you will lose about 95% of the time, and you will never be able to predict which of your tickets will win. But when you do win, you will in the long run regain more than what you have lost, and that is better than buying ticket A, which will in the long run cause you to lose more than you gain.

Economic rationality

There is much more to the rational calculus than we exemplify in the aforementioned example, but the long run maximization of expected value remains at its foundation (e.g., see Luce & Raiffa, 1957). It is the concept that guides banks in adjusting their loan interest rates to ensure their long run profit despite occasional random defaults or bankruptcies. It is the concept that guides casinos in setting gambling rules, antes, and payoffs to ensure that despite an occasional lucky winner, their long run expected return remains positive. It is the concept that guides media companies in setting their advertising rates according to the chances that prospective buyers will purchase a client's advertised goods or services. It is the concept that informs a lottery company never to sell ticket B. More generally, the long run maximization of expected value is the fundamental concept of what is called *economic rationality*, a concept that has come to dominate economic and managerial decision making during the past half century. Indeed, the maximization of expected value has long been considered the standard of economic rationality, and human folly is often described as deviation from this economic standard (see Gigerenzer, 2000; Hammond, 1996; Thorngate, 1980).

Yet, economic rationality has its limitations. One limitation can be illustrated in the following variation of what is called the St. Petersburg paradox. Suppose you had the choice of two other lottery tickets. Ticket C gives you a 99% chance of winning $1.10 and costs $1. Ticket D gives you a one in a thousand chance of winning $10 million and costs $9,999. Should you choose to buy C or D? Economic rationality prescribes that you again answer the question by calculating the expected value of C and comparing it to the expected value of D. The calculation is shown in Figure 2.

Figure 2 reveals that ticket D has a greater expected value (one dollar) than ticket C (about 9 cents), so the economically rational choice is D. Why? Because even though you would expect to lose 999 times out of 1,000 buying D tickets, when you did win, your winnings would be substantial, enough to give you an average gain of $1 per ticket, which about 11 times better than the expected gain of just under 9 cents from buying C tickets.

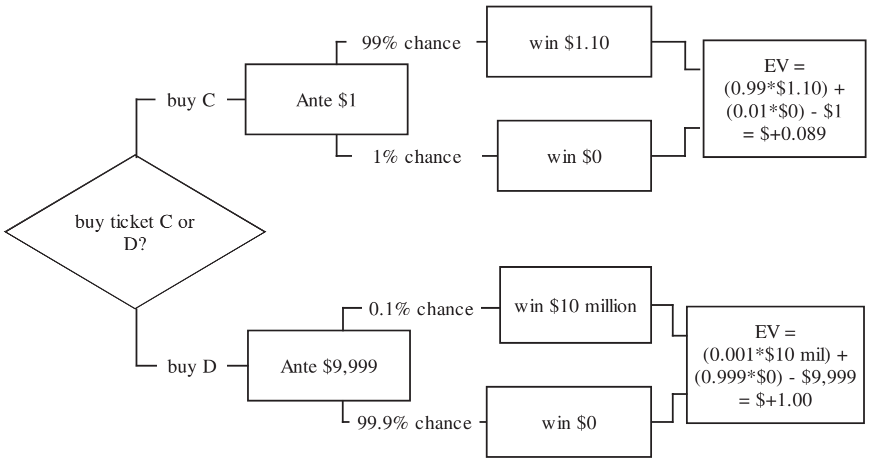

FIGURE 2: Calculating Expected Values for Buying Lottery Tickets C and D

Yet few of us would pay almost $10,000 for a D ticket, much less a long run of them. It seems foolish to bet the farm on such a risky choice, to sink that amount of money into a one in a thousand shot at riches; it seems more foolish to pay such an ante repeatedly in hopes of the big win. Most of us would choose the safer bet of ticket C. Are we irrational? Perhaps not. There are at least two reasons why C might be the more rational choice. The first reason has been studied extensively in psychology. The second reason has been almost ignored in the social sciences and forms the basis of the computer simulations reported here.

A considerable amount of psychological research indicates that our beliefs about probabilities and our feelings about money are not the same as their face value (for reviews, see Arkes & Hammond, 1986; Gigerenzer, 2000; Hammond, 1996; Kahneman & Tversky, 1979; Schneider & Shanteau, 2003; Wright, 1985). For example, a one in a hundred chance does not seem 10 times as likely as a one in a thousand chance; instead, both seem unlikely. Similarly, $20 million does not seem twice as valuable as $10 million; both feel like a lot of money. A strong argument can be made that it is more rational to make choices to maximize the subjective expectations of our subjective feelings (often called *utility*) of possible outcomes than it is to maximize the objective expectations of monetary value considered by the rational calculus. In the jargon of the discipline, we should seek to maximize our *subjective expected utility* (SEU), which might lead us to different rational decisions than would the EV prescriptions of economic rationality. For example, if the value of winning 10 cents from ticket C is, say, 2 units of joy, and if the value of losing $9,999 ticket D is 100 units of sorrow, then it is more rational to prefer an almost sure thing of 2 joy units than an almost sure thing of 100 sorrow units.

Biological rationality

The second reason for arguing that it is rational to prefer ticket C to ticket D comes from considering that deceptively simple phrase, *in the long run*. Both the EV and SEU conceptions of rationality presume that a long run of choices is possible and that fluctuations in the outcomes of these choices will average out in life's law of large numbers. The long run is assumed, and our goal in life is to maximize the average value of outcomes in this assumed long run. However, a long run cannot always be assumed. For example, few of us could afford to buy a long run of D tickets; many of us could not afford to buy one. Although it remains true that over tens of thousands of D tickets we could be mathematically assured of greater rewards than we would obtain over the same number of C tickets, those of us with limited savings could afford only a short run of D tickets. In the short run, there is a very high chance of losing a lot of money on D tickets, which makes them a bad short-term risk.

The assumption of a long run allows mathematicians and economists to derive elegant and sophisticated equations prescribing rational choice. But the act of making choices always has a cost, and whether the cost is monetary or merely the time spent on deciding, there are almost always limits to the costs that any of us can afford. As a result, it seems prudent to consider a second conception of rationality, one that shifts emphasis from the expected gains or losses in the long run to the chances that a long run can be sustained. The shift of emphasis leads us to what is called *biological rationality.*

In the biological world, a long run can never be assumed. On the contrary, if life had a goal, it would be simply to make the run of life as long as possible (see Slobodkin & Rapoport, 1974). The alternative of course is the death of an organism or extinction of a species. Biological rationality expresses itself in the thousands of structural and behavioral adaptations that organisms exhibit to sustain their kind. To be biologically rational is to maximize the chances of survival in the long run (Slobodkin & Rapoport, 1974), to avoid death for as long as we can.

This biological prescription has an analogy in the economic world: Don't go broke; avoid choices that will put you at risk of losing all your wealth. Stated more positively and generally, biological rationality suggests that we should make choices that will maintain or increase the chances of making future choices. Sometimes this will lead us to choose the same alternative as that prescribed by the expected values of economic rationality. Sometimes it will lead us to choose different alternatives.

One contrast between the prescriptions of economic rationality and biological rationality is easily illustrated by considering what each would prescribe about buying C or D tickets if your life savings were, say, $19,998 and you had no chance of borrowing more. The economically rational prescription is, as noted earlier, to buy D tickets because in the long run they will yield a greater average payoff. However, your limited savings (resources) would allow you to buy only two D tickets; only if one of them was a winner could you then afford to buy more. There is a chance of course that one of these two tickets would be a winner and that you would then be very rich—rich enough to buy a very long run of D tickets if you wished, thereby increasing your chances that another one would win before you went broke. On the other hand, it is possible that neither of the two tickets you bought would win and that you would then be unable to buy anything, including more D tickets. No long run would be possible. You would be the economic equivalent of dead.

What are the chances that you would win $10 million from one of the two tickets, or $20 million from both? Recalling the exercise in all introductory probability courses, the answer is 1 minus the probability that the first ticket will not win and that the second ticket will not win:

$$= 1 - (0.999 \times 0.999) = 1 - 0.998 = 0.002.$$

Thus, spending all your life savings on two D tickets would give you a 99.8% chance of losing all your life savings. Your "long run" of D tickets would almost certainly be limited to two chances. You would then be too poor to buy more.

Consider now what would most likely happen if you invested some or all of your $19,998 in a large number of C tickets. If you bought two of them at $1 each, you would still have almost all ($19,996) of your savings. The chance of both tickets winning is $0.99 \times 0.99 = 0.98$. It is thus close to certain that your $2 investment in the ante for two tickets will give you back $2.20, a 10% return. If you bought 100 tickets, you would expect 99 of them to win and one of them to lose, for a next expected return of $9.90 – $1 = $8.90. It would be virtually impossible to lose money in any batch of 100 C tickets. And even if this unlikely event occurred, you would still have $19,898 remaining in your savings to sample another 100. Indeed, if you bought 19,998 C tickets, the chances of losing anything would be miniscule, and the chances of losing it all would be infinitesimally small. In short, although choosing C tickets would not give you a chance at instant riches, it would virtually ensure that you would never go broke and even that you would make a modest profit from your lottery investment. So it is biologically rational to prefer ticket C to ticket D because only C virtually ensures a long run.

The divergence of economic and biological prescriptions led us to explore the biological conception of rationality in more detail. We were especially interested to determine how (a) the size of the ante relative to amount of money available to bet, (b) the chances of winning, and (c) the expected value of the bet (= expected payoff – ante) affected how long gambling could be sustained. Lacking the mathematical sophistication to derive the relations from first principles, we resorted to a series of simple Monte Carlo computer simulations for exploring these relations. We report eight of our simulations in the following, each of which represents a particular combination of the ante, the chances of winning, and the expected value, plotting for each the chances of sustaining a run of 10, 100, and 1,000 bets.

TABLE 1: An Example of Settings for One Run of the Simulation

*Group of Gamblers (*N *= 1,000)*	*Money to Start*	*Ante*	*Probability of Win = Pwin (%)*	*Amount Won = Payoff*	*Expected Value = Pwin × Payoff – Ante*
1	\$12	\$2	10	\$50.00	\$3
2	\$12	\$2	20	\$25.00	\$3
3	\$12	\$2	30	\$16.67	\$3
4	\$12	\$2	40	\$12.50	\$3
5	\$12	\$2	50	\$10.00	\$3
6	\$12	\$2	60	\$8.33	\$3
7	\$12	\$2	70	\$7.14	\$3
8	\$12	\$2	80	\$6.25	\$3
9	\$12	\$2	90	\$5.56	\$3

Method

The computer program used for our simulations (and listed in the appendix) was written in the freeware programming language Euler, similar to Matlab but less costly and more elegant (see Grothmann, 2004). The program simulated nine groups of 1,000 gamblers, each gambler in a group playing one of nine different games of chance for as long as possible. All nine games had the same expected value (= pwin × payoff – ante) but differed in their combination of the probability (pwin) and payoff of winning. The 1,000 gamblers in Group 1 repeatedly played a game that gave a 1/10 chance (pwin1 = 1/10) of winning a given payoff. The 1,000 gamblers in Group 2 played a game giving twice the chance (pwin2 = 2/10) of winning half the payoff. Those in Group 3 played a game with thrice the chance (pwin3 = 3/10) of winning one third the payoff. And so went the series, ending with 1,000 gamblers in Group 9 who played a game with nine times the chance of winning one ninth the payoff. An example is shown in Table 1. As illustrated in Table 1, each gambler in a simulation began play with the same amount of money and paid a fixed ante to play each game. The values of money and ante were varied across the eight simulations.

Each simulated gambler continued playing until he or she ran out of money or until he or she finished playing 1,000 games. The 1,000-game limit was somewhat arbitrary; it seemed sufficient to be classified as a long run but allowed the simulation program to end. The program recorded how many of the 1,000 gamblers in each of the nine groups survived 10 games, 100 games, and 1,000 games without going broke.

It is important to note that because the expected value of the gambles remained equal across the nine combinations of pwin and payoff in each simulation, economic rationality would be indifferent to these nine combinations. Through the lens of economic rationality, all nine combinations are equivalent in the long run, so no preference for one combination over the others could be prescribed.

Results

Thousands of combinations of starting money, ante, and payoff of the gamble are possible, but space permits us to show only a few. The eight combinations we report next are representative of the general trend of the results. Other combinations can be examined by running the program listed in the appendix.

Simulation 1: A wealthy extreme

We began by considering a wealthy extreme, the following combination of relatively high starting wealth and low ante allowing all gamblers to afford long runs of losses and a positive expected value:

- starting money = \$100,
- ante = \$1,
- expected payoff = \$2, giving an expected value of each gamble (expected payoff – ante) = \$1.

Not surprisingly, all 9 × 1,000 = 9,000 gamblers in this simulation survived 10, 100, and 1,000 gambles, providing a fragment of conceptual validation of the computer program.

Simulation 2: Less wealth, more ante

We next tried a more interesting combination. Figure 3 shows the number of gamblers surviving 10, 100, and 1,000 gambles when

- starting money = \$12,
- ante = \$2,
- expected payoff = \$3, giving an expected value of each gamble (expected payoff – ante) = \$1.

The rise of all three plots from left to right across Figure 3 reveals that the more conservative the gamble, that is, the higher the probability of winning, the greater the chances that a gambler would survive 10, 100, and 1,000 gambles. For example, the leftmost dot on the topmost plot indicates that gamblers with a 1/10 chance of winning \$30 had only about a 45% chance of surviving at least 10 gambles. Gamblers with a 5/10 chance of winning \$6 had a 97% chance of surviving at least 10 gambles, seen in the fifth point of the topmost plot. The overlap of the two lower plots in Figure 3 indicates that if a gambler survived 100 gambles, it was virtually certain he or she would survive 1,000 gambles—a comforting feature of gambles with positive expected value. This suggests that for gambles with an equal, positive expected value, those with a higher probability of winning yield a higher chance of sustaining a long run. Confirming the example of tickets C and D in our introduction, the results show that when expected values are positive and equal, chances of a long run increase as risks of a loss decline.

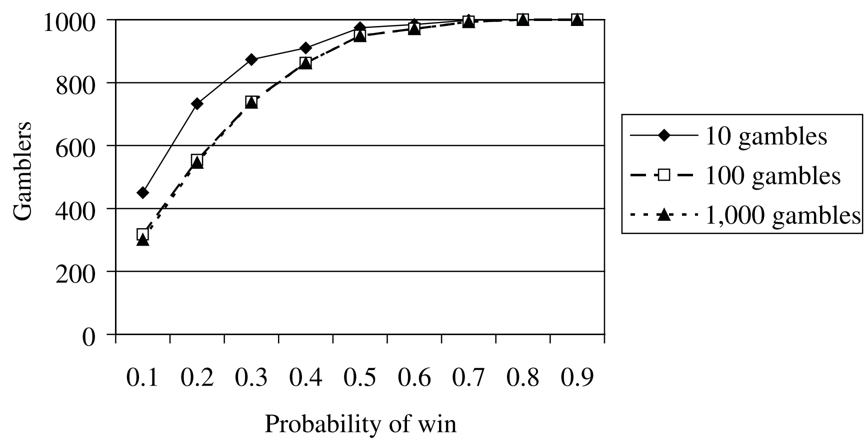

FIGURE 3: **Number of Gamblers Surviving 10, 100, and 1,000 Gambles When Money = 12, Ante = $2, Expected Payoff = $3, and Expected Value = $1**

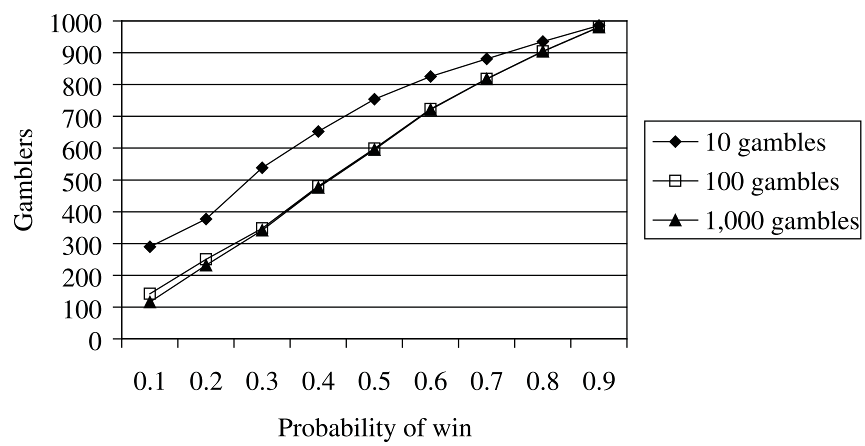

FIGURE 4: **Number of Gamblers Surviving 10, 100, and 1,000 Gambles When Money = 12, Ante = $4, Expected Payoff = $5, Expected Value = $1**

Simulation 3: Raising the ante

Figure 4 shows the number of gamblers surviving 10, 100, and 1,000 gambles when

- starting money = $12,
- ante = $4,
- expected payoff = $5, giving an expected value of each gamble (expected payoff – ante) = $1.

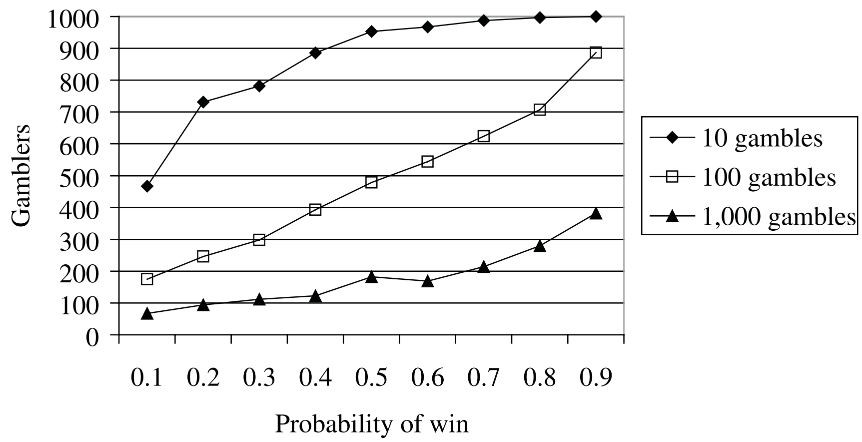

FIGURE 5: Number of Gamblers Surviving 10, 100, and 1,000 Gambles When Money = 12, Ante = $2, Expected Payoff = $2, Expected Value = $0

Although the expected value of each gamble shown in this simulation is the same as that of Simulation 2, doubling the ante from 16.7% to 33% of the starting wealth in the current simulation produces a noticeable decline in the chances of survival past 10 gambles. This can be seen by comparing the three plots in Figure 4 with those in Figure 3; all three plots are lower. Figure 4 does however confirm a trend noted in Figure 3: As the probability of a win declines, so also does the chance of survival. For example, only about 29% of gamblers with a 10% chance of winning $50 could survive past 10 gambles, and only about 12% could survive 1,000 gambles. In contrast, about 99% of gamblers with a 90% chance of winning $5.56 were able to survive 10 gambles and 98% could survive 1,000 gambles. As was true in Simulation 2, the current simulation demonstrates that when the expected value of alternative gambles are positive and equal, long run survival favors gambles with low risk.

Simulation 4: Lowering expectations

We next turned our attention to gambles with an expected value of $0. Figure 5 shows the number of gamblers surviving 10, 100, and 1,000 gambles when

- starting money = $12,
- ante = $2,
- expected payoff = $2, giving an expected value of each gamble (expected payoff – ante) = $0.

The large spread between the three plots in Figure 5 shows that when the ante of a gamble is equal to its expected payoff and thus the expected value of the gamble is

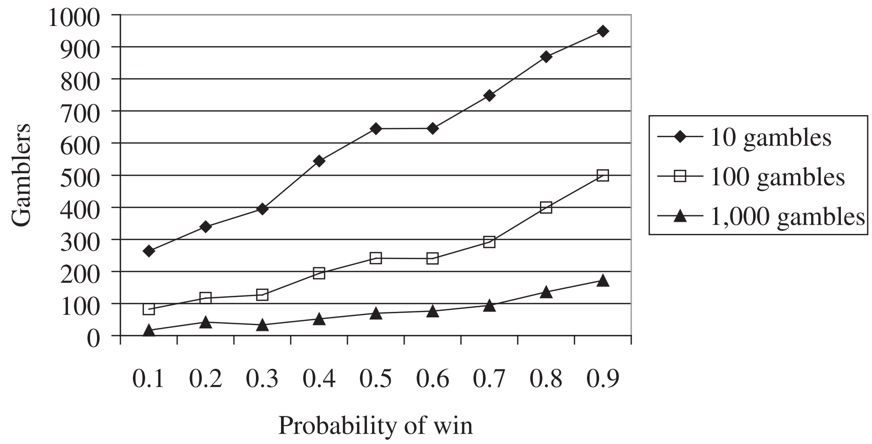

FIGURE 6: Number of Gamblers Surviving 10, 100, and 1,000 Gambles When Money = 12, Ante = $4, Expected Payoff = $4, Expected Value = $0

zero, survival past 10 or 100 gambles does not guarantee further survival. For example, even though well over 95% of gamblers with a winning probability of 0.6 or above survived 10 gambles, fewer than 40% of them survived 1,000 gambles. Even so, Figure 5 accentuates the trend shown in Figures 3 and 4: As seen from all three lines going up as the probability of a win increases, a long run is far more likely for gamblers who make safe bets for low rewards than for gamblers who make risky bets for high rewards.

Simulation 5: Increasing the ante and lowering expectations

Figure 6 plots the number of gamblers who survived 10, 100, and 1,000 gambles when

- starting money = $12,
- ante = $4,
- expected payoff = $4, giving an expected value of each gamble (expected payoff – ante) = $0.

Figure 6 shows that with a rise of the ante from 16.7% to 33% of the starting wealth, the chances of a long run of gambles with $0 expected value are again diminished. Under these conditions, it is increasingly less likely, even for gamblers who play relatively safe bets, to survive a long run of 1,000 gambles (compare the bottom line of Figures 5 and 6). Fate is not kind in the long run under these conditions, but the rise of the bottom line in Figure 6 shows again that it is still preferable to gamble on safe bets with low payoffs rather than to gamble on risky bets with high payoffs.

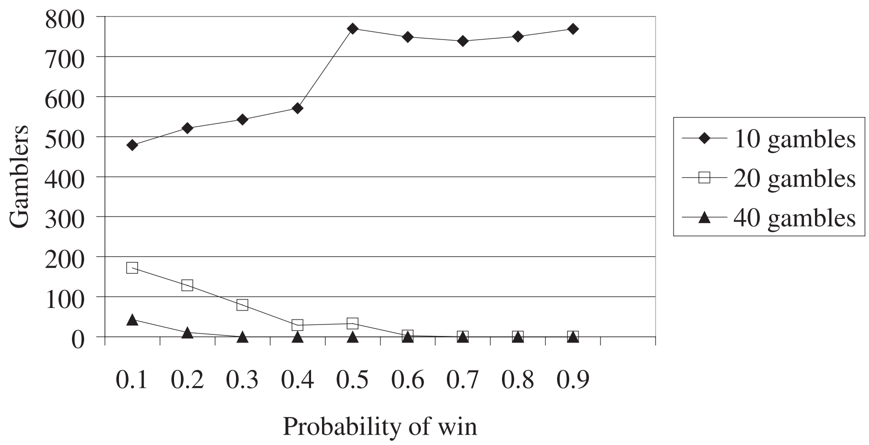

FIGURE 7: Number of Gamblers Surviving 10, 20, and 40 Gambles When Money = 12, Ante = $2, Expected Payoff = $1, Expected Value = –$1

Simulations 6 through 8: Negative expectations

Having examined gambles with equal and positive expected values (Simulations 1 through 3) and gambles with equal and zero expected values (Simulations 4 and 5), we next examined how long gamblers facing gambles with negative expected values could survive. The relevant settings of the three variables for our first negative expected value simulation were as follows:

- starting money = $12,
- ante = $2,
- expected payoff = $1, giving an expected value of each gamble (expected payoff – ante) = –$1.

Because the expected value is negative, any run is expected to be shorter than a run with zero or positive expected value. Indeed, in test runs, none of the gamblers ever survived more than 100 games with the aforementioned settings of the three variables. So we modified the simulation program to count how many gamblers would survive 10, 20, and 40 games. The results are shown in Figure 7.

Not surprisingly, Figure 7 shows that because of the negative expected value, gamblers could survive only relatively short runs. The topmost plot of Figure 7 shows that similar to the previous results, the less risky gamblers more frequently survived a short run of 10 gambles; however, no great increase in survival occurred beyond the 50% gamble (points 5 through 9 of the topmost plot). The middle plot shows that few gamblers survived more than 20 gambles. However, the gamblers who did were those who bet on the riskier gambles, not on the less risky gambles. For example, the leftmost

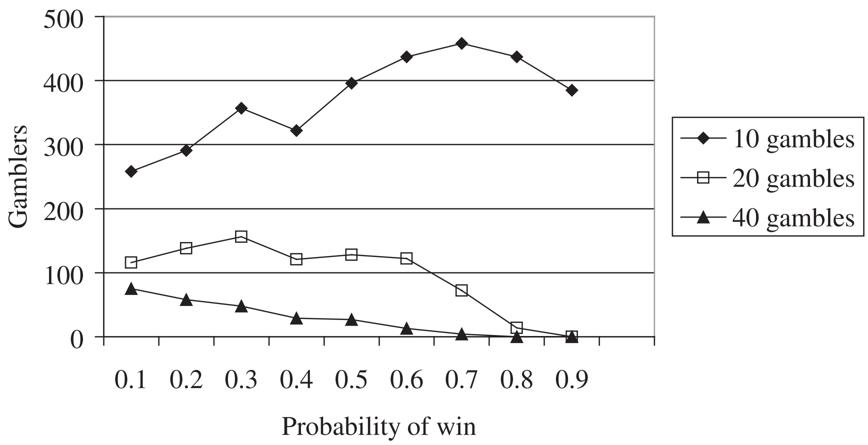

FIGURE 8: Number of Gamblers Surviving 10, 20, and 40 Gambles When Money = 12, Ante = $4, Expected Payoff = $3, Expected Value = –$1

point of the middle plot shows that about 17% of gamblers betting on a 10% chance of winning $10 survived 20 gambles and about 0.5% survived 40 gambles. In contrast, no gambler betting on a 90% chance of winning $1.11 survived 20 gambles. The results indicate that when expected value is negative, longer runs will accrue to those who bet on risky gambles with low probability of high payoffs even though all runs are relatively short.

Intrigued by this result, we again doubled the ante from 16.7% to 33% of starting wealth, keeping the expected value at –$1. The settings of variables were as follows:

- starting money = $12,
- ante = $4,
- expected payoff = $3, giving an expected value of each gamble (expected payoff – ante) = –$1.

Figure 8 shows the results of this simulation. Comparing the topmost plot in Figure 7 to the topmost in Figure 8 suggests that increasing the ante reduces the advantage of avoiding risk, even in the short run. No more than about 45% of the gamblers in the current simulation survived 10 gambles, and the greatest proportion of those who did survive were betting on a 70% chance of winning, not on the less risky 80% and 90% gambles. As in the previous simulation, a greater proportion of risky gamblers than conservative gamblers survived 20 and 40 gambles, seen in the downward slopes of the middle and bottom plots in Figure 8.

As a final test of the benefits of risk in situations with negative expected value, we increased the size of the negative expected value with the following configuration of variables:

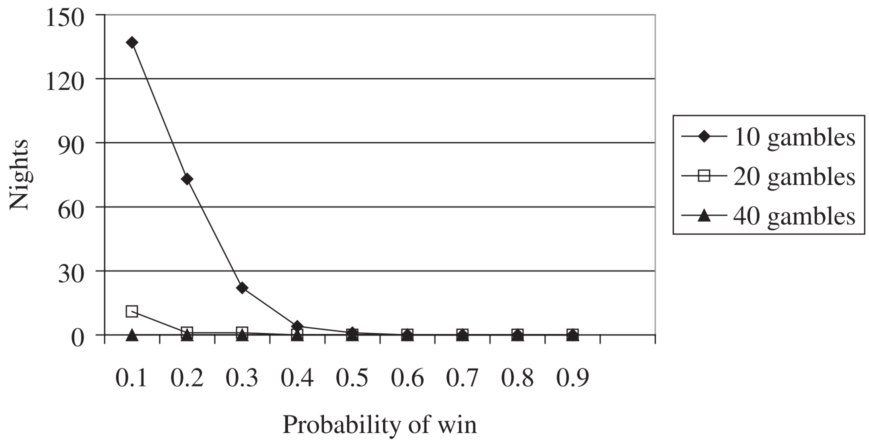

FIGURE 9: Number of Gamblers Surviving 10, 20, and 40 Gambles When Money = 12, Ante = $3, Expected Payoff = $1, Expected Value = –$2

- starting money = $12,
- ante = $3,
- expected payoff = $1, giving an expected value of each gamble (expected payoff – ante) = –$2.

The results are shown in Figure 9. It is clear in this case that all advantages of conservatism are gone. The riskier gamblers consistently show a higher chance of surviving 10 and 20 gambles, although the chances are still not high. No one survived 40 gambles.

Discussion

The simulations we report here were designed to investigate whether variations of gambles with equal expected value change the expected length of a gambling run. The results of this study clearly demonstrate that when money to gamble is limited, varying (a) the proportion of available money required for the ante and (b) the chances of winning have dramatic effects on the length of a gambling run. As the cost of play (ante) increases relative to available wealth, the chances of a long run decline. When the expected values of gambles are zero or equally positive (Simulations 1 through 5), then long runs are more likely to be sustained by choosing gambles with a lower ante and higher chance of winning, even though the amount won is smaller. However, when the expected values of gambles are equally negative (Simulations 6 through 8), then short runs are likely to be longer when choosing gambles with a lower ante, a lower chance of winning, and a higher payoff.

In sum, although economic rationality is indifferent to these gambles of equal expected value, the simulations support two clear prescriptions for sustaining a run of gambles of any kind. The first prescription applies to bountiful or neutral environments, those with positive or zero expected value: To increase your chances of a long run, keep your ante small relative to your wealth and avoid risk. This corresponds to Slobodkin and Rapoport's (1974) dictum that the best evolutionary strategy is to "minimize the stakes played" (p. 181) in the game. The second prescription extends the work of Slobodkin and Rapoport to impoverished or deteriorating environments, those with negative expected value: To increase your chances of extending your short run, take risks on outcomes that will keep you in the game.

It is worth noting that these biologically rational prescriptions do not contradict economic rationality. Instead, they increase the chances of the long run required for economic rationality. Long runs are by definition sequences of events affecting one person or group over time rather than a single event affecting many people or groups at one time. Economic rationality makes no formal distinction between the two. As a result, it makes no difference to most conceptions of economic rationality whether the average (expected) winnings of 10 gamblers comes from each gambler winning the same amount or from 1 gambler winning 10 times the average while the other 9 go broke. The difference however is probably important to the 9 destitute gamblers. Biological rationality better addresses the long run fate of one person or group with limited resources. People concerned about their own fate more than the fate of a statistical aggregate are thus likely to find the prescriptions of biological rationality more relevant to their fate than the prescriptions of economic rationality.

Which might explain the interesting connections between biologically rational prescriptions and basic assumptions of prospect theory (e.g., see Kahneman & Tversky, 1979, 2000). Prospect theory accounts for several economically irrational findings from research on human decision making in uncertain environments by postulating that people prefer to avoid risks when choosing among alternatives with possible gains and to take risks when choosing among alternatives with possible losses. Our simulations point to a plausible reason for this asymmetry: People are acting in a biologically rational way, acting to ensure their own long run. The asymmetry maximizes the chances of their long run survival.

Situations that produce a positive expected value offer people having few resources an opportunity to choose cautiously, stay in the game, and slowly build wealth to a point where a long run can be assured (a point similar to that of Simulation 1). At this point, a shift to an economically rational strategy that increases the amount won with greater ante or risk of loss might be worthwhile, simply because increased wealth makes more ante or loss affordable. This strategy seems to be followed by people who scrimp and save for years to build a nest egg for long-term investments in blue chip stocks rather than spending their first and subsequent paychecks on Multi-Billion Lotto.

Situations that produce a negative expected value erode wealth and reduce the length of a run, two outcomes that are especially threatening to the survival of people with limited resources. Most of us face such situations at some point in our life; some of us, such as those confronting a debilitating disease, failing crops, or escalating conflict, face them as the dominant theme of existence. When potentially adaptive strategies such as patience or migration are ineffective or impossible to forestall the end of a game, increasingly risky choices become biologically rational. In desperation, any small chance of a big win to keep a short run going may be rationally pursued, including chances provided by dangerous or illegal activities eschewed by those living in a comfortable world of positive expected values. Perhaps this is why many small animals fight when cornered by a larger predator, why down-on-their-luck horse race bettors often bet on long shots in the last race, or why some people who see their future as short and bleak would resort to gambling, theft, prostitution, or other risky acts of survival. When faced with the inevitable end of a run versus a small chance of sustaining a run, the small chance usually prevails.

Indeed, the desire to avoid the end of a long run might explain the biologically rational popularity of insurance. All insurance is a gamble. Our premium is the ante we pay to bet an insurance company to bet that we will have an accident. If we have an accident that falls within the confines of our insurance policy, then we will win compensation. If we do not have an accident, then the company will win our premium. Premiums are of course adjusted to ensure that the company makes money when accidents are aggregated over customers. Insurance thus has a positive expected value for those who sell it and a negative expected value for those of us who buy it and is therefore an economically irrational purchase. Yet we likely buy it for the feeling that if something bad happens, we will not lose everything; we will instead receive enough to continue a run.

Because, as our simulations demonstrate, biological rationality prescribes different strategies of survival in situations with positive versus negative expected value, it is important to understand how people assess the expected value of the situations they face. How does anyone know whether a situation has positive, zero, or negative expected value? How does anyone know when the expected value of any situation changes from positive to negative or vice versa? In short, how do people predict the future outcomes of their choices? There seems to be no clear or simple answer, but partial answers surely would include direct experience ("I know this is a losing proposition because I have lost money on it the past 11 of 12 months."), indirect experience ("I believe this is a good place to buy a house because two of my friends and my mother told me."), generalization ("I think this will be a good marriage because she looks like my dear mother."), and imagination ("I am afraid to invest my limited holiday time in Poco-Poco because I can imagine that there will be an earthquake there soon.").

Judgments about the expected value of situations also seem to be related to individual differences in optimism versus pessimism, hope versus despair. To the extent that optimists believe the future will be better than the present, they can be said to believe that most future situations will have positive expected value. In contrast, pessimists seem to believe that more future situations will have negative expected value. A belief that the future is rich in positive expected value is likely to stimulate an emotion called hope. A belief that the future is rich in negative expected value is likely to stimulate an emotion called despair. If true, then changing attitudes from despair to hope would change preferences from risky, short-term gains to cautious, long-term gains. It seems worthwhile for future research to examine these individual differences and predictions.

Several questions remain. We have compared the ability of gambles with equal expected value to sustain long runs when resources are small relative to the cost of playing a game. People often face choices among gambles of unequal expected values and unequal antes. It would be worthwhile to examine the relationships of these inequalities to determine when it might be safe to shift from biological to economic rationality and back. It would also be worthwhile to determine if biological rationality more often accounts for people's choices when they are poor than when they are rich.

Biological rationality prescribes some of the features of alternatives that will lengthen a run in any game, but it does not describe what alternatives we have. Alternative strategies in the social world are likely to be as numerous, diverse, and interconnected as those in the biological world. The diversity of life that has evolved in the long run suggests that many different alternatives can sustain a long run in the social world, depending on their relation with alternatives chosen by others. Our future research seeks to explore these interdependencies.

APPENDIX
Listing of the Euler Simulation Program

- The programming language Euler uses double periods = .. to indicate a comment following.
- To run the program after loading it, type the word *longrun*.

```
function longrun
start=input("How much money for each person to begin");
ante=input("What is the ante");
payoff=input("Expected payoff of each gamble");
seed=time()/1000;.. seed the random number generator with the clock
pwin=[1:9]/10;.. probability of winning = [ .1 .2 .3 ,,, .9]
totalgames=zeros(9,1000);.. counter for total games played up to 1,000

for gambler=1 to 1000
  money=start*ones(1,9);.. begin each gambler with starting money
  winnings=(10*payoff)/[1:9];.. make all winnings = expected payoff
  ngames=zeros(1,9);.. set beginning # of games survived to 0
  for gamble=1 to 1000
    money=money-ante;.. pay ante to bet
    ngames=ngames+(money>=0);.. one more game if wealth sufficient
    winnings=winnings*(money>=0);.. set winnings to 0 if wealth < 0
    winners=random(1,1)<=pwin;.. determine who won the bet
    money=money+(winners*winnings);.. add any winnings to money
  end
  totalgames(:,gambler)=ngames';
end

"Gamblers surviving at least 10 games="
sum(totalgames>=10)
```

```
"Gamblers surviving at least 100 games="
sum(totalgames>=100)
"Gamblers surviving at least 1000 games="
sum(totalgames>=1000)

return "Done!"
endfunction
```

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