Game Theory and Professional Baseball: Mixed-Strategy Models

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This article uses two-person game theory to model the contest between batter and pi major-league baseball. Analysis of batting-average data generates a solution ir strategies which predicts the empirical proportions of right- and left-handed batters ably well but is less successful in predicting the proportions of right- and left-hande ers. The source of the discrepancy appears to be a biological shortage of left- pitchers (only 14% of males are born left-handed). Right-handed players can lear left but not to throw left. The percentage of left-handed pitchers has increased over an attempt to keep up with the increase of left-handed batting and switch hitting shortage of left-handed pitchers remains. Thus, even though the model is only par cessful mathematically, it produces useful insights into the strategy and evolution c ball.

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Game theory is a branch of mathematics involving the creation and study of mo els of situations in which outcomes are interdependent on choices made by two or mo actors. A game model requires the following elements:

1. *Players.* These are assumed to be rational actors weighing costs and benefits as they pursue their own goals. There must be two or more players.
2. *Rules of the game.* These define the limits of action—what can and cannot be done in the game.
3. *Strategies.* These are the choices that the players can make within the rules of the game. A strategy is a complete set of choices from beginning to end of the game. For example, if a player can make three different decisions, and for each decision there are two alternatives, he has $2^3 = 8$ different strategies for the whole game.
4. *Payoffs.* These are the outcomes that accrue to players depending on the choice of strategies they and their opponents make. Payoffs may be either ordinal or cardinal.
5. *Solutions.* A solution is the set of payoffs arising from the strategies that rational players would choose under the rules of the game. Sometimes there are multiple solutions. Indeed, sometimes there are multiple solution concepts, that is, more than one line of reasoning that rational actors might employ.

Game theory emerged as a distinct intellectual enterprise in 1944 with the publicatic of the *Theory of Games and Economic Behavior*, by John von Neumann and Oskar Morgenster Its maturity was signalled fifty years later by the award of the 1994 Nobel Prize for economi to three eminent scholars in the field. Game theory is now widely used in economics ar political science, and to a lesser extent sociology, psychology, and the other social science Good introductions for nontechnical readers have been published by Dixit and Nalebu (1991), Davis (1983), and Hamburger (1979).

Curiously, game theory has been little applied to the analysis of athletic events, eve though these competitive contests have all the characteristics of games as described abov This paper is intended to show how game theory can contribute to the understanding of spo behavior.[1]

Baseball is well known for the quantity and quality of statistical data associated wi the game; and at least one major work (Cook, 1966) has used these data to propound matl ematical rules of strategy. However, Cook's approach was not game-theoretical because it di not focus on the interplay of strategic choices made by the offence and defence. Cook looke at offence and defence in isolation, calculating the productivity of various strategies long run of games. This amounts to conceiving baseball as a "game against nature," in players make optimizing choices against random events. But a baseball game is a between two teams of opponents, each of which has independent choices to make attempt to defeat the other. As such, it is an ideal subject for game-theoretical analys

The particular solution concept employed in this paper is known as "solution in strategies." It derives from the minimax theorem, proved by John von Neumann in which was a turning point in the development of game theory. Von Neumann show every two-person, zero-sum game with a finite number of strategies has a solution. Wh solution is a pair of pure strategies, it is known as a saddlepoint. Sometimes, however, do not have a single best strategy, in which case their rational choice is a random mix pure strategies in certain calculable proportions (Davis, 1983; Hamburger, 1979; Poun 1992; Rapoport, 1966; Williams, 1982). In this article, the solution of the various always represents the proportions of at-bats in professional baseball taken by left- and handed batters and pitched by left- and right-handed pitchers.

Pitchers vs. Batters

Although baseball is a complex team sport, the focus of attention is the duel b pitcher and batter. This central contest can readily be modelled as a two-person ze game with a binary choice of strategies for each player. The pitcher can throw with eit right or the left hand, and the batter can hit from either the right or the left side. There a possible pitching-batting combinations, as shown in Table 1.

Table 1
Pitching-Batting Combinations

		Pitcher	
		Throws Left	Throws Right
Batter	Hits Left	L vs. L	L vs. R
	Hits Right	R vs. L	R vs. R

Table 1 does not apply to a single encounter. Pitchers have only one good thr arm, and batters are not allowed to switch sides during their turn at the plate. Howev model does apply in a sense to managers assembling a lineup. All batting orders conta a mixture of right- and left-handed hitters, and all pitching rosters contain a mixture (right- and left-handed pitchers. During the season a pitcher can expect to face batte standing on both sides of the plate, and a batter can expect to face pitchers throwir from either side of the mound.

However, we would not expect the model to predict the composition of any particul. team. Professional baseball rosters are relatively small, containing about 10 pitchers and 1 other players for a total of 25. Pitchers, since all they do is pitch, might be balanced betwee left and right according to some mathematical principle; but hitters (except for designate hitters in the American League) have to play a defensive position and be able to run the base Moreover, because players under long-term contracts are not freely available to be hired ar fired, managers work with a limited pool of candidates in any particular year. Hence, ar roster will have to balance a number of athletic and economic considerations and cannot t predicted solely from a model of batting success.

The model, however, can be tested at a higher level of aggregation, in which there is sort of statistical contest being waged by hitters as a group against pitchers as a group. I 1995, not counting at-bats by National League pitchers, 583 batters faced 550 pitchers i 133,621 at-bats (James, 1995). We could reasonably expect a game-theory model to t predictive at this level. Such an approach resembles the work of John Maynard Smith (1982 Richard Dawkins (1989), Robert Axelrod (1984), and others in modelling population pol} morphism using game matrices with solutions in mixed strategies.

Even the most casual baseball fan knows that right-handed batters tend to do bette against left-handed pitchers, while left-handed batters do better against right-handed pitcł ers. We have all seen games held up while one manager sends in a pinch hitter to get th batter's opposite-side advantage, and the other manager responds by changing pitchers t restore the hurler's same-side advantage. The reason for the batter's opposite-side advantag has to do with the behavior of breaking-ball pitches. A natural curve ball, i.e., one throw with outward rotation of the pitcher's arm, breaks to the opposite side—to the left for a righı handed pitcher and to the right for a left-handed pitcher. A curve ball also drops and acts a a change of pace because it is slower than a fastball. All these factors fool the batter to som extent, but a curve ball moving toward you is easier to hit than one moving away from yoı Robert K. Adair (1994) explains why:

> Batting against the curve ball, the batter tends to swing too quickly at the relatively slow pitch, and he tends to underestimate the in-out curve deviation. These errors tend to add up for out-curves but cancel for in-curves.

Hence, the in-curves may be a little easier to hit, accounting for the small advantage batters have when they face a pitcher throwing from the opposite side. (p. 96)

Data published by STATS, Inc., can be used to develop and test a model of the between pitchers and hitters. First I use the so-called "lefty-righty" statistics for th season, as published by James (1995) and available on diskette for further analysis. second test, I use slightly different data published in aggregated form by Adair (1994) 1984-87 seasons.

Three indicators of batting success are readily available in the STATS, Inc. batting average, on-base percentage, and slugging percentage. Batting average is t known and most widely quoted (Runquist, 1995), and has been found in an econ analysis to be the single most important variable in explaining salary variation (A Buttross, 1988). It takes account of bases on balls, sacrifice flies and hits, and being l pitch by removing these outcomes from the total of "at-bats" in the denominator. Thi sensibly gives these lesser forms of offence some weight, but not as much weight as i to base hits, which also appear in the numerator of the fraction. A sacrifice hit or fly m runner forward one base but also produces an out, so it is not as good as a single. Nor, i cases, is a base on balls. For example, three walks in a row will load the bases, bu singles in a row will score one or even two runs. On-base percentage overvalues wa giving them the same value as hits in the numerator.

Admittedly, batting average does not do justice to extra-base hits because it them the same as singles. However, slugging percentage overvalues extra-base hits by ing all bases equally. To see why that is not justified, compare a bases-empty home run singles in a row. Both are worth four in the total bases count, which is the numer slugging percentage; but four singles in a row will produce two or even three runs, wh bases-empty homer produces only one run.

Because each of the three main batting productivity indicators has obvious im tions, I calculated separate versions of the model with all three, plus a fourth using a indicator of my own construction. Batting average gave the closest fit to the actual d the rest of the paper relies on it as a payoff indicator. Results from using other indicat presented in note 2.[2]

Table 2 summarizes major-league batting averages for the 1995 season. I have re the at-bats of pitchers in the National League because pitchers do not bat at all in the A can League and are not chosen in any case because of their batting skill.

Table 2
Major League Batting Results, 1995

Batter	Pitcher	At-Bats	Hits	Batting Average
(1) L	L	8,360	2,144	.2565
(2) L	R	30,479	8,559	.2808
(3) L	L&R	38,839	10,703	.2756
(4) R	L	20,609	5,713	.2772
(5) R	R	48,361	12,746	.2636
(6) R	L&R	68,970	18,459	.2676
(7) S	L	7,165	1,927	.2689
(8) S	R	18,647	5,030	.2697
(9) S	L&R	25,812	6,957	.2696
(10)		133,621	36,119	.2703

I begin with the simplifying procedure of counting switch-hitters as left-handed batters when th face right-handed pitchers and right-handed batters when they face left-handed pitchers. This mea combining lines (8) and (2) and lines (7) and (4) from Table 2 in order to produce Table 3. The purpo is to enable construction of a 2 X 2 model, which is the easiest to solve and interpret. However, there clearly some distortion in this procedure; being a switch-hitter is not the same as always batting from o side, because the switch-hitter chooses his batting side after seeing which pitcher he will face. Th introduces a sequential element into the game and violates the assumption that the players are maki simultaneous, independent choices. Hence, I will later treat switch-hitters as a separate category in a 3 2 model.

Table 3
Pitcher-Batter Game, 1995 (Switch-Hitters Merged)

		Pitch	
		Left	Right
Bat	Left	.2565, -.2565	.2766, -.2766
	Right	.2751, -.2751	.2636, -.2636

The solution to zero-sum games is based on the concept of security level. Eacl is assumed to act so as to guarantee for himself through unilateral action the best of th that could happen to him (i.e., play "maximin," maximizing the minimum). But sil zero-sum game your opponent's payoff is the negative of yours, you minimize his m ("minimax") when you maximize your own minimum.

If each player has a single strategy for which maximin equals minimax, the r strategy pair is the saddlepoint of the game or solution in pure strategies; but inspe Table 3 shows there is no saddlepoint for the 1995 Pitcher-Batter Game. Neither si dominant strategy; it all depends on what the other side is doing. If the pitcher is left-l you will do better on average by sending out a right-handed batter, and vice versa. H must look for a solution in mixed strategies, which means that each player should random combination of strategies in prescribed proportions. The problem is to comp proportions. This means finding the prescribed probability (p) of batting left and (batting right, and the prescribed probability (q) of pitching left and (1-q) of pitching

By looking for the point where maximin = minimax, each player wants to make invulnerable against the other's choice. You reach your security level, i.e., make y invulnerable, when nothing your opponent does can hurt you. Each player achieves selecting probabilities such that his opponent's expected payoff is the same no matte strategy the opponent selects. That is, batters want to mix their likelihood of battir and left in such proportions that it does not matter whether the pitcher throws right Similarly, pitchers want to mix their probabilities of throwing right and left in such tions that it does not matter whether hitters bat right or left.

Algebraically, this implies the following set of equations for calculating (p) an in the 1995 Pitcher-Batter Game:

$$\text{Let EV} = \text{Expected Value}$$
$$EV(\text{Pitch L}) = EV(\text{L vs. L}) + EV(\text{L vs. R})$$
$$EV(\text{Pitch L}) = -.2565p + (-.2751)(1-p)$$
$$EV(\text{Pitch R}) = EV(\text{R vs. L}) + EV(\text{R vs. R})$$
$$EV(\text{Pitch R}) = -.2766p + (-.2636)(1-p)$$
$$EV(\text{Pitch R}) = EV(\text{Pitch L})$$
$$-.2565p + (-.2751)(1-p) = -.2766p + (-.2636)(1-p)$$
$$p = .364$$
$$1-p = .636$$

If there had been a manager in charge of all hitters for 1995, he should have lineups such that players batted left 36.4% and right 63.6% of the time. With this coml nation, it would not have mattered whether his roster of batters faced a right- or le hand pitcher; the expected payoff would have been the same. This is the best that su a hypothetical manager could have done. Had he fielded more left-handed batters th the optimum, the defence could have done better by pitching left-handed as a pure str: egy; and similarly if he had played more right-handed batters, his hitters could ha been victimized by right-handed pitchers.

The calculation of (q) and (1-q) proceeds along similar lines:

$$\text{EV(Bat L)} = \text{EV(L vs. L)} + \text{EV(L vs. R)}$$
$$\text{EV(Bat L)} = .2565q + .2766(1\text{-}q)$$
$$\text{EV(Bat R)} = \text{EV(R vs. L)} + \text{EV(R vs. R)}$$
$$\text{EV(Bat R)} = .2751q + .2636(1\text{-}q)$$
$$\text{EV(Bat L)} = \text{EV(Bat R)}$$
$$.2565q + .2766(1\text{-}q) = .2751 + .2636(1\text{-}q)$$
$$q = .411$$
$$1\text{-}q = .589$$

A hypothetical manager in charge of all pitchers in 1995 should have had 41.1% of a bats pitched by left-handers and 58.9% by right-handers. The offence could have penalize any departure from this policy by converting to the pure strategy of always batting right ‹ left, in coordination with the shortage of pitchers (i.e., if there are not enough left-hande pitchers, always bat left, and so on).

A second test of the model can be performed upon the data published by Adair (199‹ for the 1984-87 seasons and presented below in Table 4. His data include only those playe who had over 250 at-bats.

Table 4

Pitcher-Batter Game, 1984-87 (Switch-Hitters Merged)

		Pitch	
		Left	Right
Bat	Left	.2568, -.2568	.2797, -.2797
	Right	.2782, -.2782	.2649, -.2649

The solutions in this second model are astonishingly close to those in the f 36.7% for 1984-87, compared to 36.4% for 1995; and q = 40.9% for 1984-87, com 41.1% for 1995. Because the two sets of numbers are so close, I will simply refer to model in the rest of the paper.

The empirical test of the model is to compare its predictions to the actual pro calculated from Table 2. The comparison is presented in Table 5.

Table 5

Comparison of Actual and Predicted Values from the Pitcher-Batter Game,
(Switch-Hitters Merged)

	Bat	Pitch	Actual %	Predicted
(1)	L		43.0	36.4
(2)	R		57.0	63.6
(3)		L	27.0	41.1
(4)		R	73.0	58.9

The model underpredicts the percentage of left-handed at-bats moderately (3 an actual figure of 43.0%) and overpredicts the percentage of left-handed pitchi substantially (41.1% vs. an actual figure of 27.0%).[2] An attempt to explain these di cies leads us into the realm of human biology. According to Coren (1992), about males are born left-handed. Although left-handed people experience higher mortalit not a significant factor at the age at which professional baseball is played. H pool of potential professional players is about 14% left-handed. Experience sh it is exceedingly rare to be able to throw effectively with the off hand, and exceptions prove the rule. When Greg Harris of the Montreal Expos pitched bo and left-handed in the same inning on September 28, 1995, he was the first pitch so in a major-league game since 1888 (McKnight, 1995). But Harris is normally handed pitcher, and the Expos' manager let him carry out the stunt for the recog brought (Gallagher, 1995).

This suggests that baseball teams would hire more left-handed pitchers if th find them, but there are just not enough available. Indeed, there is considerable a evidence that left-handed pitchers are always in demand and can command premium (Shaughnessy, 1989; Adams, 1990). Scouts go deeper into the talent pool for left pitchers than they do for right-handers; but at a certain point the trade-off will unfavorable because the advantage of having another left-handed pitcher will be (weighed by his lower native ability.

In contrast, experience shows that many players can learn to bat effectively from opposite side. In fact, in the 1995 season, 53.6% of those who batted left threw right (Jan 1995), even though their batting average was not as high as those who were natural l handers. Although data on this precise question are lacking, it may well be that a signific proportion of these right-throwing, left-batting players are only weakly right-handed have some particular combination of dominant hand, eye, and foot that enables them to differently than they throw (Coren, 1992). Coren has found that some sports, e.g., nis, favor athletes who are strongly one-sided, while others, e.g., hockey and baskett flavor those who are less laterally oriented (Porac & Coren, 1981). Thus it is not likely that lateral orientation also plays a role in choice of strategies within partic sports.

Training is also a factor because many fathers and coaches are aware that there is advantage to batting from the left. For one thing, the hitter starts out one or two steps cl to first base. Over the course of a season, this can mean several more bunts or ground b turned into infield hits. Also, as long as there is a shortage of left-handed pitchers, there i advantage to batting from the left because the batter faces a surplus of right-handed pitcl throwing curve balls that break towards rather than away from him. For these two reason and perhaps others, such as closer right-field fences, which turn harmless fly balls into ho runs (Cook, 1966)—left-handed batters do better overall than right-handed batters: .2 against .2676 in the data from Table 2. Natural left-handers, i.e., those who both throw bat left, do best of all (.2827), while converted left-handers, i.e., those who bat left but th right, have an average of .2687, still slightly above right-handed batters. Baseball teach being aware of these facts, are likely to encourage right-handed youngsters to convert to l handed batting if they show any aptitude for it. In contrast, players who throw left-han rarely are taught to bat from the right side. There are a few prominent exceptions, sucl Ricky Henderson; but in 1995 only 1.8% of players threw left and batted right (James, 19

If biological realities explain the shortage of left-handed pitchers, how do we exp the actual surplus of left-handed batters? Here the logic of game theory comes into p There is no penalty for having too many left-handed batters because the defensive side d not have enough left-handed pitchers at its disposal. Indeed, given the shortage of l handed and the surplus of right-handed pitchers, the batting side would actually do bette abandon its mixed strategy and to play nothing but left-handed batters. The offensive va of the game at equilibrium, when both sides play their optimum strategy mixtures, is a batt average of .2683. Given the actual proportion of only 27.0% left-handed pitchers, batting side could obtain an average of .2719 by batting left all the time. In fact, acc to Table 2, batters achieved a collective average of .2703 by batting left 43.0% of th and right 57.0% of the time.

In a sense, then, the question is, given the shortage of left-handed pitchers, w there any right-handed batters at all? One answer may be that the defensive positi second base, shortstop, and third base favor right-handed throwing for obvious re The reasons are not so obvious for the catcher's position, but there too right-hand almost universal. Because right-handed throwers are needed for many defensive pos right-handed batting often comes along as part of the package.

Another reason is that the mixed-strategy game model presented here does n account of individual variation. It treats all batters as if each one achieved the same s measured by batting average, but in reality there is a great range of abilities. Even t left-handed batters do better on average against right-handed pitching than right-h batters do, a manager will not turn down a Frank Thomas, Albert Belle, or Mark Mc because they bat right-handed.

An Evolutionary Perspective

While it may be obvious to managers that they should have both right- and left-h batters and pitchers, the "correct" proportions are certainly not self-evident; and we hardly expect baseball managers to solve the model in a formal sense as is done here. over, research with experimental games has shown that players do not easily hit up correct mixture of strategies under laboratory conditions. Even in a symmetrical gam one player acting as tacit instructor playing the optimal mixture, the other player h incentive to imitate the instructor. The fact that the instructor is playing optimally equ the second player's outcomes so that he gets the same average payoff no matter which egy he chooses. Under these conditions, there is no reward for success and no pena failure, and hence no incentive for learning (Rapoport, Guyer, & Gordon, 1976).

However, it seems that an evolutionary mechanism might be posited for baseball, a sufficiently long period of time. Assume that at the beginning of baseball in the mid the nineteenth century, players were represented in the game in the same proportions as general male population, i.e., 14-86 left- to right-handed. In fact, at that time the prop of left-handers may have been even lower because parents and schools often attemp convert left-handed children to favor their right hand. With only 14% or fewer handed pitchers, left-handed batters would have feasted upon the mainly right-ha pitching they faced. It would have become obvious quite quickly that left-handed ters were an asset. But as left-handed batters proliferated, it would also have becor obvious that left-handed pitchers were more adept at getting them out.

This line of thought yields two empirically testable predictions: (a) the proportions left-handed players, both batters and pitchers, should tend to rise over time until reachi their respective optimums; and (b) the increase in left-handed batters should start before t increase in left-handed pitchers and should continue to lead until reaching equilibrium.

These hypotheses were tested against two samples from *The Baseball Encyclopedi* which contains career records of all men who have ever played big-league baseball (Reichl 1979). For each case in the sample of 174 offensive players, I noted his batting side and t year in which he entered major-league baseball (ranging from 1876 to 1974). If there ev was a time when the percentage of left-handed batters approximated the general populati percentage, it must lie in the distant past before 1876. Of the 26 players who started befo 1900, 38.5% batted left or switched; and of the 93 who started before 1940, 36.6% batted le or switched. More recently, there has been a slight decline in pure left-handed batters but large increase in switch-hitters, who of course bat left most of the time. Of the positi players listed in the 1996 *Major League Handbook*, 28.4% batted left and 16.4% were switc hitters.

The story is quite different, however, in the sample of 222 pitchers. Of the 24 wh started before 1900, only 2 (8.3%) were left-handed. In comparison, 26.8% of those wh started after 1900 were left-handed $\chi^2(1, N = 228) = 3.3$, $.10 > p > .05$; and for the 19 season, 29.8% of all pitchers were left-handed (James, 1995). The evidence seems to co firm the prediction of the evolutionary model that the growth in left-handed batting shou lead the growth in left-handed pitching. In approximate terms, left-handed batting reache its current level well before 1900, whereas left-handed pitching did not start to catch up un after the turn of the century.

Switch-Hitters

Up to this point, we have been using the simplified 2 X 2 model, which merge switch-hitters with others; now we must try to isolate that important group of batter who took 19.3% of at-bats during the 1995 season. The 3 X 2 model including switc hitters as a separate group is shown below in Table 6.

There are at least three surprises buried in this matrix. First, it is mildly surprising th switch-hitting is not a dominant strategy for batters. A switch-hitter always takes the adva tageous side, batting left-handed against a right-handed pitcher and right-handed against left-handed pitcher. Therefore, one might think that switch-hitters' results should be bett than those of batters who are always stuck on the same side of the plate. Howev expectation is not confirmed. Switch-hitters do better than right-handed batters do right-handed pitchers, but they are less successful than left-handed batters are agains handed pitchers. A similar pattern exists against left-handed pitching, as can be verifi Table 6. Against both types of pitching, switch-hitters average .2696, a little bett right-handed hitters (.2676) but not as good as left-handed hitters (.2756).

Table 6
Payoff Matrix for Pitcher-Batter Game, 1995
(Including Switch-Hitting as a Separate Strategy)

		Pitcher	
		Throws Left	Throws Right
	Hits Left	.2565, -.2565	.2808, -.2808
Batter	Hits Right	.2772, -.2772	.2636, -.2636
	Switches	.2689, -.2689	.2697, -.2697

A second surprise is that, far from being a dominant strategy for batters, switch-h actually a dominated strategy—dominated by the optimal mixture of pure right- and left- batting. According to game-theoretic reasoning, a dominated strategy—one which alway less than some available alternative, whether a pure strategy or a mixture of strategies—wi be chosen (Hamburger, 1979).

This is illustrated visually in the graphic representation in Figure 1. Each of the three strategies is depicted by the straight line connecting its payoff against right-handed pitc Axis 1 to its payoff against left-handed pitching on Axis 2. The fact that the lines R and L i above line S shows that the optimum mixture of R and L dominates S. In general, the soluti M X 2 game always entails a mixture of only two strategies for the player with M alternati the critical pair is identified by the lowest point on the upper boundary of the set of lines (W 1982).

Using the payoffs in Table 6, the mixed strategies for batting at equilibrium are 35.9 left-handed, 64.1% pure right-handed, and 0% switch-hitting; for pitching they are 45.4 handed and 54.6% right-handed. At equilibrium, the value of the mixture of left- and right- batting is .2697, higher than the value of .2693 that switch-hitters would earn against

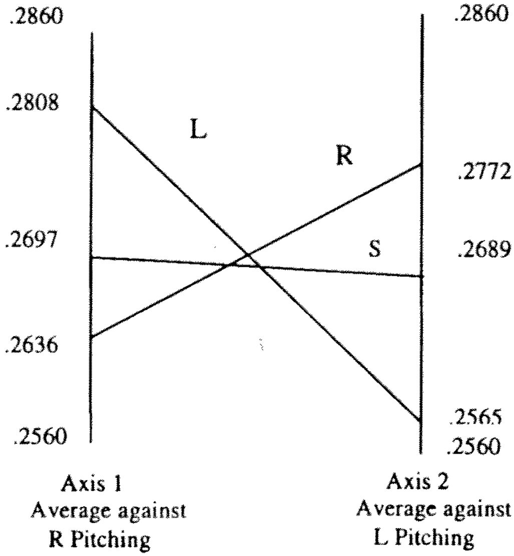

Figure 1. Graphic representation of 3 x 2 pitcher-batter game 1995.

optimal pitching mixture. Switch-hitting is not dominated by much, but it is dominate

Table 7 compares the predictions of the 3 X 2 model against the actual data f 1995:

Table 7
Comparison of Actual and Predicted Values
3 X 2 Pitcher-Batter Game, 1995

	Bat	Pitch	Actual %	Predicted %
(1)	L		29.1	35.9
(2)	R		51.6	64.1
(3)	S		19.3	00.0
(4)		L	27.0	45.4
(5)		R	73.0	54.6

The 3 X 2 model is less successful than the 2 X 2 model on two counts. Fir: though the 3 X 2 model was designed to take account of switch-hitting, it predicts th should be no switch-hitters at all. Second, the 3 X 2 model's prediction of the ɪ proportions lies even farther from the actual figures than does the 2 X 2 model's pre

Although far off the mark empirically, the 3 X 2 model does lead to a fruitful e› tion of the phenomenon of switch-hitting. Coaches recommend switch hitting to a kind of player—the "Charlie Hustle" type, exemplified by Pete Rose, who fields wε the bases, bunts, and does whatever else it takes to help the team. Mickey Mantle an Murray are well-known exceptions, but in general there have been few long-ball hitters. They are generally contact hitters whose short, compact swings produce lir and ground-ball singles rather than home runs and extra-base hits (Weiskopf, 1985). all the great natural hitters from Babe Ruth and Ty Cobb onwards have batted from o side of the plate. It is noteworthy that in 1995, of the 25 active players with the highes slugging percentages, none were switch-hitters (James, 1995).

This suggests that switch-hitters probably have less natural hitting ability on ; but make up for it with greater practice and effort. For them, learning to bat from (almost all are natural right-handers; only 6.2% of switch-hitters threw left in 199: extra advantage that brings them, as a group, almost up to the batting average of the population of players. From there they can build a career with base-running and de play.

Conclusions

Although neither the 2 X 2 nor the 3 X 2 model is entirely accurate in a predictive se attempt to use game theory to model the duel between pitchers and batters has led to a nu interesting hypotheses at least tentatively supported by empirical data. The most important following:

1. Due to biological constraints, there is a chronic shortage of left-handed pitchers.
2. The shortage of left-handed pitchers makes profitable a surplus of left-handed a bats. Thus players who naturally throw right-handed take up left-handed batting (switch-hitting.
3. Left-handed pitching increased as a response to the success of left-handed battin in the early decades of major-league baseball.
4. The recent rise of switch-hitting may be a response to the increase of left-hande pitching.

Baseball is a game in which actors make strategic choices as permitted by rul and the outcomes are interdependent on the choices of both sides. This analysis baseball shows that a mixed-strategy model can be used with some success to predi the proportions of strategies chosen at the population level, and the errors in the predi tions can be plausibly linked to known factors of human biology. Moreover, the attem to explain the discrepancies between predicted and actual data values point to know facts about switch-hitting and generate new and non-obvious hypotheses about the ev lution of professional baseball—hypotheses that can also be supported by data. In vie of these promising results, researchers may wish to consider further applications of gan theory to baseball and other sports.

Note

[1]After this article was in press, I received a copy of Goldstein and Young (199 Their paper also applies game theory to baseball and reaches conclusions similar, thou not identical, to mine.

[2]This note summarizes the results derived from using other indicators of batting pr ductivity and compares them to the actual data as well as the predictions derived from usi batting average. (On-base percentage and slugging percentage follow standard definition For "total batter offence," the denominator is plate appearances and the numerator is tot bases + bases on balls + hit by pitcher + sacrifice flies + sacrifice hits.)

Indicator predicts	% Bat Left	% Pitch Left
On-base percentage	39.9	53.7
Slugging percentage	28.4	12.8
Total batter offence	20.5	47.5
Batting average	36.4	41.1
Actual	43.0	27.0

On-base percentage gives the best prediction of batting but is far off the mark o pitching. Slugging percentage does almost as well on pitching as batting average does but less accurate in predicting batting. Overall, batting average performs the best.

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